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Source / Vabo Composites

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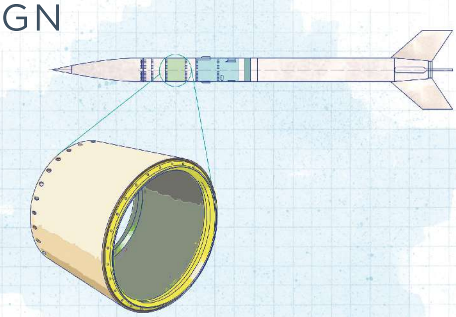

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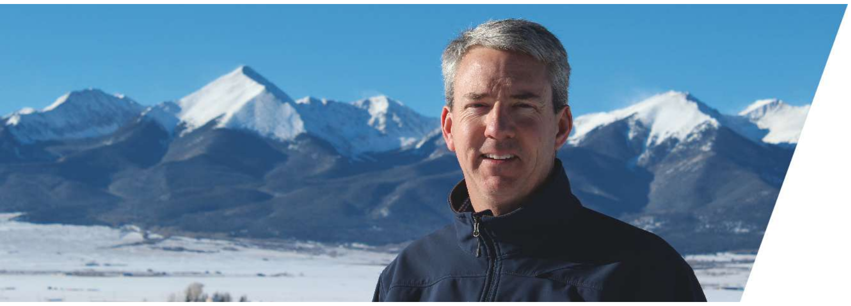

» Each fall, *CompositesWorld* hosts the Carbon Fiber conference, and in early December I attended the 2018 version in La Jolla, CA. It was my 11th Carbon Fiber since I became editor-in-chief of *CW* in 2006, and it was, as usual, full of highly informative presentations, highly engaged attendees, and sponsors and exhibitors invested in the carbon fiber supply chain. I'm working on a complete report of every presentation from the two-day conference, which will be available soon. In the meantime, some of the highlights:

Brett Schneider, president, global fibers, at carbon fiber manufacturer Hexcel (Stamford, CT, US) kicked off the conference and said that current global demand for carbon fiber is 60,000-65,000 MT per year, with a global nameplate capacity of 160,000 MT. Acknowledging that this appears to show a carbon fiber surplus, he cautioned that the variability of carbon fiber properties — tow count, mechanical properties, sizings, fiber forms, etc. — combined with production knockdown, may actually limit availability of some types of carbon fiber. Schneider also spent a fair amount of time addressing the commoditization question — the idea that the aforementioned variability creates too much complexity and makes carbon fiber adoption difficult. I can't succinctly summarize all of Schneider's commoditization comments here except to say that he thinks it's not viable and to offer this quote from his presentation: "Which one or two fibers would you like us to commoditize?" Another of Schneider's comments also got a few chuckles and was referenced, tongue in cheek, by other presenters throughout the conference: "If you hand someone a bobbin of carbon fiber, it is incredibly useless by itself." Meaning, applying carbon fiber takes some know-how.

Applying carbon fiber takes some know-how.

Contrasting Schneider somewhat was Dan Pichler, managing director of CarbConsult GmbH (Hofheim am Taunus, Germany), a composites industry consulting firm. He estimates that carbon fiber demand is in the 85,000-90,000-MT range, with 60-65% of that in the small-tow (1k-24k) segment and 35-40% in the large-tow segment. He said 65% of all carbon fiber goes to the industrial end market, 20% to the aerospace market and 15% to the sporting goods market. Year-over-year carbon fiber growth, he said, is 9-14%. On the capacity side, Pichler sees more tightness than Schneider does. Pichler estimates that global carbon fiber nameplate capacity is 140,000 MT, with actual capacity (after knockdown) of 90,000-95,000 MT. One-third of the world's carbon fiber manufacturers are expanding right now, Pichler said. He addressed commoditization, which he referred to as standardization, via the sole-source challenge for many OEMs that use carbon fiber and noted that "purchasing guys want multiple suppliers. There is pull among our customers, in the real world, for standardization." He noted, however, as Schneider did, that material stratification makes that difficult — but not impossible: "In some cases they will get that standardization. In some cases they won't."

Pierre Harter, director of R&D at Spirit AeroSystems (Wichita, KS, US), provided a look ahead at the materials and technologies the aerospace giant is evaluating for next-generation aircraft applications. Harter emphasized a need for "step-function change in cost and performance" to meet aerospace OEM expectations in terms of manufacturing efficiency and throughput, citing work he and his team are doing with multi-functional materials, advanced preforms, high-rate fiber/tape placement, structural bonding, additive manufacturing, fiber steering and inspection. In short, Harter said, "The next airplanes have to be made at a lower cost than what we have seen in the past."

Among those addressing carbon fiber in automotive was Lars Herbeck, managing director of Voith Composites (Garching, Germany), which developed a highly automated tape placement/preforming/resin transfer molding (RTM) process for the manufacture of the carbon fiber/epoxy rear wall of the Audi *A8*. Herbeck also assessed the state of the art of resin cure in automotive and found much he likes, noting that since 1950, epoxy cure times have dropped precipitously, from 24 hours to 1.5 minutes today. "We are approaching 1,000 parts a day on one press," he said. "Thermoset is as fast as thermoplastic." Ultimately, however, he said the cost of composite parts for automotive must be reduced to less than €18/kg. To achieve this, he said, the cost of carbon fiber must be reduced to less than €10/kg, to be sustainable.

Keep your eyes peeled for a full report soon.

JEFF SLOAN — Editor-In-Chief

CALL FOR PAPERS

# The best job I ever had

» *Editor's note: CompositesWorld senior editor Sara Black, the magazine's longest tenured employee, is retiring at the end of February. I asked Sara, as she says good bye, to reflect on her two decades of working in and writing about the composites industry. Below are Sara's parting words. She will be missed.*
*— Jeff Sloan, editor-in-chief*

Well, I've come to the end of the road here at *CompositesWorld*, and will be officially retired next month — although you might see my byline now and again as a contributing writer. How did nearly 20 years come and go so quickly? I got this job through a newspaper ad in the summer of 1999 and was lucky enough to figure out what "the glue and the string" meant, at least for simple applications. Eventually I was able to cobble words together in the magazine's style. I had never interviewed anyone before, so that took some courage to do, and to learn. An early lesson: Shut up and listen and use a small pocket tape recorder, then transcribe the tape.

My first stories were about a high-performance rowing shell and the strengthening of concrete bridge columns with carbon fiber wraps. We believed those strengthening wraps were to be the next big thing in infrastructure; they did, eventually, become more widespread with time, after a learning curve. I also remember interviewing someone about a new resin that he had formulated, literally, in his own garage. This was not uncommon, I discovered; many enterprises started that way, and we only found out about their efforts through their persistence in keeping in touch with the magazine. I learned about how cultured marble was made, and what pultrusion was; one early article involved pultrusion of thermoplastics, again in a garage. Early on I was assigned an article on tooling; it took a lot of telephone time for the patient gentlemen at Coast Composites (now Ascent Aerospace) to explain to me what tooling was, how it was used to make composite parts, what an eggcrate structure meant and the definition of coefficient of thermal expansion.

I guess I came to composites just when it was starting to transition from a fragmented cottage and craftsman-ish industry into a real source of high-performance materials that was to be taken seriously. While many of the early applications I wrote about were very one-off, like a carbon fiber portable bridge for the US Army, a pultruded carbon fiber lattice structure for a wind turbine tower or a custom-built offshore race boat (using S-glass), Boeing's 787 *Dreamliner* launch changed things, as did the Airbus A350 XWB. Suddenly composites seemed more important and more of an industry. I recall a Boeing spokesman giving a presentation on the 7E7 (what would become the 787) at the 2004 SAMPE in Long Beach, CA, US. I remember the room was absolutely packed but almost silent, as we learned that composites would make up more than 50% of the aircraft. Today, that aircraft design and procurement cycle is now almost over, as the Boeing NMA/797, and new versions of the Boeing 737 and Airbus A320, come forward.

Someone once remarked that a trade show was like a big reunion of all your cousins, and it did feel that way, like I knew all of you kind of well but had forgotten your names. (Please let me humbly apologize right now and say that I have always been terrible at remembering names — that's why I was always looking at your badge.) Being an introvert, trade shows were hard for me, but I managed to make some good friends and acquaintances over the years. Some events stand out, like the Carbon Fiber conference held in Toulouse, France. I sat next to an interesting fellow there, and that led to a great story in *CW* on how Antonov used carbon fiber in the tails of its aircraft. And I'll never forget the Icelandic volcano eruption during the JEC Paris event in 2010, which stranded our *CW* group in Paris for three days, until we mobilized to Madrid via train, with strangers helping us, to catch flights home. I returned to Madrid twice following that trip, to tour Airbus plants, as well as Carbures facilities and the MTorres campus. I also remember the hard times from 2007-2009, especially when we tried to launch CompositesWorld Expo.

It's been a privilege to know and work with great composites champions and visionaries, and I want to thank all of you I had the opportunity to talk with and interview, who helped me create interesting and exciting stories for our readers, and make this my dream job. Now, I'm looking forward to more time co-piloting with my husband Ken (see photo). I wish all of you the very best. CW


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# Aerospace outlook: A dynamic, evolving supply chain and market

» The aircraft production market is set to grow 5.8% annually, from a value of US$164 billion in 2017 to US$218 billion in 2022, according to The Teal Group. The largest segment, air transport, will grow 6.5% annually and will exceed US$150 billion by 2022. The macro factors driving this prediction include a steady upward growth in the total number of global airline passengers, with a 7.6% growth in revenue passenger kilometers (RPKs), 6.3% growth in airline seat kilometers (ASKs, the number of available seats times the distance flown), 9% growth in freight ton kilometers (FTKs) and an overall passenger load factor of 81.4%. The Boeing 737 MAX and Airbus A320neo family will drive growth in aircraft deliveries and revenue, and a big part of that growth will come from aeroengine production. Air transport engine manufacturing is currently worth $17 billion, and is led by the CFM56, made by CFM International (a 50/50 joint venture between Safran and GE), the Trent XWB by Rolls Royce and the GE90 from GE Aviation.

Additive manufacturing continues to gain ground in aerospace.

The industry is currently awaiting Boeing's formal announcement of its proposed new mid-size airplane (NMA) to meet the needs of the "middle of the market (MoM)" space — an aircraft larger than the 737 or A319/320/321, but smaller than the 777, 787 or A330, intended to replace the now-retired 757 and 767. This MoM segment is difficult to build for, as it represents the intersection of narrow-body and wide-body (twin-aisle) designs, and decisions revolve around issues such as cargo volume, boarding time and gate turnaround time. The question of which engine supplier will be selected for the NMA — bids were reportedly submitted in June 2018 — is yet to be answered. Airbus could respond to the NMA with a stretch version of the A321, dubbed A322, equipped with larger engines and composite wings. According to Boeing, the NMA will prioritize cost reduction over new technology introduction, and low-cost materials and processes will likely be a priority. Although Boeing has indicated that the fuselage and wing will likely be composite, the company may tailor the materials to reduce costs.

The business jet and general aviation segment has been relatively flat since 2010, after an unusual spike in 2008, and there are signs that business jet deliveries are set for an increase. Large, very large and ultra large private jets will lead the way, with planes such as the Gulfstream G650ER. After years of flat spending, the US defense budget is on the rise with a FY2019 request of $686 billion. The F-35 will dominate US military fixed-wing deliveries, followed by Northrop Grumman's B-21, which will be the second largest military jet program by 2026.

These market predictions reflect four significant factors that are currently influencing the aerospace supply chain: customer consolidation, increasing vertical integration, the disruptive growth of additive manufacturing and the political climate, including protectionism and tariffs. Related to customer consolidation, a duo-duopoly has lately emerged, following Airbus' purchase of a 50.1% stake in Bombardier's *CSeries* program, now branded as the A220, and Boeing's purchase of an 80% stake in Embraer. With these purchases, the Big Two will get even bigger and bring more pressure on suppliers. At the same time, aircraft equipment suppliers are also consolidating, including UTC and Collins (that deal is awaiting Chinese government approval) as well as Safran and Zodiac, a merger that occurred earlier in 2018.

An ongoing trend towards vertical integration is apparent at Boeing, where it seems the company will play a greater role as a systems integrator on future programs. In my view, this likely means direct relationships with more suppliers going forward than during the 787 experience. And, consistent with more vertical integration, Boeing is also exploring selective use of "focused factories" at the Tier 2 level — facilities with a narrow range of products, customers and processes for greater efficiency and simplicity. Boeing has already made vertical integration moves in avionics, interiors and auxiliary power units (APUs), including a recently announced APU joint venture plan with Safran. Airbus, in similar fashion, has decided to vertically integrate by offering nacelles for the Pratt & Whitney PW1100G-powered A320neo. While UTC Aerospace Systems (UTAS) is the current nacelle supplier for the PW1100G, Airbus plans to compete *against* it by the mid-2020s. Additional OEM targets for vertical integration are myriad and could include virtually any aircraft subsystem.

Additive manufacturing continues to gain ground in aerospace. Norsk Titanium is already producing four structural titanium parts for the 787, via rapid plasma deposition (RPD). Further, Norsk expects the US Federal Aviation Admin. (FAA) to eventually certify the manufacturing process and material properties so that they can be used on more 787 parts and for other aircraft. Norsk has separately announced an agreement with Spirit AeroSystems for more additive parts, as part of Spirit's ongoing cost reduction efforts. RPD reportedly can cut the buy-to-fly ratio down to about 3:1 — much lower than traditional processes. Airbus has also introduced an additively manufactured titanium part for the A350, a bracket for a serial production A350 pylon produced by Arconic. Arconic (Alcoa Inc.'s new name) has several long-term agreements to 3D print titanium fuselage components and superalloy ducting for the A320 and A350. Airbus also has a research effort underway with US-based Sciaky Inc. to evaluate its electron beam additive manufacturing process.

In the Tier 1 space, GE continues to expand its additive manufacturing activities — it recently announced creation of a separate business to focus on third-party additive manufacturing. Its 2016 acquisitions of Arcam and Concept Laser are key enablers for technology adoption. For example, 35% of the parts on GE's *Catalyst* turboprop (which powers the Cessna *Denali* aircraft) will be additively manufactured. It has been reported that 855 conventionally manufactured parts have been replaced by just 12 additive parts in the *Catalyst* engine, greatly reducing complexity and speeding production. The engine will enter service in 2019. And, in 2017, GE's Auburn, AL, US, facility 3D printed more than 10,000 LEAP engine fuel nozzle injectors.

As for the political situation, the impact of tariffs and counter-reactions is a major wildcard. Earlier this year, the Trump Administration announced 25% tariffs on imported steel and a 10% levy on imported aluminum, both of which are key aerospace raw materials. The tariffs include mill product as well as forgings, castings, extrusions and pipe. Canada and Mexico were initially exempted from these tariffs, but in June 2018, tariffs were applied to them based on "national security concerns." Unfortunately, the proposed revision to the NAFTA agreement does not remove the raw material tariffs on Canada and Mexico. The estimated impact of tariffs on aerospace mill product is US$100 million to US$200 million; the impact on forgings, castings, extrusions and pipe is unknown at this point. Additional tariffs were imposed on China in several large tranches covering many industries. These tariff moves raise key questions: What is the end game for the Trump Administration? Will China target Boeing for retaliation? And which suppliers will absorb the costs? How the answers play out over the next few years will, it is hoped, keep the aerospace industry on a growth trajectory. CW

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# How do I know if my measured composite properties are correct, or even reasonable?

» Those familiar with mechanical testing of composite materials are well aware of the challenges associated with proper testing and accurate measurement of their mechanical properties. To date, many of my columns have focused on such challenges associated with specific types of tests performed with composite materials. In this column, we explore ways to determine whether the properties obtained from mechanical testing of composites are correct — or even reasonable. We'll focus on the more fundamental types of mechanical tests performed on unidirectional fiber-reinforced composites to measure their stiffness and strength properties.

Stiffness properties, also referred to as *elastic* properties, include the modulus of elasticity *E,* the shear modulus *G* and Poisson's ratio *υ*. For isotropic materials such as metals and plastics, stiffness properties are independent of material orientation and thus only one value exists for each of these three stiffness properties. In contrast, the stiffness properties of unidirectional fiber-reinforced composites are highly dependent on the fiber orientation relative to the applied force. To fully characterize the material stiffness of composites, tests must be performed at three mutually perpendicular material orientations relative to the applied loading, resulting in three values for each stiffness property (Fig. 1). However, for a unidirectional composite, the random distribution of fibers in the plane perpendicular to the fiber direction (the 2-3 plane shown in Fig. 2) results in isotropy within this transverse plane. Thus, for example, a unidirectional composite has the same stiffness in the 2 and 3 directions, or $E_2 = E_3$. In total, of the nine stiffness properties for a unidirectional composite material, the number of independent stiffness properties that must be measured is reduced to five due to transverse isotropy[1] (Fig. 2).

> A common starting point is to look for published test results from the same material.

In addition to stiffness properties, the *strength* properties of a unidirectional fiber-reinforced composite are also highly dependent on the material orientation relative to the applied force. Additionally, the strength properties can be significantly different under tension and compression loading due to different failure modes. Although there are a total of nine strength properties for a unidirectional composite, the number of independent strength properties is reduced to six under the assumption of transverse isotropy in the 2-3 plane[1] (Fig. 2), similar to the case for the stiffness properties described above. In contrast, metals typically require only two strength properties to be measured: the tension and shear strength.

After measuring any of these stiffness or strength properties for a unidirectional fiber-reinforced composite, how do we determine if the measured value is correct or even reasonable? A common starting point is to look for published test results from the same material, or a material that is considered similar. Fortunately, there are several publicly available sources of material property information for composites. For example, a composite material supplier's data sheets are one source of such information. They typically report fiber-direction stiffness and strength properties under tension and compression loading, as well as in-plane shear properties. Some material properties may also be provided at environmental conditions other than room temperature.

Publicly available databases are another resource. For example, the Advanced General Aviation Transport Experiments (AGATE) database[2] was developed for commonly used composites in the general aviation industry in the 1990s. The online AGATE database includes lamina material properties for carbon fiber- and glass fiber-reinforced composites with woven fabric and unidirectional fibers. Additionally, the follow-on National Center for Advanced Materials Performance (NCAMP) database[3], initiated in 2005, expanded its focus to the general aerospace industry. The online NCAMP database includes lamina and laminate property data for a variety of composite materials. Finally, mechanical property data for a variety of composite materials of general interest are available in Volume 2 of the *Composite Materials Handbook* (CMH-17)[4], which is available for purchase from SAE International.

Even though sources of mechanical property information are available for many composites, there are considerably more possible fiber and matrix combinations currently available. Thus, it may not be possible to find published information about the desired mechanical properties for a particular composite material of interest. Additionally, since the mechanical properties depend to various degrees on the processing method and fiber volume fraction of the composite, they may not be representative of the as-fabricated material of interest. Further, s*imilar* composite materials, perhaps with the same type of fiber but with a different matrix material, may not have *similar* material properties. Some

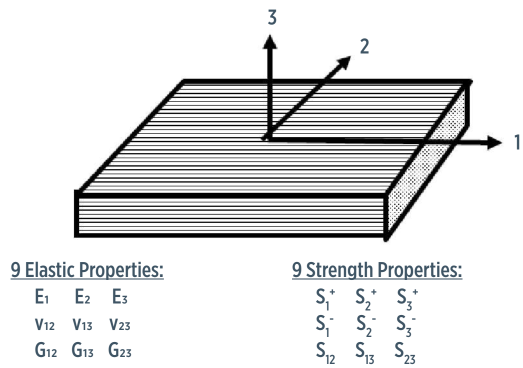


**FIG. 1** Independent elastic and strength properties of a unidirectional composite

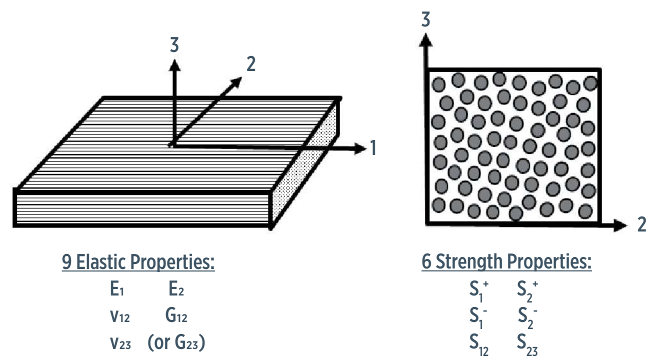


**FIG. 2** Independent and elastic strength properties of a unidirectional composite assuming transverse isotropy

mechanical properties, such as the fiber-direction (0°) tension stiffness $E_1$ and tension strength $S_1^+$, typically are *fiber-dominated* such that the choice of a *similar* polymer matrix material does not produce a significant difference. However, other mechanical properties such as the 90° tension stiffness $E_2$ and tension strength $S_2^+$ are more *matrix-dominated* properties, and may not be affected significantly when used with a similar fiber. Additionally, the fiber-direction (0°) compression strength $S_1^-$ depends on the fiber *and* matrix, as the matrix material provides resistance to fiber microbuckling, the typical failure mode under an applied compression force. Thus, an apparently *similar* composite material may *not* produce similar mechanical properties.

Despite the challenges associated with using reference material property values to assess whether test results are *correct*, they are of value in determining whether the results are *reasonable*. Material properties from these data sheets and databases may provide a feel for the approximate magnitudes and the amount of variability in the mechanical properties of interest for composites with fiber variations, matrix material variations or both.

In addition to using published data, two mechanical properties of unidirectional composites may be predicted relatively accurately based on properties of the fiber and matrix, as well as the fiber volume fraction of the composite. The fiber-direction (0°) stiffness $E_1$ and tension strength $S_1^+$ may be calculated using a simple rule-of-mixtures equation derived from a constant-strain "springs in parallel" model[1]. The modulus $E_1$ may be calculated using the equation:

$$E_1 = (E_f)\,(v_f) + (E_m)(v_m),$$

where the subscripts *f* and *m* denote fiber and matrix properties, respectively, and *v* is the volume fraction of the constituents. Similarly, the fiber-direction tensile strength $S_1^+$ of a unidirectional composite may be calculated from the same constant strain model using the equation:

$$S_1^+ = (S_f^+)\,(v_f) + (S_m^+)\,(v_m).$$

Using these equations, the fiber-direction stiffness and strength of a unidirectional composite can be approximated with reasonable accuracy simply by knowing the fiber stiffness and strength as well as the volume fraction of the constituents. CW

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Dr. Daniel O. Adams is a professor of mechanical engineering and has been the director for 22 years of the Composite Mechanics Laboratory at the University of Utah and vice president of Wyoming Test Fixtures Inc. (Salt Lake City, UT, US). He holds a BS in mechanical engineering and an MS and Ph.D. in engineering mechanics. Adams has a combined 39 years of academic/industry experience in the composite materials field. He has published more than 120 technical papers, is vice-chair of ASTM Committee D30 on Composite Materials and co-chair of the Testing Committee for the Composite Materials Handbook (CMH-17). He regularly provides testing seminars and consulting services to the composites industry.

# Looking ahead in 2019

» Each year, when January comes around, it provides an opportunity to reflect on what happened in the year prior, and to prognosticate on what might make headlines or progress significantly in the year ahead. One year ago, in my January 2018 *CW* column "Driving down costs," I laid out a handful of technologies to follow in 2018, including advances in manufacturing process simulation, automated layup and molding, and hybrid (continuous/discontinuous fiber) molding. I also suggested composites recycling and the Industrial Internet of Things (IIoT) would advance significantly. All of these would work to drive down the cost of composites.

Indeed, each of these technologies made great strides last year. Manufacturing process simulation tools are finding greater use with composite designers and producers, and Purdue University, under the umbrella of the Institute for Advanced Composites Manufacturing Innovation (IACMI, Knoxville, TN, US), has developed simulation "apps," integrating software from various companies, including Dassault Systèmes, ESI, Moldex 3D and Convergent, among others, using a single input file, with the app performing the data handoffs automatically between each step of the process. On the layup side, Voith and Audi have entered production using high-level, automated dry fiber placement followed by resin injection and cure for the *A8* model vehicle, while JEC Paris featured layup equipment from additional suppliers that will see deliveries in 2019.

I predict that 2019 will be a watershed year for demonstration of personal air mobility.

A look around at various trade shows in 2018 revealed numerous prototypes of hybrid molding, both in thermosets and thermoplastics, pointing toward upcoming widespread deployment in automotive components, given typical product development cycles. More companies now offer carbon fiber recovered from scrap textiles, prepreg and cured parts, and I have seen several projects working to take these materials downstream into molding compounds and finished parts. And the IIoT train keeps on rolling. Companies like Plataine (material tracking) and Aligned Vision (in-process inspection of fiber placement) are perhaps the most visible examples in terms of promotion, but there is plenty of development in sensor and signal processing technology across the spectrum.

So, what am I watching in 2019? Rather than technologies, I am looking at three key markets for composites, although technology plays a key enabling role in each. First up is infrastructure, especially in the US. With a divided US Congress starting in January, this may finally be the year for federal funding to rebuild American roads and bridges. It seems this is supported by both Republicans and Democrats, as well as most citizens. While this would certainly be a boost for concrete and steel, I wrote last month that I believe fiberglass rebar is at a tipping point and should benefit greatly from any major infrastructure initiative. Coincident with an overall infrastructure bill, I believe Congress will enact a version of the IMAGINE Act, or something similar, to further research into composites applications in infrastructure.

Next, I think we are moving into a new era for wind energy, which is already one of the largest markets for composites. Following relatively flat years in 2017 and 2018 in terms of new capacity installations, the Global Wind Energy Council forecasts a return to record growth in 2019 and 2020. While some of this is tied to expiring tax credits in some countries (including the US), wind power is being contracted at rates of US$0.03/kW-hr, making it equally competitive to, and in some cases more than, fossil fuel energy. A key driver is longer blades, not only onshore, but especially offshore, where we are approaching 100m lengths. This bodes well for the use of carbon fiber in spar caps, especially those made with low-cost production methods such as pultrusion.

Finally, I predict that 2019 will be a watershed year for demonstration of personal air mobility. We won't see regular "flying taxi" services in 2019, but the sheer number of companies entering this space will be flying test platforms to convince the regulatory agencies, the public and rideshare companies like Lyft and Uber that they have the right vehicles to meet both future demand and safety requirements. Uber has announced that it plans to conduct limited service of its Uber Air flight services in 2020 in Dallas and Los Angeles. Already, Airbus, Rolls Royce, Aston Martin, Joby Aviation, Volocopter and others have rolled out concepts or early prototypes. Since these vehicles will have more in common with helicopters than with airplanes, expect to see widespread use of composites to keep weight down, as many will be either entirely battery powered or have hybrid powertrains.

Other markets, including automotive and aerospace, may hold some surprises in store to make 2019 even more exciting for composites. Let's hope so! CW


## ABOUT THE AUTHOR

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

# Index expands on supplier deliveries and improved exports

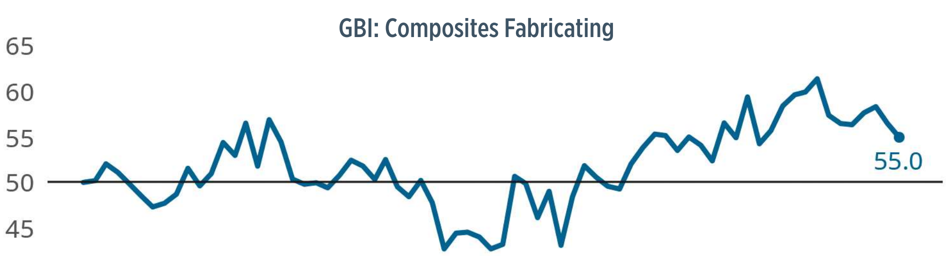
## November 2018 — 55.0

» The GBI: Composites Index for November registered 55.0, very nearly matching the Index's average expansion rate of 55.1 in 2017. November's reading slightly lowers the year-to-date average reading to 57.9. Barring an unprecedented fall in the Index in December, 2018 is almost certain to claim the title of fastest expanding calendar year for the Index since at least 2012. Compared to the same month one year ago, the Index is 1.2% higher. Gardner Intelligence's review of the underlying data indicates that the November Index was pulled higher by supplier deliveries, new orders and production. The Index — calculated as an average — was pulled lower by employment, backlogs and exports. No components of the Index experienced contraction during the month.

For a third consecutive month, supplier deliveries continued to be the fastest expanding component of the Index. This may be due in part to the wave of new orders which swept through the industry in the first half of the year. Compared to past years, supplier deliveries readings have been exceptionally strong in 2018, particularly in recent months. As the industry's supply chains continue to grow, production rates have also grown at record levels. The net result has been made apparent by the recently slowing growth in backlogs. Backlogs have grown every month in 2018, making this the longest continuous period of backlog growth in the industry's recorded history. CW

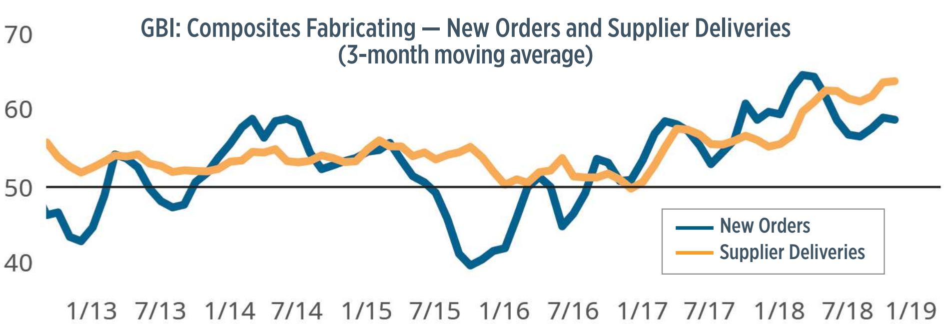
ABOUT THE AUTHOR

Michael Guckes is the chief economist for Gardner Intelligence, a division of Gardner Business Media (Cincinnati, OH, US). He has performed economic analysis, modeling and forecasting work for nearly 20 years in a wide range of industries. Guckes received his BA in political science and economics from Kenyon College and his MBA from Ohio State University. **mguckes@gardnerweb.com**




### Supplier deliveries driving growth

The Composites Fabricating Index was led higher for a third consecutive month by supplier deliveries. Production and new orders also supported the Index during November. The Index's growth throughout the calendar year has largely been driven by these three business factors.




### Supplier deliveries illustrate responsiveness to demand growth

Strong expansion in supplier deliveries in the second half of 2018 suggest that the industry is still adjusting to meet the greater demand for composite products first observed early in the year.

**A partnership between Boeing and recycling company ELG Carbon Fibre, expanding uses of pultrusion in the automotive industry, research into bio-based carbon fiber and more.**

CARBON FIBER

## Boeing to supply ELG carbon fiber for recycling

The Boeing Co. (Seattle, WA, US) and carbon fiber recycling specialist ELG Carbon Fibre Ltd. (Coseley, UK) announced that they have signed a five-year agreement whereby Boeing will supply to ELG cured and uncured carbon fiber composites that will be converted by ELG into secondary products for use in other composites manufacturing applications.

The cured and uncured carbon fiber waste will come from 11 Boeing composites manufacturing operations, including the 777X Composites Wing Center in Everett, WA, Boeing South Carolina in Charleston, SC, and eight other Boeing US sites involved in manufacturing commercial airplanes, rotorcraft and other products. The agreement also includes carbon fiber composites waste from Boeing's composites fabrication operations in Melbourne, Australia.

Source | ELG Carbon Fibre


Source | Boeing

Boeing says it provided about 380,000 lb of waste material to ELG during an 18-month pilot project, begun in March 2017. Under the new agreement, the company anticipates the initial volume will be about 1 million lb/year from its Puget Sound sites. That amount is expected to double over the next five years as excess material is collected from all of Boeing's composite manufacturing sites. This will support Boeing's goal to reduce the amount of solid waste going to landfills by 20% by 2025.

The agreement marks the first formal material supply relationship between a major aircraft OEM and a carbon fiber recycler. Frazer Barnes, managing director of ELG, says his company has been working with Boeing for four years to evaluate and characterize the properties of materials derived from Boeing's carbon fiber waste. ELG, he says, expects to integrate the Boeing waste into carbon fiber nonwoven products ELG manufactures, as well as chopped carbon fiber for use in thermoplastics compounding, both under the CARBISO trade name.

Although the technology to recycle cured and uncured carbon fiber materials has existed for several years, the composites recycling industry is still in the nascent stages of developing markets for materials it produces from recyclate. Barnes also notes that growth has been limited by concern among some potential users who desire supply stability: "One of the things that most concerns the end user is supply chain security. Obviously, this agreement goes a long way toward establishing that security."

Boeing, for its part, is eager to make sure that its composites manufacturing operations are as efficient as possible. Kevin Bartelson, senior director of 777 and 777X wing programs at Boeing, and a major recycling proponent at the company, says the ultimate goal with its unused composites is zero waste/zero landfill.

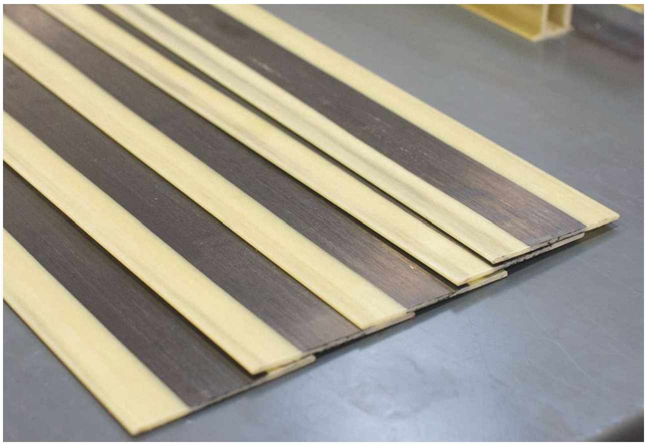
ELG's Barnes says that in the initial phase of the five-year contract, ELG will transport waste from Boeing facilities to ELG's UK plant via ship. "This is quite economical, actually," Barnes says, but adds that "this contract with Boeing is another step forward in closing the business case for an ELG recycling facility in the US."

Bartelson says that although Boeing would not characterize the exact quantity of carbon fiber waste the company expects to deliver to ELG (Barnes calls it "a lot of material"), he does report that the ratio of cured to uncured material is currently about 1:1. However, he reports, Boeing is increasing efforts to re-use uncured carbon fiber waste in-house via tow respooling and other methods. As a result, he says, Boeing expects, eventually, to reduce the amount of uncured carbon fiber it sends to ELG for recycling.

As a result of the partnership with Boeing, ELG estimates the number of its employees will nearly triple from 39 in 2016 to an expected 112 by the end of 2019, as the recycling market continues to expand. ELG employs 73 people today. Boeing and ELG, a subsidiary of global metals recycling leader ELG Haniel Group, are considering expanding their partnership to include excess composite material from Boeing manufacturing sites in Canada, China and Malaysia.

AUTOMOTIVE

# Pultrusion picks up speed in automotive applications



Source | L&L Products

Pultrusion is one of the most cost-effective processes for manufacturing high-volume composite parts. Most commonly associated with glass fiber-reinforced profiles used in construction and corrosion-resistance applications, tailored pultrusions for automotive applications — including bumper beams, roof beams, front-end support systems, door intrusion beams, chassis rails and transmission tunnels — were highlighted as a key area for growth by the European Pultrusion Technology Association (EPTA, Frankfurt, Germany) in its 2018 World Pultrusion Conference report.

Two commercial launches highlighted at CAMX 2018 (Oct. 16-18, Dallas, TX, US) seem to confirm this technology/market fit. L&L Products Inc. launched its Continuous Composite Systems (CCS) pultrusions, which use polyurethane resin for automotive applications such as side sills and crash structures. Designed to replace traditional metal structures that require bulkheads for necessary stiffness, CCS pultrusions offer light weight — 75% less mass than steel and 30% less than aluminum — at an economic price. Continuous fiber profiles include three variations: *CCS Set* using glass fiber, *CCS Hybrid* using a customized mix of glass fiber and carbon fiber, and *CCS Extreme* using only carbon fiber. A short-fiber version co-extruded with adhesive comprises a fourth product, *CCS Co-Ex*. The three continuous-fiber products may also be combined with L&L's adhesives as part of the company's in-line processing, further reducing manufacturing costs and time-to-delivery. Beyond automotive, CCS products are also aimed at wind turbine blade spar caps and industrial and architectural applications.

Shape Corp. (Grand Haven, MI, US) also is developing pultrusions for automotive, but with a curve — literally. The company has the first operational installation of Thomas Technik & Innovation's (TTI, Bremervoerde, Germany) Radius-Pultrusion system, which was exhibited at CAMX 2018. Shape Corp. is a global Tier 1 supplier of metal, plastic and composite automotive components, and as described in the June 2017 *CW* article, "Curved pultrusion?," its Radius-Pultrusion system was purchased "to enable manufacture of automotive bumper beams." The company was a 2017 CAMX ACE award finalist in the Infinite Possibility for Market Growth category for its use of curved pultrusion to create highly engineered hollow and closed profiles. The technology also enables the use of multiple types of reinforcement in a single, tailored laminate. After extensive trials to develop a laminate architecture and resin formulation that best works with Radius-Pultrusion, Shape chose polyurethane. "It offers exceptional toughness properties at reasonable cost while allowing us to achieve some very fast production rates," says Toby Jacobson, Shape's plastic materials and process manager/advanced product development. "For reinforcements, we are running unidirectional, biaxial and triaxial noncrimp [stitched nonwoven] fabrics. We're also pulling some individual unidirectional tows when necessary. While most of the current interest is with carbon fiber, this process will excel with fiberglass and a variety of other reinforcements." Polyurethane and hybrid fiber pultrusions are also being developed in Europe, where TTI is working with partners such as KraussMaffei (Munich, Germany) and Covestro (Leverkeusen, Germany).

# 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

**NASA project looks to carbon nanotube composite materials**
The Super-lightweight Aerospace Composites (SAC) project seeks to scale up the manufacturing and use of carbon nanotube composite materials for rockets and spacecraft.
11/2/18 | short.compositesworld.com/NASA_nano

**LM Wind Power opens new development facility for wind turbine blade technology**
The new Technology Center Americas facility will develop and test new techniques for designing and building wind turbine blades.
11/8/18 | short.compositesworld.com/LMWind

**Hartzell Propeller to partner with Eviation Aircraft on electric commuter aircraft**
Eviation's all-electric Alice aircraft will utilize Hartzell's 5-blade carbon fiber blades and Bantam hub series.
11/12/18 | short.compositesworld.com/elec_plane

**Rocket Lab launches 7 payloads into orbit**
The mission, named "It's Business Time," marks Rocket Lab's second successful orbital launch of its all-composite *Electron* launch vehicle.
11/12/18 | short.compositesworld.com/RL_launch7

**Aurora reveals Odysseus solar-powered UAV**
Powered only by the sun, *Odysseus* is an ultra-long endurance, high-altitude platform that utilizes advanced solar cells and lightweight materials including a carbon fiber frame.
11/14/18 | short.compositesworld.com/Odysseus

**Thermwood and US Navy explore additive manufacturing for ships and ship systems**
The validation program centered on printing an unclassified scale nose of a submarine using Thermwood's Large Scale Additive Manufacturing (LSAM) system.
11/14/18 | short.compositesworld.com/TW_Navy

**GKN Fokker to implement automated kitting solution from Airborne**
The automated kitting solution is said to reduce costs by saving man-hours and material scrap, and it enables a flexible and digital workflow.
11/16/18 | short.compositesworld.com/Airborne

**Technical University of Munich researchers explore using algae to make carbon fiber**
The process uses algae to convert $CO_2$ from the atmosphere and manufacturing exhaust into algae oil, which is then used to produce polyacrylonitrile (PAN) carbon fiber precursor.
11/19/18 | short.compositesworld.com/CF_algae

**McLaren Automotive opens new carbon fiber innovation and production center**
McLaren Composites Technology Centre (MCTC) will focus on innovating lightweight carbon fiber and composites for improved energy efficiencies in automobiles.
11/19/18 | short.compositesworld.com/McLaren

**Bally Ribbon Mills offers film infusion for 3D woven joints**
In the film infusion process, a frozen sheet or film of resin is infused onto the custom 3D woven joint, saving customers the trouble of infusing the resin themselves.
11/21/18| short.compositesworld.com/infusion3D

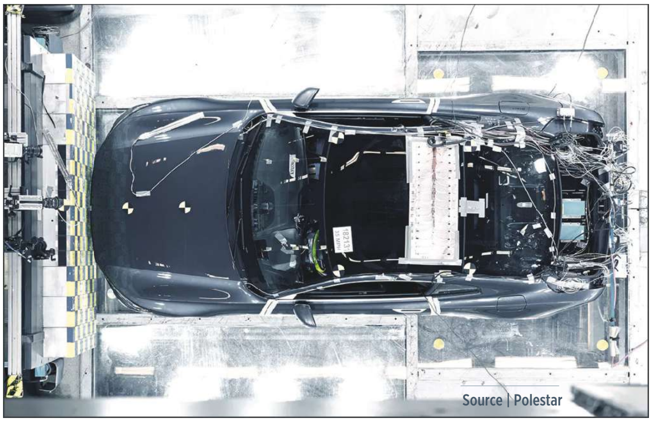
AUTOMOTIVE

## Polestar conducts crash test evaluating carbon fiber strength

Polestar (Gothenburg, Sweden) has undertaken the first of a series of crash tests as part of the development of the *Polestar 1.* This represents the first time the Volvo Car Group has assessed the strength of a carbon fiber-reinforced polymer body in a real crash situation.

In contrast to a steel body where bending helps the integrated crumple zones to reduce the amount of crash energy that reaches the vehicle's occupants, carbon fiber dissipates energy by cracking and shattering. Close attention was given to the way the carbon fiber body of the vehicle reacted to the extreme forces involved in the impact. The engineers also focused on how the underlying steel body structure, and carbon fiber "dragonfly" which strengthens it, managed the forces.

The *Polestar 1* verification prototype, part of the first *Polestar 1* build series, was propelled into a stationary

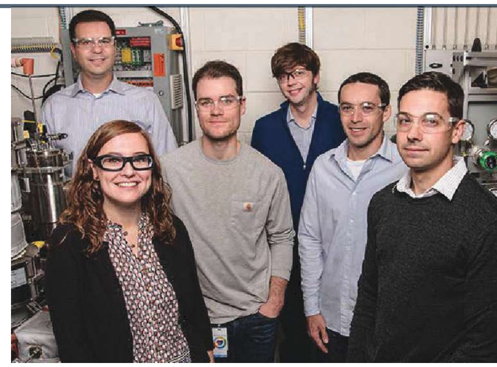


Source | Polestar

barrier at 56 kmh, simulating a frontal collision. Most of the energy was absorbed by the car's crash structure, with the remaining energy mitigated by the carbon fiber body panels into the body structure which remained rigid and did not show signs of bending or misalignment after the crash.

CARBON FIBER

## NREL makes strides with bio-based acrylonitrile



NREL researchers (from left) Adam Bratis, Violeta Sànchez i Nogué, Todd Eaton, Gregg Beckham, Vassili Vorotnikov and Eric Karp all worked to make renewable acrylonitrile a reality.

Source | Dennis Schroeder, NREL

The National Renewable Energy Laboratory (NREL, Golden, CO, US) recently reported that it is making progress with ongoing research based on early 20$^{th}$ century techniques for making chemicals from natural products. The laboratory says the research could lead to a cleaner method of transforming acrylonitrile (ACN) into carbon fiber by replacing petrochemicals with biomass as the starting point.

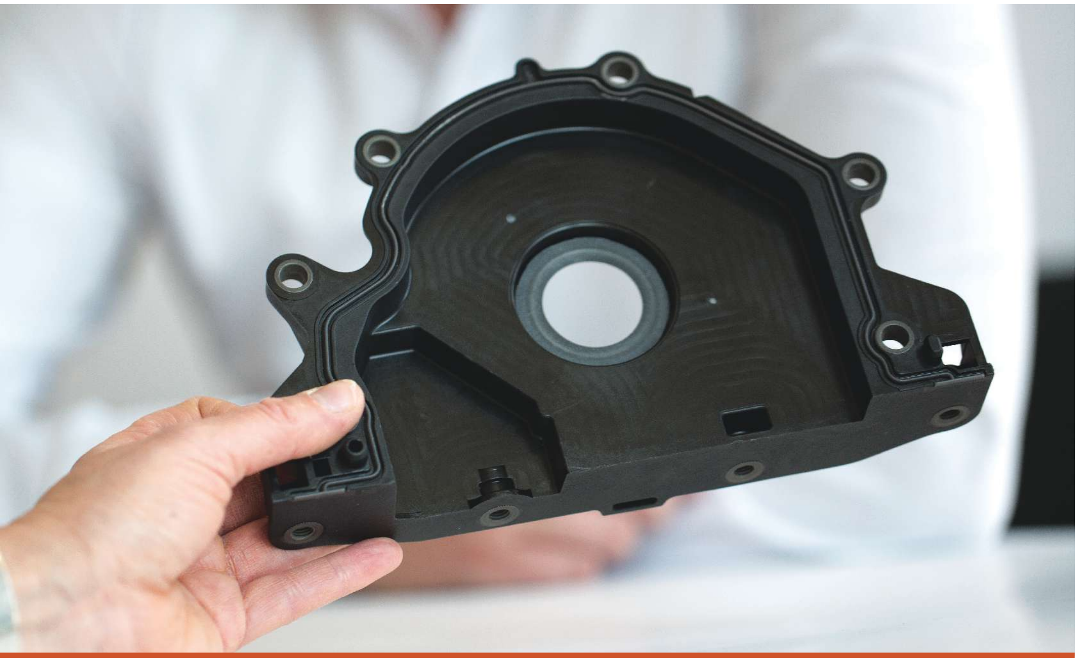
NREL has successfully produced 50g of bio-derived ACN, which capped the first phase of a US Department of Energy (DOE)-funded program. During the first phase, NREL researchers used corn stover, which consists of the stalks and leaves left over after harvesting the crop. The sugars in the biomass are converted by a microorganism into 3-hydroxypropionic acid (3-HP), which in subsequent steps is transformed into acrylonitrile.

The second phase, now underway, calls for the production of 50 kg of ACN that will be converted into carbon fiber and tested. The larger volumes needed will be produced by Cargill Inc. (Wayzata, MN, US). A West Virginia nonprofit research institute, MATRIC (South Charleston, WV, US), will then convert Cargill's 3-HP into ACN. Then a Portuguese company will produce the carbon fiber and hand it off to Ford Motor Co. (Dearborn, MI, US). The car manufacturer will fashion the carbon fiber into parts and compare the biomass-derived versions against those made through the traditional process.

# Bio-composites break into structural automotive applications

## A relatively new and still evolving bio-based, polyamide composite comes with a unique property profile that may help it carve a niche in automotive applications.

**By Michael LeGault** / Contributing Writer



**EcoPaXX crankshaft cover replacing aluminum**

This 200-by-120-mm crankshaft cover is made from a 50% chopped-glass fiber injection molding grade of EcoPaXX. The part, which is insert molded over a dynamic PTFE seal, is installed on VW's MDB-4 diesel engine and replaced a die-cast aluminum part, producing weight savings of 40%.

Source | DSM Engineering Plastics

» Bio-based resin systems are not new to composites manufacturing. In fact, bio materials have been used as feedstock in some resin systems for more than a decade, starting with soybean oil and corn ethanol used in unsaturated polyester and progressing to sugar cane, lignin, vegetable oils, glycerols and other plant-based biomasses. Such materials have been marketed primarily as greener alternatives to traditional hyrdrocarbon-based resins, designed to reduce the carbon footprint of the final product in which they are used. However, despite their wide availability, bio-based resins have struggled to displace their petroleum-based predecessors. That is starting to change, however, and evidence of this can be found in the automotive composites market.

This is where DSM Engineering Plastics (Galeen, The Netherlands) finds itself with its EcoPaXX PA 410, a bio-based polyamide that has been certified as carbon neutral, thanks in part to its being 70% derived from the castor oil bean plant. This resin is available in a number of glass fiber- and carbon fiber-filled versions, as well as in a line of unidirectional (UD) tapes that are targeted toward automotive parts. The automotive environment is a good fit with the polymer's high-temperature stability, enhanced hydrophobicity compared with other polyamides and superior oil and chemical resistance.

One of the first commercial applications of EcoPaXX, a crankshaft cover on Volkwagen's MDB-4 TDI diesel engines used in a variety of car models made by VW, Audi and others, won a 2014 Society of Plastics Engineers (SPE) Innovation Award in the Powertrain category, replacing a die-cast aluminum cover with a resulting weight savings of 40% and a total production system cost savings of 25%. The part, manufactured by KACO GmbH (Kirchardt, Germany), comprises a 50% chopped glass fiber, injection molding grade of EcoPaXX insert molded over a plasma-activated, dynamic PTFE seal, with a liquid silicone rubber static seal. KACO developed the patented PTFE seal process, which is said to reduce friction and improve engine efficiency.

The crankshaft cover is approximately 200 mm long by 120-140 mm wide by 2-4 mm thick. In operation, the interior of the part is fully immersed in oil. Ronald Ligthart, DSM's global technical product manager, Stanyl and EcoPaXX, says for this application, the 410 polymer is competing with polyamide 46 and 66, as well as polyphthalamide (PPA). He notes that while the EcoPaXX 410 molecule provides similar mechanical properties to PA 66 and PA 46 (the polymer comprising DSM's Stanyl line of resins), it is the combination of the 4 monomer (1-4 diamino butane) with the 10 monomer (sebacic acid), that imparts enhanced chemical, oil and water resistance compared to these other material options.

"The aliphatic, hydrophobic nature of the 10 monomer acts as a counterbalance to the hydrophilic properties of PA 46 and 66, which is critical for a part such as the crankshaft cover as it provides better dimensional stability in the high heat and humidity found under the hood," says Ligthart. When customers are looking for improved dimensional stability and/or improved hydrolysis/chemical resistance versus PA 66 in these conditions, he says EcoPaXX is an improved, drop-in replacement for PA 66 molds.

The molecular structure of EcoPaXX also provides the glass-filled injection molding grade, formally QHG10, with low viscosity and high temperature stability — properties that are said to make it easy to mold. "The processing window of PA 66 is very restricted, typically to a range of 20-30°C; however, with EcoPaXX, as a consequence of the 10 monomer, the processing window is really wide, in the range of 250-350°C, which gives the molder a lot of flexibility to fine-tune the flow during processing," reports Ligthart.

**Lighter, stronger wheels**

Maxion Wheels is developing a lighter, stronger wheel comprising a steel rim section thinned by 50% and wound, in three locations — left, center and right — with 60% glass fiber-reinforced EcoPaXX tape. The polyamide resin has been formulated with energy-absorbing compounds and appears black. Radial fatigue testing has shown the tape-wound wheel has about 30% improved fatigue resistance compared to a standard steel wheel, and provides a weight savings of about 2 kg per standard passenger car wheel and about 6 kg per standard commercial truck wheel.

Source | DSM

## UD tapes target automotive lightweighting

Looking to the future, DSM is planning installation in 2019 of a production line for rolls of 1m-wide continuous glass fiber- and carbon fiber-reinforced EcoPaXX tapes, as well as tapes made from its other polyamide resins, such as Stanyl. The EcoPaXX tapes were initially developed from 2012 to 2016 as part of a consortium project sponsored by the European Union, ENLIGHT, comprising automotive OEMs and suppliers. The goal was to accelerate development of new lightweight materials and processes for automotive manufacturing.

DSM, the sole materials supplier in the project, formulated EcoPaXX tapes, in part, as a response to the project's near-term objective for cost-effective, bio-based thermoplastics to reduce weight and the carbon impact for application in medium- to high-volume electric vehicle production by 2020-2025, for specific car sub-systems, including the subframe » and suspension, front module and cross-car door beams and enclosures.

Raj Mathur, DSM global R & T manager, advanced thermoplastics composites, reports the material and mechanical properties of the tapes were first characterized by standard lab testing. The material data was then used as input for finite element analysis simulations — for example, side pole crash tests of door panels. In the final phase of the project, DSM and partners demonstrated viable manufacturing techniques by weaving the UD tape into non-crimp fabrics and then thermoforming and joining the door panel sections, and other demonstrator parts, into final shape.

Currently, DSM offers grades of glass fiber- and carbon fiber-reinforced EcoPaXX UD tape produced on a pilot production line in rolls 600 mm wide and up to 300m long, typically 0.20-0.30-mm thick, with a fiber content of 50-60%. Mathur says customers typically slit the tape to widths (±0.1 mm) appropriate for the application. In conjunction with the ENLIGHT project, DSM has tested and confirmed that the tapes are compatible with a handful of manufacturing processes, including tape winding, metal-composite hybrid fabrication and automated tape layup (ATL) combined with thermoforming and injection overmolding. The latter process was proved out in a demonstrator part produced with geometries typically found in automotive parts such as engine and battery covers. To manufacture the part, first an ATL machine equipped with a robotic arm and trailing roller lays down a laminate up to 4 mm thick. This laminate is then thermoformed to final shape in a process similar to metal stamping. Finally, the part is fixed in a tool and injection overmolded to add features to the part, such as ribs and bosses.

> The metal-hybrid MaxFiber wheel resulted in about 6 kg of weight savings per standard truck wheel.

One of the more promising, long-term commercial applications entails a collaboration between Maxion Wheels (Konigswinter, Germany) and DSM in the development of the metal-hybrid MaxFiber Steel Wheel. One of the goals with the wheel was to decrease the original steel wheel rim section thickness to 1 mm (from 2 mm), compensating by wrapping the rim with 60% glass fiber-filled UD EcoPaXX tape in three locations: the center "groove," called the drop well, and two side grooves, one on the left and right, termed the bead well (see photo on p. 19). The tape wound in the drop well is twice as wide as the tape wound in the two bead wells. The EcoPaXX resin was formulated with conductive additives in order to absorb laser energy during winding and curing. The reduced steel use and subsequent winding with glass fiber-reinforced tape resulted in about 2 kg of weight savings per standard 16-inch passenger car wheel, and about 6 kg of weight savings per standard truck wheel.

The critical benchmark for success of the project, Mathur reports, was passing the SAE J328 Radial Fatigue Test, which simulates a wheel/tire assembly in normal operation as it would be with a standard vehicle load. During the test, over time, the load is multiplied, thus simulating the life cycle of a wheel in a relatively short time. While there are several loading tests required to validate a new wheel, the J328 is the test that most directly affects the wheel in the reinforced area. Mathur says the test results showed the tape-wound wheel had an improved strength and fatigue-resistance of about 30%, compared to a standard steel wheel control of the same dimensions and thickness, proving the feasibility of validating the wheel design for full commercial operation.

While testing on the MaxFiber wheel is ongoing, Mathur says the value proposition of the wheel is better for commercial trucks rather than passenger cars as trucks have heavier, and more, wheels. With an average of six wheels per truck, at a minimum 6 kg of weight savings per wheel, the total weight savings of 36 kg "adds up to a sufficiently high number to attract the attention of commercial truck operators," says Mathur.

The development work on the hybrid metal-composite wheels revealed another appealing attribute of the EcoPaXX tapes: When consolidated into a laminate, the tapes have a higher interlaminar shear strength than many other typical glass fiber-filled thermoplastic and thermoset laminates, reports Mathur. "Compared to composites in general, which have interlaminar shear values typically in the range of 50-60 MPA, EcoPaXX is 80-90 MPA. This means a fabricator or designer can use less material to make parts with the required structural properties."

As with composite tape products in general, the EcoPaXX tape has an inherent cost advantage compared with parts cured in an autoclave. Mathur says that to ensure the commercial viability of EcoPaXX, and the company's line of thermoplastic composite tapes in general, DSM is working with equipment suppliers to reduce fabrication costs, maximize throughput and reduce cycle times. Ultimately, DSM would like to see cycle times closer to 1 minute, which would put the material and process on par with automotive industry standards. CW

**ABOUT THE AUTHOR**

Michael R. LeGault is a freelance writer located in Seattle, WA, US, and the former editor of *Canadian Plastics* magazine (Toronto, ON, Canada). **mlegault@compositesworld.com**

**FIG. 1** A dedicated educator

Steve Nutt (center) is director of the University of Southern California's M.C. Gill Composites Center and, for 24 years, has been a professor of engineering at USC. Source | USC

# Developing next-generation composites talent

## The M.C. Gill Composites Center at the University of Southern California has steadily grown to become one of the industry's educational and R&D stalwarts.

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

» Any educational institution that has developed a specialized area of study — engineering, history, art, medicine — likely can trace its genesis back to a person who supplied a great deal of personal dedication and passion to help bring that specialization to life. More often than not, that person is an educator, and someone who sustained that dedication over many years, in the process drawing the students and acolytes who built the critical mass necessary to make the program self-sustaining.

The composites industry, which is itself relatively young, has had only a little time to develop such specialization at colleges and universities. Still, throughout the world, there is now a healthy handful of strong composites engineering programs that are turning students into composites manufacturing professionals.

One such program can be found at the University of Southern California (USC, Los Angeles, CA, US), where a dedicated educator and a generous, deep-pocketed alumnus have steadily built a highly respected composites engineering program. The generous alumnus was the late M.C. Gill, namesake of composites fabricator Gill Corp. (El Monte, CA, US) and endower of USC's M.C. Gill Composites Center. The educator is Steve Nutt, director of the M.C. Gill Composites Center and, for 24 years, a professor of engineering at USC (Fig. 1). *CW* was invited to visit Nutt and the M.C. Gill Composites Center to learn more about the program and the work it is doing.

Nutt, sitting in his office in Vivian Hall within USC's Viterbi School of Engineering, explains that the M.C. Gill Composites Center has become a popular destination for engineering students, attractive in part because it offers a hands-on program focused primarily on work with prepreg materials and liquid molding. Nutt, assisted by research professor Timotei Centea, lecturer Lessa Grunenfelder and research scientist Bo Jin, leads the research projects of 14 Ph.D. students, six Masters students and eight undergraduates who work in several labs spread out across the center.

The research done at the center, says Nutt, is very much student-led, but guided by faculty. Because of this, students are given much free rein to explore a variety of materials and processing technologies, employing a large variety of tools populating the center's labs.

The center's facilities include a layup room with cutting table, a glass-walled miniature autoclave (more on that below), a polishing lab (with an electron polishing machine), a stereoscopy lab and a large catch-all lab that includes five Instron testing machines, a digital image correlator, a Wabash hot press, an RTM tool, a small autoclave, a Radius Engineering RTM injector, a small CNC machine and freezers for prepreg storage. During *CW*'s visit, students were at work in each of these facilities, setting up the glass-walled autoclave,

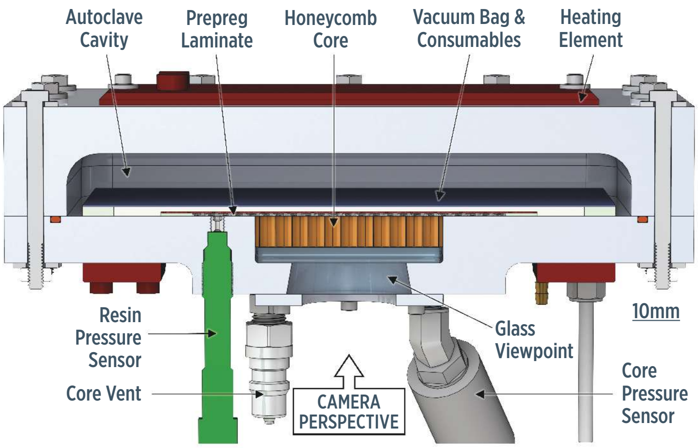



**FIG. 2 Miniature autoclave for student research**

This schematic shows a cutaway view of the miniature autoclave, with viewport, that M.C. Gill Composites Center students use to conduct in-situ visualizations of resin, fiber and core behavior during cure. This is the autoclave Mark Anders used to conduct his research on bubble behavior. Source | Mark Anders

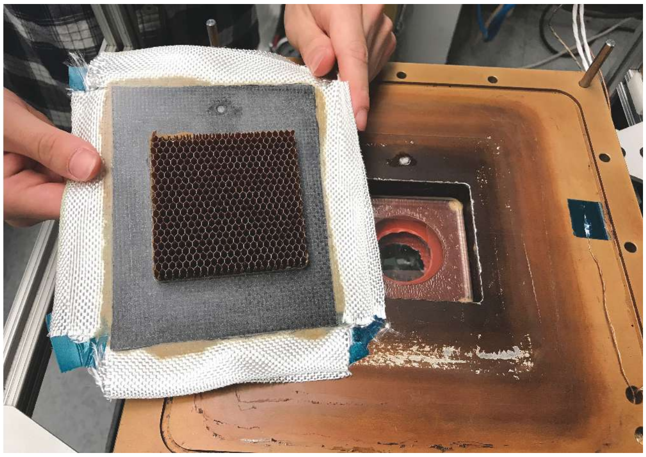


**FIG. 3 Core-and-laminate research sample**

This shows the open autoclave, with viewport visible. A USC student is holding a sample of the type of core-and-laminate construction used with the autoclave. The sample was placed core-side down over the viewport, bagged, sealed and cured. Source | *CW* Photo | Jeff Sloan

bagging a laminate and evaluating polishing technology.

Nutt, because of his long tenure at the school and the center, is closely associated with the program and its success. He says, however, that whatever success the program enjoys flows not from him, but from its students: "If I can take any credit for the success of this program," Nutt concedes, "it's for the ability to attract incredible talent."

## In-situ visualization

It would be difficult to summarize all of the student-led research being done at the M.C. Gill Composites Center, but there are two students whose work is notable and worth closer scrutiny. Both students are part of small teams in which individual researchers focus on different aspects of a common problem.

The first is Mark Anders, who is pursuing a Ph.D. in mechanical engineering. His work, part of a project co-led at USC by Nutt and Centea, and performed in collaboration with another Ph.D. student (Daniel Zebrine) as well as the University of Delaware, has focused on research involving the glass-walled miniature autoclave referenced above. The mini-autoclave is a staple of the center and has been used in several projects. It features an 11-by-11-inch heated aluminum tool plate with a 3-by-3-inch cavity cut from its center. This cavity is filled with a glass viewport through which a bottom-mounted video camera records resin, fiber and core material behavior during the cure process (Fig. 2). Visual observation through the autoclave's viewport — which enables the "in-situ visualization" — offers insight into material behavior during cure that is, otherwise, difficult to assess.

Anders says the premise of the team's research was relatively simple: "What can happen to a honeycomb sandwich structure when a given set of materials, for a given temperature cycle, cures under various pressure conditions?" Anders and his colleagues at USC hypothesized that unmanaged gas pressure in the

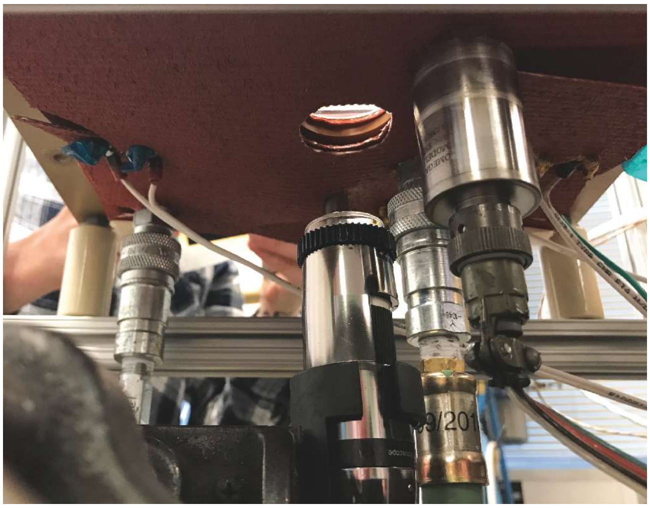


**FIG. 4 Autoclave viewport**

Looking at the miniature autoclave from below, one can see the viewport and video recording equipment used by students to study material behavior during the cure process. Source | *CW* Photo | Jeff Sloan

honeycomb cells can lead to defects in the bondline caused by volatile-release behavior of both the film adhesive and the prepreg resin. Further, by extension he thought that active and knowledge-driven management of vacuum bag and core pressures might reduce bondline void formation.

For his work, he built a partial sandwich structure laid over the autoclave viewport, comprising a 76-by-76-mm square of aramid honeycomb core (from Gill Corp.) topped by a film adhesive (from Henkel, Bay Point, CA, US), topped by four plies of plain weave carbon fiber/epoxy prepreg laminate (from Hexcel, Stamford, CT, US), topped by a vacuum bag (Fig. 3). During cure, the camera, »

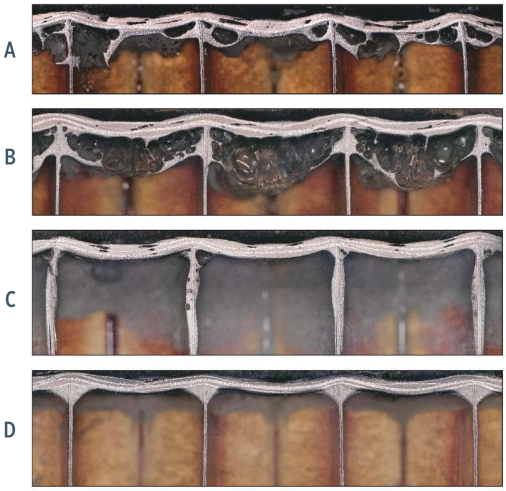



**FIG. 5 Research results**

This micrograph of the cured core-and-laminate sample shows bubble formation in the four cases evaluated by Anders. The top two rows, Cases A and B, show significant bubble formation, as well as intermingling of the resin and adhesive. The bottom two rows, Cases C and D, show significantly reduced bubble formation and good segregation of resin and adhesive. Source | Mark Anders

looking through the viewport and up into the honeycomb core cells (Fig. 4, p. 23), captured resin and film adhesive behavior during the cure cycle. Anders evaluated material behavior under four conditions, labeled A, B, C and D:

- Case A featured a continuous adhesive film, a sealed core and a simple temperature/pressure cycle (1-hour room temperature hold followed by 377 kPa and temperature dwells at 110°C and 180°C).
- Case B featured a reticulated adhesive film, a sealed core and a simple temperature/pressure cycle.
- Case C featured a reticulated adhesive film and a simple cycle, plus, importantly, equilibration of the core and vacuum bag pressures throughout cure.
- Case D featured a reticulated adhesive film, equilibrated core/bag pressures and a three-stage pressure profile.

Anders reticulated the adhesive film by heating and then perforating the film in the middle of each honeycomb cell. Surface tension in the film then caused the adhesive to retract from the middle of the cell and agglomerate along the edge of the honeycomb. Discontinuity of the adhesive, the team discovered in Cases A and B, affected the pressure distribution throughout the core and laminate. In both cases, however, unwanted bubbles grew and remained in the cured structure, thereby increasing porosity and compromising the integrity of the finished part (Fig. 5).

This realization led Anders to Cases C and D, where he began to manipulate pressure inside and outside the vacuum bag and, eventually, to modify the pressure profile of the cure process to minimize bubble formation. In Case C, very low core pressures caused bubbles to grow and then burst, reducing the final porosity but also reducing the size of adhesive fillets (since the bursting process redistributed the adhesive onto the cell's walls). In Case D, Anders says, the three-stage pressure profile allowed him not to evacuate all entrapped gases (as might be a reasonable goal), but to moderate and manage bubble formation. "Rather than get the gases out," he says, "we dissolve them in the resin — keep bubbles from forming in the first place. This keeps porosity low."

In the end, says Anders, the team's work showed that bag and core pressure must be managed separately from consolidation pressure: "Basically, you need to set your bag and core pressure to whatever you need to avoid voids, then you set the autoclave pressure to what is required for compaction." Lab-scale tools such as the glass-walled mini-autoclave provide the means to visually identify the conditions required to suppress defects, and enable knowledge-driven decisions about manufacturing processes.

Anders admits he was surprised at how effective management of in-bag pressure was for minimizing voids. He was also surprised to find so little existing research on the subject. The earliest research he could find that addressed super-ambient in-bag pressure during cure was in a January 1984 paper, "Processing Science of Epoxy Resin Composites," written by R.A. Brand et al of the General Dynamics Convair Div. (San Diego, CA, US) and published by US Air Force Wright Aeronautical Laboratories (Wright-Patterson Air Force Base, OH, US). The paper describes development of an "internally pressurized cure cycle" for the fabrication of an F-16 vertical tail skin, and reinforces much of what Anders discovered.

Anders is now working on research to understand how gas transport through prepreg relative to resin viscosity affects core pressure. For more, read Anders et al's paper, published by Elsevier, titled "Process Diagnostics for Co-cure of Sandwich Structures Using In-situ Visualization" and Brand et al's paper, "Processing Science of Epoxy Resin Composites."

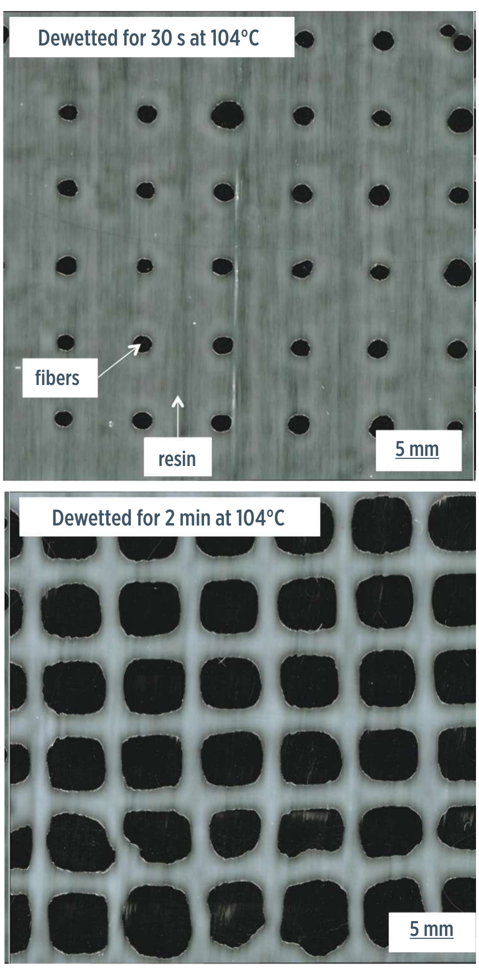



**FIG. 6 Prepreg dewetting**

Sarah Schechter's work at USC has focused on development and evaluation of prepreg dewetting processes, and their effect on cured part properties. Dewetted (or discontinuous) prepreg should, in theory, allow air to escape the laminate and core in the z-direction during cure. These micrographs show resin condition after dewetting at two intervals, 30 seconds and 2 minutes. Source | Sarah Schechter

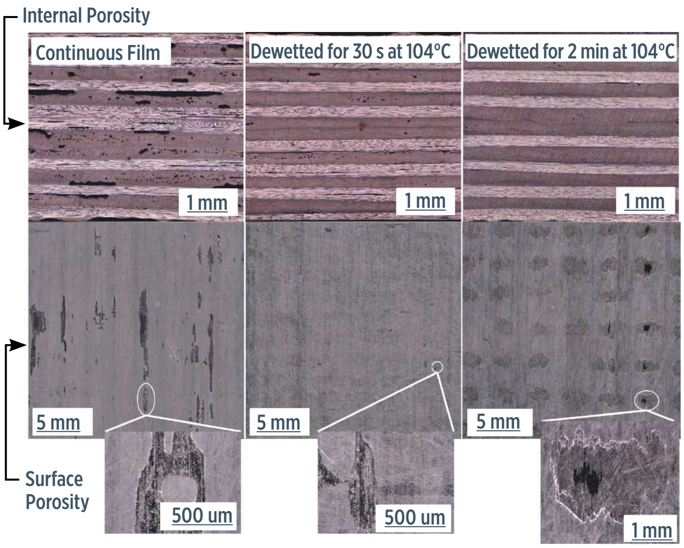



**FIG. 7** **Internal and surface porosity**

These micrographs show internal and surface porosity for the three prepreg types Schechter evaluated. Data from her work showed that prepreg dewetted at 104°C for 2 minutes (104-120) produced cured composite parts with the best properties.

Source | Sarah Schechter

## Dewetting prepreg

Addressing similar material behavior is Sarah Schechter, a fourth-year Ph.D. student conducting research on creating advanced prepregs using dewetting. Previous research performed at USC by Lessa Grunenfelder (now a lecturer at the school), Amy Dills and Timotei Centea showed that prepregs with discontinuous resin distributions can reduce defect levels during out-of-autoclave cure compared to materials with continuous resin films. Resin discontinuity can be created by dewetting conventional prepregs, as in a process patented by Cytec (now Solvay Composite Materials, Alpharetta, GA, US). However, these previous approaches did not allow for the creation of discontinuous resin patterns in a controlled manner, as the patterns created were dependent on the fiber bed architecture. Schechter says she set out to create an efficient way to create discontinuous resin patterns independent of the fiber bed and, ultimately, allow for its application to any fiber bed.

The premise of USC's approach is simple: Apply resin to fiber in a regular but discontinuous fashion such that, during cure, entrapped air has a z-direction escape path. The dewetted prepreg Schechter used is one embodiment of a family of materials commonly referred to as USCpreg; it was compared to a control prepreg, which featured continuous resin film (Fig. 6, p. 24). Schechter dewetted the resin films used to produce the USCpreg with a handheld spike roller at three temperatures (89°C, 104°C and 119°C) over several time spans, ranging from 15 seconds to 8 minutes. The distance between the spikes on the roller was 3.2 mm. Laminates consisted of 16 plies of unidirectional carbon fiber tape, with each tape prepregged on both sides; laminates were cured under vacuum bag on metal tooling, or on a glass window in an oven, analogous to USC's glass-walled autoclave. Materials were tested with and without edge-breathing dams. Schechter eventually settled on three prepreg types for her assessment: the control prepreg, with continuous film resin; a USCpreg dewetted at 104°C for 30 seconds (104-30); and a USCpreg dewetted at 104°C for 2 minutes (104-120).

Schechter's hypothesis was simple: Dewetting leads to a discontinuous resin pattern, which creates additional pathways in the through-thickness direction for gases to evacuate, resulting in a finished part with superior properties. She tested and evaluated pre-cure resin distribution, pre-cure microstructure, resin flow during cure using in-situ visualization, surface defects, bulk porosity and laminate structure. She evaluated the prepregs in optimal and sub-optimal molding conditions.

Details of test results Schechter generated can be found in her paper, "Polymer Film Dewetting for Fabrication of Out-of-Autoclave Prepreg With High Through-Thickness Permeability," published by Elsevier in the journal *Composites: Part A*. In summary, however, what became clear is that the overall best-performing dewetted prepreg was 104-120. Consider, for instance, the bulk void content of laminates cured with sealed edges. The control prepreg had a bulk void content of 3.2%. The 104-30 dewetted prepreg had a bulk void content of 0.2-0.3%. The 104-120 dewetted prepreg had a bulk void content of 0.1% (Fig. 7). Schechter notes in her paper, "The insensitivity of dewetted prepregs to restricted in-plane air evacuation demonstrates that air evacuation occurred almost exclusively by breathe-out in the z-direction." Further, Schechter notes, dewetted prepregs were more forgiving in sub-optimal molding conditions.

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Collectively, these findings confirm that discontinuous prepregs can address two long-standing limitations of vacuum bag-only prepreg cure — namely, scaling challenges associated with reliance on edge breathing, and high-defect levels caused by non-ideal manufacturing conditions.

Schechter and others at USC are evaluating processes to more quickly and consistently fabricate discontinuous prepreg in an effort to identify potential commercialization options. Nutt says he has been reaching out to prepreggers and prepreg machinery manufacturers to evaluate dewetting options provided by them as well.

Looking back, Nutt credits M.C. Gill, a pioneer in the composites field, for recognizing the importance of manufacturing technology to American industry. "M.C. foresaw the need to train future generations of engineers in composites processing, and he wanted USC to become a leader in the effort to address that need," Nutt says. "We see abundant opportunities for innovation and problem-solving in composites manufacturing, and we are gratified to be training some of the engineers who will solve these problems." CW

**ABOUT THE AUTHOR**

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# Autocomposites from waste: Garbage in, valuable, functional parts out

## Automakers explore use of waste materials to make commercial car parts.

**By Peggy Malnati** / Contributing Writer

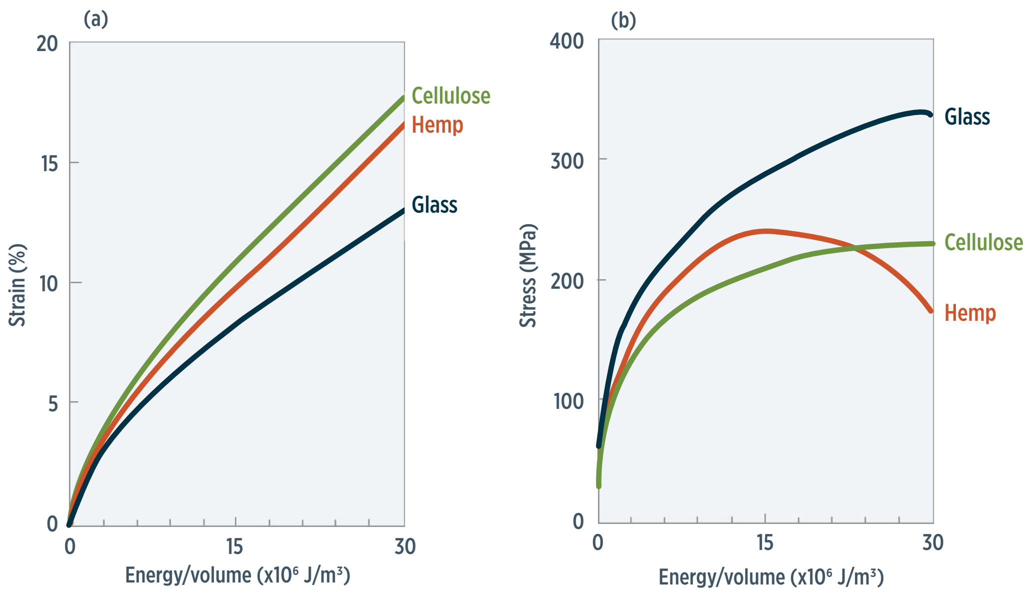
» In a lot of industries, the aphorism "garbage in, garbage out" is a reliable maxim. If your inputs are of poor quality or little value, your final products will probably be as well. However, the automotive industry is turning that adage on its head by repurposing *waste* materials normally considered to have no use into functional, beautiful and valuable automotive parts for vehicles already on the road. In doing so, automotive companies are keeping materials out of landfills and waterways, providing jobs in distressed communities and giving farmers another income stream, all while reducing part weight and cost, stabilizing long-term material prices and *greening* their vehicles. This is a good example of another saying: "One man's trash is another man's treasure."

### Key members of the team

From left to right, Alper Kiziltas, Ph.D., lead research scientist, holds a fan molded from glass fiber-reinforced PCR PP/PA6/6; Dan Frantz, research engineer, holds a soy-based polyurethane foam block used for seat cushioning; Debbie Mielewski, Ph.D., senior technical leader, holds coffee chaff and a headlamp housing molded with carbonized coffee-chaff-filled PP; Cindy Barrera-Martinez, Ph.D., research engineer, holds a bamboo stalk and a bio-based polyurethane engine cover incorporating recycled tire rubber; Sandeep Tamrakar, Ph.D., post-doctoral researcher, holds a cellulose/LFT hybrid composite sill shield; and Md. Golam Rasul, doctoral intern, holds a kenaf-reinforced PP door bolster. Source | Ford Motor Co.

### Ag waste

A lot of these repurposed waste materials are the agricultural by-products of food production. They're generally the outer wrappings of crop plants, such as tomato skins from




**Comparing strain and stress for glass, hemp and cellulose**

A comparison of % strain (a) and stress (b) vs. energy dissipation/unit volume for fiberglass, hemp fiber and cellulose fiber for a vinyl ester matrix shows that natural fibers dissipate energy at lower stress states and higher strains than glass, which, in turn, demonstrates that natural fibers offer improved energy absorption at higher strain rates.

Source | Ford Motor Co.

ketchup production or agave fiber from tequila production. These inedible wrappings (often from seeds) are the parts of plants that either will not compost or will not compost easily, and that have little or no utility as animal bedding. Their lack of utility causes these wrappings to accumulate in waste piles where they can prove a nuisance or, if ignored long enough, become a health and safety challenge. However, these fibrous outer wrappings are proving to be useful as natural fiber reinforcements for a variety of composites.

"People don't understand that natural fibers *are* lightweight alternatives," explains Debbie Mielewski, Ph.D., senior technical leader for sustainable materials research at Ford Motor Co. (Dearborn, MI, US). "They think that natural fibers are just for *greening* products and they look to far more costly materials like carbon fiber to cut pounds out of vehicles. At Ford, we believe we can remove tens of pounds [from a vehicle] using natural fibers. Not only are they an abundant local resource nearly everywhere, but our studies suggest they're very good at absorbing impact energy, far outperforming glass [fiber]. Furthermore, natural fibers are far more recyclable than glass in that they tend to bend rather than break during processing like glass, so you don't have to downcycle performance expectations for recycled materials. They're also more flexible and bendable, and much more isotropic to design with than glass."

It is no surprise that Ford has taken up the mantle that former DaimlerChrysler (DCX, now FCA US LLC, Auburn Hills, MI, US) carried in the early 2000s by using many natural fiber products in vehicle components. However, unlike DCX, which primarily worked with conventional bast-type fibers from inner bark/phloem from plants like kenaf, flax, sisal and jute, Ford has a knack for finding previously unused fibers that are equally effective. In fact, Mielewski says Ford's vision is to use whatever natural resources are locally available near its production plants to reduce the costs and carbon footprint of shipping natural fibers around the world. For example, Ford might use agave fiber from tequila production in its Mexico facilities, bamboo fiber for Asian part production and tomato skins from ketchup production in North America. The automaker is even reportedly studying uses for dandelions, algae and the durable linen/cotton blend from retired currency.

> Ford's vision is to use whatever natural resources are locally available near its production plants.

## Going nuts

Coconuts might seem an odd choice to reinforce automotive parts, but it turns out they're plentiful between the Tropics of Cancer and Capricorn, and their properties are consistent from season to season, species to species and soil to soil across that geographic region. Once coconut meat and milk are extracted at processing plants, the shell and its outer (coir-fiber) husk tend to accumulate in refuse mountains because villagers often lack the ability to dispose of them. Unfortunately, neither shell nor husk are edible, they have no animal or human bedding use, they don't burn easily and they compost very slowly. On the positive side, at 250 microns, coir fiber's diameter is significantly larger than that of most other natural and synthetic fibers, which contributes bending stiffness, strength and ductility to composites. Owing to the fiber's high lignin content, it's also inherently flame retardant, indigestible to insects and microbes (reducing odor) and is less prone to swelling under humid conditions. »

### Rice hull-reinforced cowl bracket

In its 2014 MY *F-150* pickups, Ford Motor Co. used an electrical cowl bracket injection molded from rice hull-reinforced PP. The automaker says rice hulls were a drop-in replacement for talc, reducing development costs and time and eliminating the need for tooling changes. The material is both renewable and recyclable.

Sources | SPE Automotive Division (below) and Ford Motor Co. (right)

In addition, coconut shells can be ground into a fine powder and used as a lighter, less abrasive replacement for mineral fillers like talc in plastics and composites. Ford, working with suppliers like Essentium Materials LLC (College Station, TX, US), has developed a number of applications for coir fiber and coconut shell powder starting with 2012 model year (MY) Ford *Focus* battery-electric vehicles (BEVs). In that case, coir was commingled with polypropylene (PP) fiber, then carded, needled and converted to a nonwoven felt. The felt was then die-cut, bonded to pressboard (itself containing recycled fibers) and sandwiched between recycled carpet on the A (face) side and polyester scrim on the B (reverse) side to produce a load floor/package shelf to cover (yet allow access to) onboard battery packs — all while providing a stable surface for consumer packages in the rear trunk. The porous felt core was light, stiff and absorbed sound on the vehicle interior.

The automaker next turned to ground coconut shells combined with rubber from shredded tires to produce a thermoplastic elastomer (TPE) that was injection molded into structural guards for 2013 MY Ford *F-250 Super Duty* pickups. The parts were lighter, less costly, and less abrasive on tooling than mineral-reinforced predecessors. In 2015, coconut powder was used for injection molded thermoplastic polyolefin (TPO) decklid appliqué brackets and side-door cladding on Ford *Mustang* sports cars in combination with shredded battery cases and magnesium-silica fibers from Milliken & Co. (Spartanburg, SC, US). This interesting combination reduced density, wall thickness, cycle time and cost.

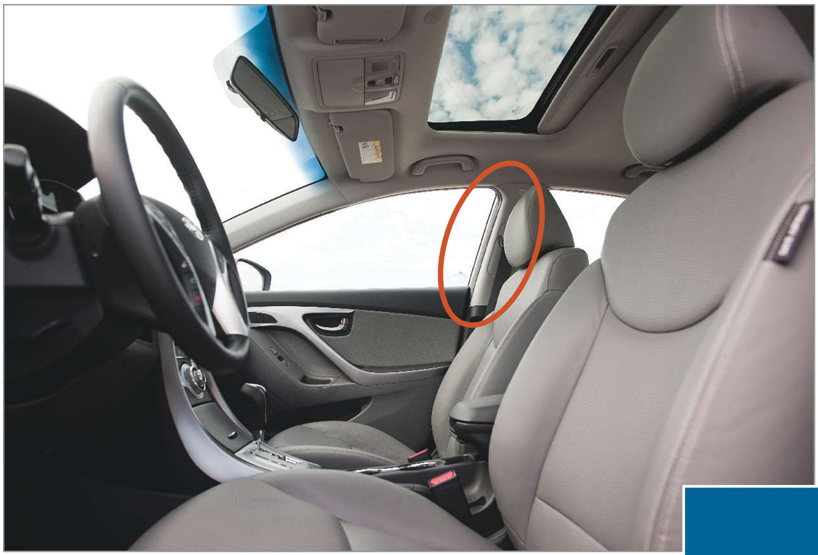
### Cereal part production

Cereal grain leavings are another group of agricultural waste that Ford has explored in reinforced plastics and composites. First used in 2010 on Ford *Flex* cross-over utility vehicles (CUVs), wheat straw replaced talc in injection molded PP quarter-trim bins. More wheat straw is produced in Ford's home state of Michigan and in the Western Canadian provinces than can realistically be sold as animal bedding or composted in the region's cold, wet soils. By using wheat straw to reinforce car parts, farmers gained additional income and avoided sending plant material to landfills, while the automaker improved dimensional stability of parts vs. unfilled versions and reduced part mass with a greener alternative than talc.

Rice hulls from the US Gulf Coast were another reinforcement Ford experimented with on high-volume 2014 MY *F-Series* pickups. Normally landfilled after extracting from fast-growing rice crops, the hulls were combined with PP — itself containing 25% post-consumer recyclate (PCR) — to form injection molded electrical cowl brackets that are renewable and recyclable. Although this first application was cost and weight neutral, the novel reinforcement was environmentally beneficial and brought additional revenue to farmers.

### Wood you believe trees?

Ironically, one successful environmental effort — to reduce US paper usage — has led to economic challenges for pulp and paper companies that now are searching for new markets for cellulose



## Volcanic rock composite pillar trim

Hyundai Motor Group developed a composite from the volcanic rock scoria, PET fabric pile, glass microspheres and PP resin to injection mold pillar trim panels for its 2011 MY Kia *Pride* subcompacts and *Optima* midsize sedans, plus Hyundai *Elantra* midsize sedans. The textured parts feature tiny flecks of color and have a fabric-like feel that enabled the automaker to eliminate the cost of fabric-wrapping the parts and the cost and environmental burden of painting them.

Sources | SPE Automotive Division (below) and Hyundai Motor Group (left)

fiber, a by-product of lumber operations in sustainably harvested forests. In turn, that's led to another non-traditional natural fiber reinforcement that Ford is exploring — at both the macro and the nano level — to replace glass fibers. The first automotive application of cellulose fiber was console armrests on 2013 MY Lincoln *MKX* luxury CUVs that were injection molded with 20% cellulose-reinforced PP. The parts were cost neutral, 6% lighter, less abrasive on tooling and reduced injection molding energy requirements by 10% thanks to faster molding cycles and lower molding temperatures. Ford also estimated that, vs. glass fiber/PP, the greener parts reduced $CO_2$ emissions by more than 11% and would save 9,464 liters of fuel over the life of each vehicle.

Another tree product that has found its way into vehicle interiors is cork — the inner bark of cork oaks that is harvested once a decade and is most commonly found stoppering bottles of wine. In this case, Hyundai Motor Group (Seoul, South Korea) is using cork-wood films to replace multilayer hardwood veneers (which are costly, labor-intensive to produce and non-renewable) on door-trim panels for 2017 MY Hyundai *Azera* (called *Grandeur* in Asia) midsize hybrid-electric sedans. By eliminating the 20-step process normally required to produce hardwood veneers, the simplified insert-molded cork films plus acrylonitrile butadiene styrene (ABS) produces parts that are 24% lighter and 65% less costly. Furthermore, cork's honeycomb structure provides elasticity, thermal insulation and sound damping, in addition to good looks. The automaker indicates that its researchers are also considering cork's use as a possible material to reduce noise/vibration/harshness (NVH).

And in the 2018 SPE Automotive Innovation Awards Competition, Ford nominated what it described as the industry's first use of a hybrid composite combining long-fiber (glass) thermoplastic (LFT) polypropylene with cellulose (in post-industrial recyclate resin). The center console components were produced via injection molding.

### Rockin' fillers

Another interesting Hyundai application involved the use of the mineral scoria — a low-density volcanic rock similar to pumice, but higher in density — that tends to form tall cones around volcanic sites. Its porous structure (created as gas escapes cooling lava) provides high surface area and strength vs. weight, plus it is available in a range of colors — from dark brown to red, purple and black. Scoria is typically used as a landscaping stone, in drainage works, in gas barbeque grills, as a high-temperature insulation, to improve traction on icy roads and around oil wells to keep heavy-trucks from sinking into mud.

Perhaps its most famous use was on Easter Island, where the Rapanui people used it to form the topknots and some bodies of their renowned moai statues. Hyundai extended scoria's use to automotive parts on the 2011 MY Kia *Pride* subcompacts and *Optima* midsize sedans, plus Hyundai *Elantra* midsize sedans. In this case, crushed scoria was combined with polyethylene terephthalate (PET) fiber pile and glass microspheres in a PP compound that was injection molded to produce textured pillar trim panels for vehicle interiors. The unusual filler combination creates a surface with tiny flecks of color and eliminated the need to paint or fabric-wrap the molded trim panels, reducing mass 10% (vs. talc) and direct costs 50%, while eliminating the cost of fabric »

### Turning spilled oil into air baffles

A closed-loop recycling program produced air baffles for 2011 MY Chevrolet *Volt* hybrid-electric vehicles from General Motors. The parts were injection molded from equal parts styrene butadiene rubber (SBR), PP and polyethylene (PE). The material was obtained from shredded automotive tires, plastic packaging aids from GM's production facilities, post-consumer bottles and oil-containment booms that had helped clean up the Gulf of Mexico after the DeepWater Horizon oil spill in 2010.

Sources | SPE Automotive Division (below) and General Motor Co. (right)

wrapping and the cost and environmental burden of paint.

"We developed (these) novel materials to make an imitation cloth-feeling composite," notes Daesik Kim, Ph.D., Hyundai part leader of the plastic materials development team. "The combination of volcanic rock and PET pile was the most efficient approach. PET pile alone was too costly. The volcanic rock was low in price and had good processability and durability. When we applied common minerals like talc and mica, it didn't work at all."

### Waste not, want not

Automakers are turning to other non-traditional waste products to make car parts, too. An intriguing closed-loop recycling application that General Motors Co. (GM, Detroit, MI, US) used on 2011 MY Chevrolet *Volt* extended-range hybrid-electric vehicles (HEVs) helped with clean-up efforts in the Gulf of Mexico after the 2010 DeepWater Horizon oil spill. First, companies collected post-industrial recyclate (PIR) automotive packaging waste made up of PP and polyethylene (PE). That material got another life when it was used to produce absorbent materials for oil-containment booms, which help prevent oil spills from spreading and allow the mess to be mopped up from bodies of water. After cleaning up the oil spill, petroleum products were removed from the absorbent materials, which were then given yet another life when they were combined with equal parts styrene butadiene rubber (SBR) from shredded tires, more packaging aids from GM facilities and post-consumer recyclate (PCR) PE bottles. The resulting compound was injection molded into air-baffle components for *Volt* HEVs. The automaker described the application as a way for automotive engineers to help improve the response to Gulf cleanup efforts, conserve materials and support local communities.

GM also spearheaded another closed-loop recycling program that turned the problem of lead-contaminated drinking water in Flint, MI, US, into an opportunity that brought jobs to disadvantaged communities while repurposing valuable waste consumer packaging back into car parts, assembly-plant goods and clothing for the homeless. To date, very few of the lead-contaminated water pipes have been replaced in Flint, so residents still rely primarily on bottled water, which has created a waste problem with empty PET bottles. Led by John Bradburn, now retired project leader and global manager of waste reduction at GM, a multi-stakeholder supply chain was assembled to collect water bottles from Flint's municipal recycling program as well as from GM's assembly plants, engineering centers and administrative facilities throughout Michigan. These bottles were recycled into PET fiber, which, in turn, was converted into nonwoven fleece. The fleece was then used to produce insulation for the B-side of 15% glass fiber-reinforced polyamide 6/6 (PA6/6) engine manifold covers on 2017 MY Chevrolet *Equinox* sport-utility vehicles (SUVs). The fleece also was used by at-risk individuals in a Flint-based jobs training program called St. Luke's N.E.W. Life Center to produce large air filters for 10 GM manufacturing plants. Still another use for the fleece was as insulation for coats sewn by formerly homeless women employed by the Detroit-based Empowerment Plan.

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Read more online | short.compositesworld.com/autowaste

There is a water bottle recycling program under way at Ford as well. Although not as ambitious as GM's, PET water bottles from Ford's Research & Engineering Center, local community materials-recovery facilities (MRFs) and Ford's own post-industrial scrap are recycled and spun into PET fiber, which in turn is used to weave durable REPREVE seat fabrics. The 100% PCR/PIR fabric debuted on 2012 MY Ford *Focus* BEVs and expanded in 2015 into Ford *F-150* pickups and 2016 MY Ford *Explorer* SUVs, supporting the automaker's goal of translating the fabric across all its vehicles. With just the *F-150* platform, use of the 100% recycled fabric diverts 5 million water bottles/year from landfills. Further, what fiber and fabric Ford doesn't use is converted for use in clothing, tote bags and socks.

Where do automakers think this waste-repurposing work could ultimately go? Mielewski says there are more ideas out there than there are hours in a day and staff to investigate. Corporations and trade associations are starting to see the opportunities that partnering with the automotive industry can bring and are reaching out to OEMs with ideas of their own. For example, a project at Ford, where researchers are trying to sequester the greenhouse gas $CO_2$ to produce automotive parts happened because of involvement by and funding from the Canadian Carbonization Research Assn. (CCRA, Hamilton, ON, Canada). Ford also has been approached by other organizations, including the California Almond Board (Modesto, CA, US) to explore the use of ground almond shells. "The sheer number of materials that *could* be used to make more sustainable car parts far exceeds our ability to research them," Mielewski muses. "And that doesn't even consider what we could do with blends that might combine several different kinds of material, like hybrids of natural fibers or natural resins with fibers," she adds. "However, what we're trying to do [at Ford] right now is to remove every reason not to make the move to more sustainable materials. If you're serious about lightweighting, for example, we've got materials ready to go that have already been tested and proven out." CW

**ABOUT THE AUTHOR**

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# Mastering the art (and science) of large composite assemblies

## Vabo Composites designs, builds and assembles 10m-tall composite radar masts, improving weight, stability and performance for modern megayachts.

**By Ginger Gardiner** / Senior Editor

» Vabo Composites (Emmeloord, The Netherlands) designs and builds a diverse array of composite structures. The company began in 2001 with several small marine projects, as well as antennas for mobile television broadcast systems, carbon fiber-reinforced valves and manipulator doors for fast-moving palletizing machines and a glass fiber-reinforced front-loader bucket, for which it won a 2015 JEC Innovation Award. The company has also become adept at architectural and building projects and continues to advance its industrial production of ACCEDOO composite ship doors (see Learn More) which won a 2017 JEC Innovation Award.

Vabo Composites has also become well known for its expertise as a fabricator of large radar masts for yachts, which house navigation electronics and circuitry as well as exhaust systems from the engines. It has recently completed a 10-by-10-by-10m glass fiber/vinyl ester mast for a 156m-long

**Large composites, creative transport**

This 10-by-14m carbon fiber composite canopy requires a creative solution for transport to an assembly site where it will be joined with a 10m-tall radar mast and installed on the 90m-long yacht for which it has been designed.

Source for all images | Vabo Composites.

**FIG. 1** The 10-by-10-by-10m glass fiber/vinyl ester mast for a 156m-long yacht (*left*) features two legs joined to form a "T" from which four platforms extend, three forward and one rearward.

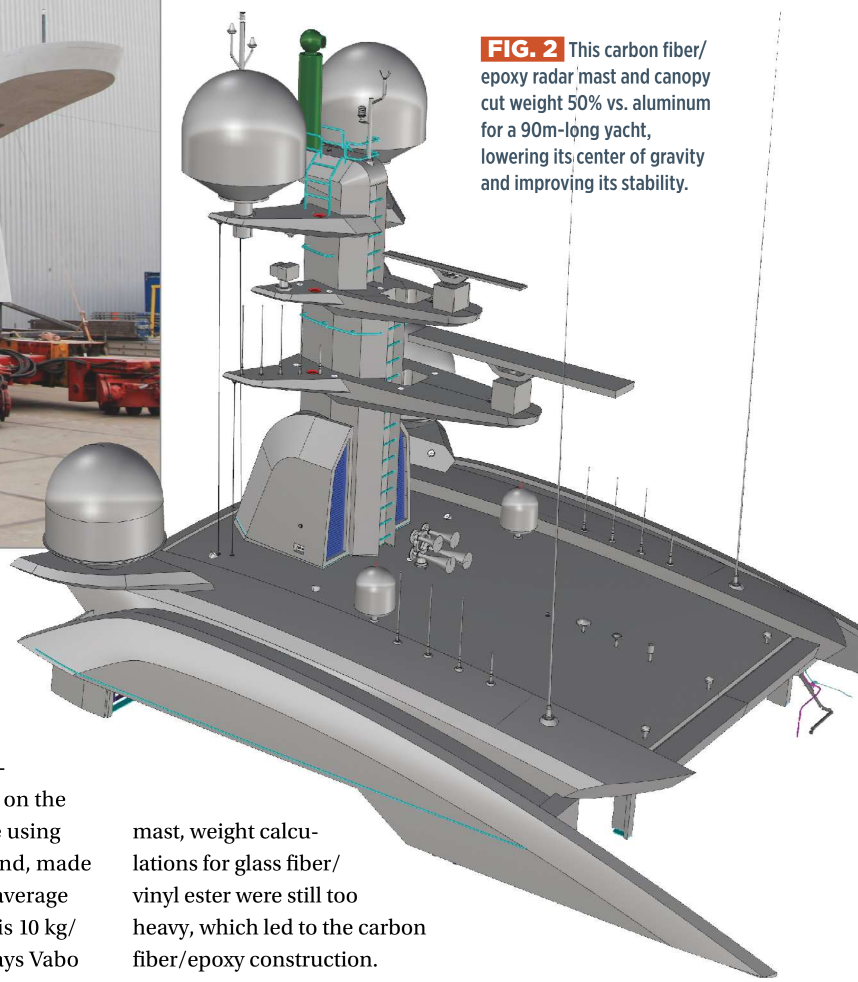

**FIG. 2** This carbon fiber/epoxy radar mast and canopy cut weight 50% vs. aluminum for a 90m-long yacht, lowering its center of gravity and improving its stability.

megayacht, as well as a 10m-tall mast with a 10-by-14m canopy beneath, both made from carbon fiber/epoxy, for a 90m yacht. Normally built from aluminum, these composite masts provide unparalleled structural performance, resist corrosion, help lower the center of gravity on the yacht and, of course, save weight — the first mast, made using glass fiber, achieved a 30% mass reduction and the second, made with carbon fiber, increased mass savings to 50%. "The average weight for this lighter carbon fiber composite structure is 10 kg/m$^2$ while the canopy is supported at only four points," says Vabo Composites director Arnold Vaandrager. "Aluminum was not an option because of the lightweight and structural performance required."

### Designing to class

"For this type of project, we start by collecting all of the requirements for the structure," says Vaandrager, "including the operational and environmental requirements, as well as what will surround it and attach to it. We then begin the design process, looking at different materials and calculating the weight and frequency." Frequency? "Yes, because we are replacing aluminum with much stiffer composites, the structure responds differently to engine and propeller vibrations," he explains. "So we put the laminate properties into a vibrational analysis." For the second mast, weight calculations for glass fiber/vinyl ester were still too heavy, which led to the carbon fiber/epoxy construction.

In addition, says Vaandrager, large yachts are typically built "to class," meaning their design and construction is overseen by a classification society and must meet those regulations. The yachts for both masts discussed here were classed to Lloyd's Register (London, UK). "Lloyd's must approve our drawings, construction process and materials," says Vaandrager. To achieve this approval, Vabo Composites built laminate samples reflecting the proposed materials and process, and then tested these to prove the design properties to Lloyd's. Vaandrager explains: "They can look up aluminum and steel properties, but with composites, we are making the material as we make the structure, so we have to show what the properties will be." Then, throughout the fabrication of the masts, Lloyd's performs checks to prove that Vabo Composites has followed the laminate cure »

1 Vabo Composites CNC-machined 10 molds for the glass fiber/vinyl ester mast project (shown here) and seven molds for the carbon fiber/epoxy project comprising mast and canopy.

2 Parts fabrication began with laying glass reinforcements onto molds, along with perforated foam core, to create a dry laminate stack.

3 Dry stacks were vacuum bagged and Vabo Composites' one-shot resin infusion method was employed for the glass fiber/vinyl ester mast, with legs and platforms completed in 2-3 hours.


4 Infused glass fiber/vinyl ester parts were demolded.

5 Reinforcing ribs were CNC machined — including holes for cables and exhaust pipes — from resin-infused, foam-cored glass fiber/vinyl ester flat panels (left image). Ribs were then bonded to the mast legs at roughly 1m intervals (right image).


6 The two large legs, four platforms and all other parts were trucked to a covered shed adjacent to the yacht construction yard for assembly and installation.

7 The composite legs were prepared for final assembly, inserting exhaust pipes and cable chases.

8 Each leg was lifted by crane onto a rail-mounted fixture and slid into scaffolding that located and supported legs and platforms during assembly.

9 A single-piece mast is crane-lifted and prefit to the yacht, followed by final systems installation, exterior painting and, at last, final installation onto the yacht.

cycles and other process steps as specified. "We also have workshop approval to Lloyd's," Vaandrager adds. This certifies that quality assurance processes are in place and followed.

With materials, design and processes approved, Vabo Composites began engineering the necessary molds and buying materials. "After engineering is finished, these masts typically take six to seven months to complete," says Vaandrager.

## Multiple molds and parts

The first step was to make the molds (Step 1). The design for the glass fiber/vinyl ester mast comprised two "L"-shaped legs, attached to form a "T," from which four platforms extend perpendicularly — three forward and one rearward (see Fig. 1, p. 33, and Step 9). The carbon fiber/epoxy mast design combined two semicircular uprights with three shelves attached for supporting radar domes, open-array radar scanners (the long bars that spin on a central support), antennas and other electronics (Fig. 2, p. 33).

Ten molds were used for the glass fiber/vinyl ester mast, while the carbon fiber/epoxy mast required six molds; the canopy was made in a single 10-by-14m tool. Vabo Composites machined these molds from tooling foam and paste, attaching support structure as required by the weight and size of each part.

Fabrication of the composite parts then began (Step 2), using four plies of biaxial stitched glass fiber fabrics and VE100T vinyl ester resin, both supplied by MC Technics (Visé, Belgium). "We cut and laid in the fabrics," says Vaandrager, "using spray adhesive where needed to hold the dry laminate stack onto vertical sides and into corners." Both masts used CORECELL M structural foam core from Gurit (Newport, Isle of Wight, UK), which was perforated to help with resin flow during infusion. "For the glass fiber/vinyl ester mast, we used our typical one-shot infusion method on the skin-core-skin dry stacks." He notes that infusion took just 2-3 hours for each leg and platform (Step 3).

"For the carbon fiber mast, we used a different technique because of the difficulty in getting good resin flow in the much thinner, tightly packed layers," Vaandrager explains. Laminates comprised two plies of woven and stitched biaxial carbon fiber fabric and Sika Axson Bi-resin CR83 infusion epoxy supplied by Fatol-Kunststoffen BV (Hengelo, The Netherlands). "We first laid the outer skin and infused it. We then bonded in the core with epoxy adhesive and vacuum bagged it to the outer skin. We then laid the inner skin and infused that final layer. So this technique was much more labor-intensive, requiring at least twice the time of the glass fiber mast." He notes the canopy was produced using the same three-step process and infused in 4-6 hours.

All of the parts for the carbon fiber mast had to be post-cured to attain full epoxy structural properties; also, some parts would be painted a dark color and thus needed the »


**FIG. 3** Vabo Composites' second mast project will install this carbon fiber/epoxy radar mast on top of the canopy shown on p. 33 to form a single-piece, installation-ready assembly for a 90m-long yacht.

higher heat deflection temperature that a post-cure provides. The carbon fiber/epoxy laminates were cured in 6 hours at 70°C and post-cured in 2-3 hours at 90-100°C. This was achieved in Vabo Composites' 8-by-5m oven for smaller parts, but for the large legs a 10-by-20-by-5m tent was used as a temporary oven with a large diesel heater. "We thermocoupled the parts and used a digital controller to ensure that we achieved the correct cure cycle, which also provided a record for Lloyd's," says Vaandrager.

Infused parts were demolded (Step 4) and stiffening ribs were fabricated for the uprights/legs of both masts and for the carbon fiber mast's canopy. Made from the same basic glass fiber and carbon fiber foam-cored laminates as the parts they would reinforce, the ribs were cut from large, flat infused panels (Step 5). Holes for the exhaust pipes and cable chases that would be encased within each mast were also CNC-machined from each rib. "We hand sand the composite laminate to prepare the bonding surfaces for the ribs and also when we bond mounting plates for equipment and small inserts for hardware," says Vaandrager. The stiffening ribs were then bonded roughly 1m apart in the mast legs and carbon fiber canopy (Step 5).

**LEARN MORE**

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

Read more about Vabo Composites in the online blog | short.compositesworld.com/Vabo

Read about Airborne's development of affordable thermoplastic composites | short.compositesworld.com/MassTPCs

## Assembly and installation

With all parts fabricated, each mast project could move forward to the next stage — assembly. "For the glass fiber mast, we transported the two large legs, four platforms and all other parts to a covered shed next to where that yacht was being constructed," Vaandrager relates (Step 6). "We built scaffolding to support and locate the platforms for attaching to the legs. Meanwhile, we prepared the legs, inserting the exhaust pipes and cable chases." (Step 7)

Vabo Composites used a crane to lift each completed leg onto a fixture mounted on steel rails in the floor (Step 8). "We then slid each leg on its fixture into the scaffolding to mate with the platforms," Vaandrager recalls. Note that each leg had been built with small cutouts to receive the platforms. "So there was only one way the legs and platforms could fit together," he adds.

"This mast was designed to adhesively bond together, but we were not sure if assembly would occur in the summer or winter, and the shed was covered but not temperature controlled," says Vaandrager. "So we chose to adhesively bond *and* bolt the legs and platforms together. However, we could have used adhesive only. The mechanical fastening just helped to alleviate any temperature-induced tolerance issues." The bolts also held the parts together while the Gurit Spabond adhesive cured at ambient temperature.

The same adhesive was used to bond the carbon fiber/epoxy mast, but parts were clamped together, not mechanically fastened. "Also for this mast, every bondline was taped [with epoxy-impregnated woven carbon fabric] because we were pushing the structure so far to the edge [for lightweight], we needed every layer," Vaandrager explains. For the glass fiber/vinyl ester mast, some of the ribs were taped, and all of the major structure joins were taped after the legs and platforms were bonded and bolted. He notes a workmanship detail during this process: Where the outer join lines are taped, there are recesses designed into the parts so that once taped, the whole surface is flush and smooth for a high-quality cosmetic finish after painting.

The reduction of weight high up on the yacht lowers the vessel's center of gravity, improving stability.

At this point, each mast is ready for installation on its yacht. "One single part is lifted and placed onto the yacht," says Vaandrager, "complete with pipe chases inside and everything prepared for installation of the cables and electronics equipment, exhaust system, etc. This is what we promise and sell." The yachtbuilder/refitter — Vabo Composites works with some of the most renowned companies in the industry — actually secures and installs the mast onto the yacht (Step 9). "They use a crane and first prefit it to the vessel," he explains. "They will then move the mast back off the yacht and prepare the mast for paint and systems installation. They install the cables, exhaust, etc., and then apply final paint, after which they place the mast once with the crane and complete the final installation onto the yacht. We support them throughout this process as needed."

## Future growth, need for change

What is the largest challenge in these projects? "Managing the complete process and myriad details," says Vaandrager. There are so many simultaneous processes occurring during yacht construction — exterior design, interiors, electronics, propulsion and steering — sometimes changes are made to solve emerging problems without understanding the huge impact they could have on the fit and installation of the composite mast.

Composites, however, offer a multitude of benefits in this application. "We do see that these large structures will continue for us," Vaandrager asserts. "The yachtbuilders try to solve weight and performance issues with aluminum for as long as they can, but in the end, they see they must go to composites. Vessels continue to be larger and taller, which causes weight and center of gravity issues." The reduction of weight high up on the yacht lowers the vessel's center of gravity, improving its stability in the water. The composite structure also saves on maintenance costs, eliminating the need for repainting due to its excellent corrosion resistance in saltwater. "We have more requests now than in the past," notes Vaandrager. "And I think that builders will increasingly start the vessel designs with these types of structures in composites from the project beginning, instead of switching from aluminum later on, to save time and cost."

What materials and process needs does he see for future marine composites construction? "If you could make your own molds using robots and then they could also cut pieces like ribs, then the price of construction will go down 20-30%," Vaandrager replies. "If you could do more in an automated way to drop labor hours. We began working with a robot this year for our ACEDOO composite doors for ships. Here, we have a simple goal: build a door without man-hours. The only problem we had was with interfaces in the software between programs. But these robots are cheaper and much more flexible than large CNC systems."

He also points out what is possible now in composites with thermoplastics. "Airborne is a Dutch company and we see what they are doing," Vaandrager explains (see Learn More). "In automotive, they are building composite parts in 3 minutes in order to make them affordable. So we see this is possible. It is just a matter of adapting the technology in a way that makes sense for boatbuilding budgets and structures."

Another issue with these large structures is molds. "We have more kg in molds than we do in our products for projects like the masts," he observes. "This construction method is not sustainable. We invest hundreds of thousands of euros for the molds and then must pay to scrap them. We need a new solution. If we could build molds out of recyclable thermoplastic or sheet foam, then that would be better for the environment and cheaper." He notes the development of 3D printing for boat and yacht molds, and believes this also may be promising. "But if we started, not with a mold, but with beams and then cover the beams with a skin, this is another way of thinking," says Vaandrager. "Now, with digital technologies, it may be possible to use this method and still achieve accurately shaped and dimensioned structures, but there are still many solutions needed for such an approach." CW

**ABOUT THE AUTHOR**

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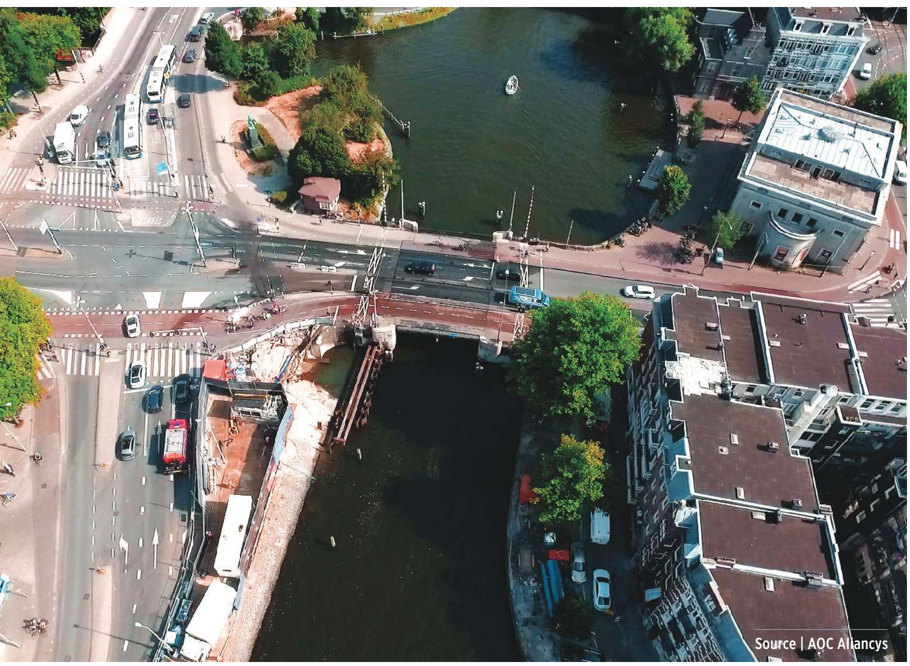
# COMPOSITES RESTORE DRINKING WATER IN HISTORIC AMSTERDAM

## A fiberglass-reinforced liner helped resurrect a corroded waterline pipe.

› In March 2018, a drinking water supply pipeline in the Nassaukade quarter in central Amsterdam unexpectedly collapsed, along with part of a canal wall. The 50m-long, 600-mm-diameter pipe was a vital part of the city's infrastructure, delivering potable water to many households in the historic city center.

"The customer initially thought that a new pipe would need to be installed," says Ton van Geest, research and development manager of pipe relining specialist Insituform Europe (Zoetermeer, The Netherlands) at the time of the project (Insituform is now owned by Aegion, St. Louis, MO, US). "However, they realized this involved major, lengthy construction in a very busy and congested part of the town." Also, the soil underneath the historic quarter of Amsterdam is relatively soft, and construction projects can be complex to avoid damage to the surrounding historical buildings.

Fortunately, workers discovered a 100-year-old, unused cast-iron pipe beneath the canal waters. They believed the pipe could be converted into a new drinking water pipeline, if it could be made waterproof, pressure-proof and able to carry potable water. Insituform was brought into the project thanks to its InsituMain pipe relining technology. InsituMain, like Insituform's other products, consists of a composite sleeve, usually glass or polyester fiber and impregnated with uncured resin. After transport to the job site in a temperature-controlled truck, the sleeve is inserted into the pipeline using injected water or air, so that the as-yet uncured resin is forced against the pipe wall. When in place, the sleeve is filled with hot water or steam, which cures the resin to form a strong, leak-free liner within the host pipe.



Source | AOC Aliancys

In this case, because the pipeline would be carrying pressurized drinking water, InsituMain was chosen because the fiberglass-reinforced sleeve is formulated with new, styrene-free, trademarked Beyone 700-T-01 FC vinyl ester resin, safe for food and water contact and supplied by AOC Aliancys Europe (Schaffhausen, Switzerland). "Insituform and AOC Aliancys have been working together for the past five years to develop this robust relining technology," says Rob van de Laarschot, head of technical service at AOC Aliancys Europe. He adds that the InsituMain liner technology with Beyone resin and fiberglass has been approved by KIWA-ATA (a testing, inspection and certification group that certifies Dutch drinking water).


Source | AOC Aliancys

Insituform relined the 50m-long pipe in only two days, and the renovated system was back in service within five working days. Says van Geest, "The composite pipe provides structural integrity, corrosion resistance and the ability to cope with water pressure fluctuations for many years to come." CW

# Composites Events

**Jan. 10-12, 2019 — Mumbai, India**
ICERP 2019
icerpshow.com

CW **Jan. 17, 2019 — Detroit, MI, US**
Compression Molding Workshop
cwworkshops.com

**Jan. 30-Feb. 1, 2019 — Tokyo, Japan**
TCT Japan 2019
tctjapan.jp/index_en.html

**Feb. 19-20, 2019 — Charleston, SC, US**
SPE 2019 Thermoset Topical Conference – TOPCON
spethermosets.org

**Feb. 26-28, 2019 — Raleigh, NC, US**
Techtextil North America 2019
techtextil-north-america.us.messefrankfurt.com

**March 4-5, 2019 — Detroit, MI, US**
Graphene Automotive 2019
usa.graphene-automotive-conference.com

**March 6-8, 2019 — Rome, Italy**
5th Annual World Congress of Smart Materials: 2019
bitcongress.com

**March 12-14, 2019 — Paris, France**
JEC World 2019
jeccomposites.com

**March 21, 2019 — Belfast, UK**
Joining of Composites Conference
ktn-uk.co.uk/events

**March 24-28, 2019 — Nashville, TN, US**
NACE Corrosion 2019
nacecorrosion.org

**April 7-10, 2019 — Charleston, SC, US**
TRFA Annual Meeting
trfa.org/meeting

**April 8-10, 2019 — Rosemont, IL, US**
North American Pultrusion Conference
s1.goeshow.com/acma/2017PultrusionConference/ereg419088.cfm

**April 8-11, 2019 — Colorado Springs, CO, US**
35th Space Symposium
spacesymposium.org

**April 9-11, 2019 — Detroit, MI, US**
SAE 2019 World Congress & Exhibition
10times.com/sae-world-congress

**April 10-11, 2019 — Amsterdam, The Netherlands**
CompIC 2019
compositesinconstruction.com

**April 23-25, 2019 — Moscow, Russia**
Composite-Expo-2019
composite-expo.com

**April 29-May 2, 2019 — Long Beach, CA, US**
AeroDef 2019
aerodefevent.com

**April 29-May 2, 2019 — Chicago, IL, US**
AUVSI XPONENTIAL 2019
xponential.org

**May 6-8, 2019 — Beijing, China**
SAMPE China 2019
sampechina.org

**May 20-23, 2019 — Houston, TX, US**
AWEA WINDPOWER Conference 2019
windpowerexpo.org

**May 20-23, 2019 — Charlotte, NC, US**
SAMPE 2019 Technical Conference and Exhibition
nasampe.org

**June 12-13, 2019 — Stade, Germany**
CFK-Valley Stade Convention 2019
CFK-Valley.com

**June 19-20, 2019 — Chicago, IL, US**
JEC Chicago 2019
jec-chicago.events

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# New Products

» THERMOSET RESINS & ADHESIVE SYSTEMS

## Anti-corrosion agent and flame retardant

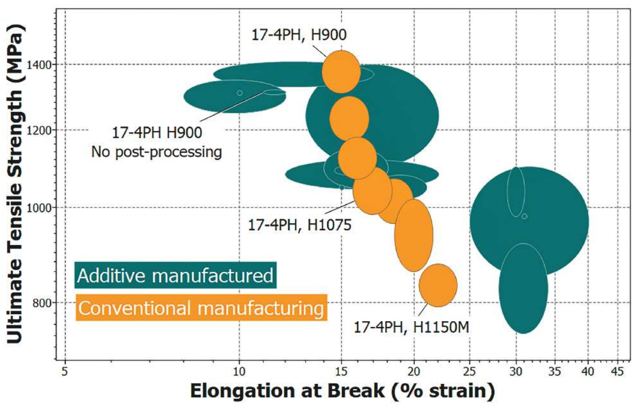
**Evonik** (Essen, Germany) has developed VISIOMER HEMA-P 70M, a 2-hydroxyethyl methacrylate phosphate that is an anti-corrosion agent and flame retardant. Typical product applications of this methacrylate monomer include adhesives and plastics, paints and coatings, fibers, composite resins and gel coats.

The monomer is typically used as an adhesion promoter, but according to Evonik, it has also been shown to be an effective halogen-free, reactive flame retardant or anti-corrosion agent. Since the substance serves as a reactive diluent or as a co-monomer bonded within the polymer backbone, it does not migrate like conventional flame retardants. It reportedly further improves flame retardancy in combination with non-polymerizable flame retardants. The monomer contains 30% methyl methacrylate and has a low viscosity, as well as a low color index for optical applications in acrylate and methacrylate systems, enabling its use in applications with high demands for transparency and surface quality. The monomer also is said to protect against static charging and to have an emulsion stabilizing effect. **corporate.evonik.com**

» THERMOSET RESINS & ADHESIVE SYSTEMS

## Wet laminating resin systems

Advanced composites specialist **Gurit** (Isle of Wight, UK) has announced the launch of Ampreg 31 and Ampreg 36 epoxy resins and ancillaries. The new products complement Gurit's Ampreg 30 epoxy, which was recognized with the 2018 Composites UK Innovation in Materials Award. Featuring what Gurit says is a robust resin matrix, the Ampreg line reportedly enables good mechanical and thermal properties of laminates for the manufacture of large composite structures in the marine, wind and construction industries. The new resins use the same Ampreg 30 hardeners, all applying the same simple mix ratio, and the ability to blend hardeners to achieve a range of intermediate working times. According to Gurit, the new Ampreg resins and ancillaries prioritize user health and safety. Ampreg 31 and Ampreg 36 feature light-reflective technology (LRT) for easy inspection of workwear, equipment and workspace for potential resin contamination by means of standard UV lamps. **gurit.com**


» PROCESS CONTROL SYSTEMS & SOFTWARE

## Materials selection software updated

**Granta Design** (Cambridge, UK) has announced the release of CES Selector 2019, the company's software tool for materials selection and graphical analysis of materials properties. The 2019 version offers improved support for additive manufacturing, vibration avoidance and simulation projects. The 2019 version also includes updates to the CES Selector library of specialist datasets.

New features of CES Selector 2019 include the ability to:

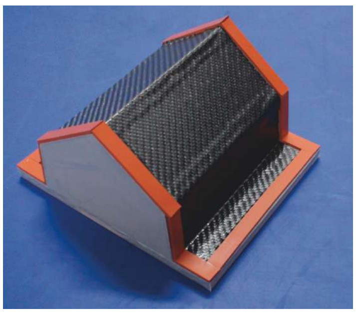
- Compare additive machines and materials against conventionally manufactured products and technologies, and gain a clear understanding of performance.
- Select materials early in a project and check load-bearing characteristics by using the new performance indices for longitudinal and flexural vibration.
- Access supporting resources and best practice information on Granta's eLearning site.
- Reference Granta's comprehensive MaterialUniverse dataset of engineering, economic and environmental property profiles designed for like-to-like comparisons across the whole spectrum of material and processing possibilities.

The CES Selector 2019 also features the latest updates of the following specialist datasets: Prospector Plastics; CAMPUS & M-Base Plastics; MMPDS-12 aerospace alloys; JAHM Curve Data for simulation; Senvol Database for additive manufacturing. **grantadesign.com**

» PREPREG MATERIALS

## Low-temperature cure carbon fiber prepregs

**Airtech Advanced Materials Group** (Huntington Beach, CA, US) has introduced its new line of LTC3 Carbon Prepregs, said to offer a low-temperature cure and high-temperature use after post cure, and the use of lower-cost master model materials. According to Airtech, the new prepregs minimize the effects of thermal expansion and offer greater tooling accuracy and less tool/part reworking. The prepregs are offered in three weights:



LTC3-G1400 is a *lightweight* tooling prepreg with a low-temperature cure for the manufacture of composite tooling laminates capable of high-temperature use.

LTC3-G1600 is a *heavyweight* tooling prepreg with a low-temperature cure for the manufacture of composite tooling laminates capable of high-temperature use.

LTC3-G1800 is a *heavier weight* tooling prepreg used to produce molds with a low-temperature cure. The heavyweight material is used to build laminate bulk faster, reducing the number of plies required, saving up to 30% labor time on standard laminates. **airtechonline.com**

» CARBON FIBER

## Aerospace-grade carbon fiber targets next-generation aircraft

**Hyosung Advanced Materials Corp.'s** Carbon Fiber Business Division (Seoul, South Korea) is launching a new carbon fiber, designed for next-generation primary and secondary aerospace structures. The fiber is available now in 24k tow format, with 6k and 12k tow coming soon. Hyosung officials say that the material offers higher tensile strength than what is currently available in the intermediate modulus range. Properties include 6,120 MPa (887 Ksi) tensile strength and 293 GPa (42.5 Msi) tensile modulus. The fiber is available unsized for thermoplastics use, or with epoxy-standard sizing. **m.hyosung.com**

» RESIN ADDITIVES AND MODIFIERS

## Thermally conductive additives for modified polymeric systems

**Huber | Martinswerk**, part of the Huber Engineered Materials division of J.M. Huber Corp. (Atlanta, GA, US), has developed a series of Martoxid alumina-based thermally conductive powders that are said to offer unique properties and performance for modified polymeric systems. Martoxid TM-4000 Series products are specially designed for polyamides. The Martoxid TM-4250 thermally conductive filler is the newest grade in the series and can reportedly increase orientation-independent (isotropic) thermal conductivity in PA6 and PA66 up to 2.5 W/mK (in-plane and through plane). Huber says tests conducted at Fraunhofer LBF (Darmstadt, Germany) on PA6 compounds indicate that the abrasion level of Martoxid TM-4250 is low and much less abrasive compared with fillers that have a lower Mohs hardness, such as aluminosilicate and glass fiber. Because of the optimized rheological behavior, Huber says the Martoxid TM-4000 series can be used in complex and integrative designs of parts, including sub-millimeter wall thicknesses via standard injection molding techniques. According to Huber, injection molding production processes showed a reduced cycle time up to 50% compared to standard polyamide parts as a result of a faster cooling time. **hubermaterials.com**

» ADDITIVE MANUFACTURING

## Carbon fiber-reinforced resin for 3D printing

**Cincinnati Inc.** (Harrison, OH, US) has released a new carbon fiber-reinforced material for its SAAM (Small Area Additive Manufacturing) 3D printing system. The new material, comprising chopped carbon fiber in a PA matrix resin, is said to be impact resistant, lightweight and has a very high strength-to-weight ratio. Carbon fiber reinforcement makes the material stiff, durable and low warping. Cincinnati Inc. says advanced interlayer adhesion results in accurate parts with good dimensions. The company also reports that the material's high-quality surface finish makes it well-suited for custom tooling applications, as well as assembly, CMM, welding and CNC fixtures. **e-ci.com**

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## SHOWCASE

# A giant leap in rocket weight savings

## Taking advantage of carbon fiber/PEEK mechanical and thermal performance, the Technical University of Munich replaces an aluminum rocket module with a 40+% lighter composite alternative.

**By Karen Mason** / Contributing Writer

» "Ambitious" may be an understated characterization when it comes to the space industry's goals for reducing the cost of space transport. A case in point, the US National Atmospheric and Space Administration (NASA, Washington, D.C.) reports that one of its aims is to reduce the cost of putting a payload into Earth orbit from US$10,000/lb today to hundreds of dollars per pound within 25 years, and tens of dollars per pound within 40 years. Across the Atlantic, the goals are also lofty: The European Space Agency (ESA, Paris, France), for example, has stated its intent for the *Ariane 6* rocket to match or beat the payload cost per kilogram of the SpaceX (Hawthorne, CA, US) *Falcon 9*, estimated to be less than US$7,500/kg for geosynchronous transfer orbit (where most satellites reside) and less than $3,000/kg for low Earth orbit.

**Press-formed load input rings**

Load input rings, which are used to bolt-connect the CFRP module to adjacent modules of the REXUS rocket, are produced by filling a tool cavity with long-fiber thermoplastic (LFT) carbon fiber/PEEK granules, then compacting the material into the heated ring-shaped mold. Source | Technical University of Munich

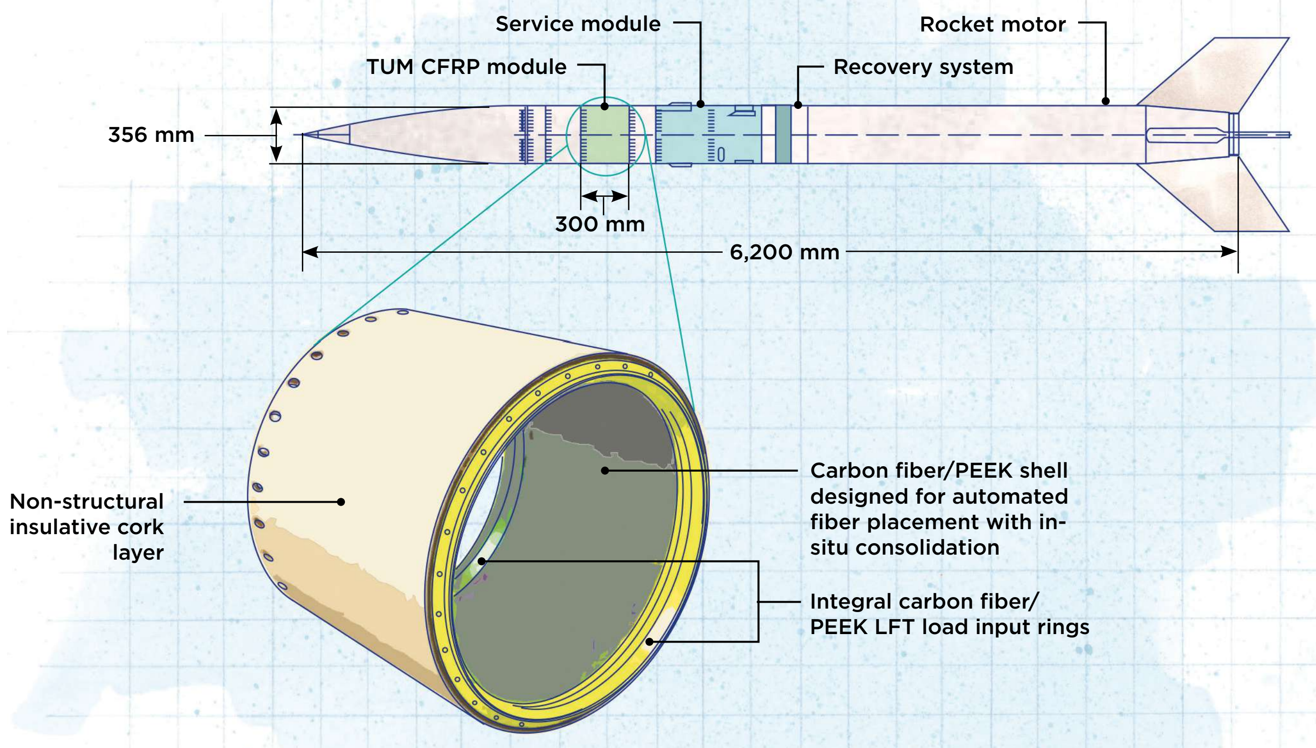
It should come as no surprise, then, that rocket structural lightweighting is being pursued by numerous space industry organizations, or that composite materials are showcased in such efforts. Success in these pursuits depends initially on finding ways to achieve lightweighting goals while complying with standards already established for baseline metal components, including part geometry and thermo-mechanical properties.

Happily, such constraints have not kept the Technical University of Munich (TUM, Munich, Germany) Chair of Carbon Composites from exceeding early estimates of a possible 30% weight reduction of a research rocket's scientific payload module. In fact, the first such carbon fiber-reinforced polymer (CFRP) module, which TUM designed and built under the Rocket Experiments for University Students (REXUS) program, achieved greater than 40% weight reduction, reports Ralf Engelhardt, research associate at the Chair of Carbon Composites. Such weight reduction yields numerous cost-saving options for the mission: heavier payloads, higher apogees or reduced fuel consumption.

### Designing within boundary conditions

TUM's rocket module comprises one section of the REXUS research rocket, which is funded by the German Aerospace Center (DLR, Cologne, Germany), the Swedish National Space Agency (SNSA, Stockholm, Sweden) and the ESA. REXUS also funds university projects across Europe. REXUS research rockets are launched twice annually to enable university experimentation during suborbital flight. They fly to a maximum height of 80-100 km, with a maximum vertical speed of about 1,200 m/s and maximum acceleration of about 20G. The baseline structure of the scientific payload modules is aluminum, with an outside diameter of 356 mm and length of 300 mm. The TUM CFRP module was designed for REXUS Mission 23, for which the current expected launch date is early 2019.

While the REXUS program typically supports university science projects conducted *inside* the scientific payload modules, the TUM project is unique in that the experiment's subject is the *composite*




**DESIGN RESULTS** | **CFRP/PEEK Rocket Module for REXUS Rocket**

- More than 40% weight reduction compared to aluminum
- Designed for in-situ consolidation of thermoplastic composites, which enables integration of subcomponents without additional adhesives or fasteners
- Potential for incorporation of recycled carbon fiber/PEEK material

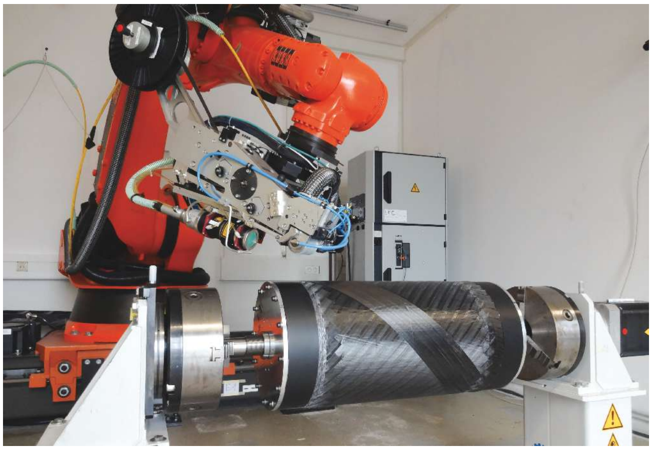
Illustration / **Karl Reque**

*module* itself — its design, manufacture, performance and qualification for flight. "Our primary goal was to replace aluminum with CFRP, which is not the typical mission," Engelhardt emphasizes.

The module consists of a cylindrical CFRP shell — 356 mm in diameter and 300 mm long, like the original aluminum — and two thermoplastic composite radial-axial (radax) load input rings, one male and one female, which provide bolt connection to adjacent modules. The CFRP design was created to meet specific geometric and thermo-mechanical property requirements, necessitated because the module must perform according to standards consistent with the rest of the rocket. Because of this, the module's geometry was pre-defined, including a requirement to match the wall thickness of the aluminum version. The module also had to achieve the same stiffness as the aluminum version. The least flexible module features are the geometry and mechanical properties of the module's load input rings, which must maintain position and integrity relative to the modules to which they are attached.

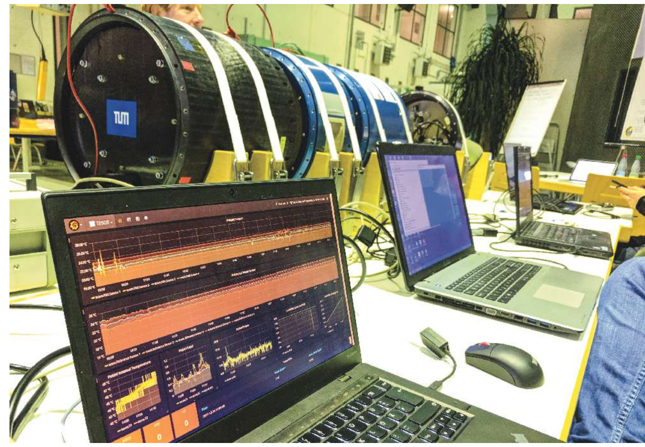
The TUM module is made from a carbon fiber/polyetheretherketone (PEEK) material, selected for its high mechanical and thermal performance, as well as its higher specific strength and stiffness compared to aluminum. In the final assembly, a cork layer is adhesively bonded to the shell to provide thermal insulation. In addition to the expected weight reduction of 30%, TUM also pursued an efficient manufacturing approach. The initial design includes a manufacturing concept in which the radax rings are press-formed from long-fiber thermoplastic (LFT) granules, demolded and prepared for integration; then the full module is laid up using thermoplastic automated fiber placement with in-situ consolidation (TP-AFP).

Of course, with the module itself serving as the primary "experiment," TUM had an opportunity to load needed equipment for secondary experiments inside the module. The team chose to measure temperatures internal to the composite structure using embedded fiber-optic sensors (FOS). Engelhardt explains that FOS were chosen over thermocouples because their thin diameter and fibrous shape result in minimal reduction of the CFRP shell's mechanical performance and because optical signals are not prone to disturbance in the electromagnetic fields that the rocket encounters. Four FOS — specifically, capsuled fiber Bragg grating (FBG) sensors — are embedded during TP-AFP »



**Thermoplastic automated fiber placement with in-situ consolidation**

TUM researchers designed the REXUS rocket module specifically for TP-AFP processing. The cylindrical shell is consolidated onto the pre-formed load input rings. Source | Technical University of Munich



**Scientific payload testing**

At the the University of Bremen (Germany) Center of Applied Space Technology and Microgravity (ZARM) test facility, the experiment modules undergo an integration test of all rocket experiments.

Source | Technical University of Munich

**In-situ integration**

The finished CFRP module is a single unified part, with load-input rings and fiber-optic sensors fully integrated during manufacture.

Source | Technical University of Munich

manufacturing at different positions and depths within the laminate and are later connected to a measurement system inside the module that operates the sensors. The measurement system collects and manages the data and provides a downlink to the ground station.

### Two-step manufacturing process

To manufacture the module, the TUM team first forms the rings. Victrex plc (Lancashire, UK) PEEK 450CA30 LFT granules (containing carbon fiber in lengths of 2-3 mm) are press-formed into ring-shaped molds. The press is heated to 390°C, compacted at increasing force levels (50-200 kN), then cooled and demolded at 100°C.

The shell is made from Teijin (Tokyo, Japan) Tenax unidirectional carbon fiber/PEEK prepreg tape on TP-AFP equipment from AFPT GmbH (Doerth, Germany). The TP-AFP process enables in-situ consolidation of the thermoplastic tape at room temperature onto the CFRP load input rings. No autoclave consolidation is required, and the consolidation onto the previously manufactured rings eliminates the need for additional mechanical fasteners or adhesives. Engelhardt is pleased with the outcome of this two-step process. “This is a new combination,” he notes. “It is always a challenge performing in-situ consolidation with thermoplastic tape, but here, we successfully placed the tape on thick, monolithic rings.”

Engelhardt is also pleased with FOS integration, which was a new technical challenge. TUM had experience employing FOS in neat resin but not in a composite laminate, and not using a thermoplastic AFP process. The team met this challenge and achieved flight-qualification performance.

**Full-scale testing**

As part of flight qualification, the CFRP module is connected to adjoining modules and subjected to vibration testing at the University of Bremen ZARM test facility. Testing includes a dummy load and heating to service temperature.

Source | Technical University of Munich

■ **Final launch preparation**

Before launch was postponed, TUM team members traveled to Kiruna, Sweden, and conducted integration testing. Left to right: Jonathan Oelhafen, Ralf Engelhardt, Stefan Ehard, Rupert Amann, Patrick Guenzel.

Source | Technical University of Munich

Finally, the module incorporates a separate bulkhead that serves as a mounting plate for measurement devices. The bulkhead is thermoformed into its dome shape from a flat organosheet composed of the same carbon fiber/PEEK material as the module's cylinder.

## Design to qualification

To reach flight qualification, TUM advanced this project through a complete testing, simulation and evaluation process. First, materials were characterized on the coupon level at room temperature and at a maximum service temperature of 135°C. Subcomponent testing helped to ensure acceptable interlaminar shear performance of the interface between rings and shell, as well as adequate pullout strength of the fasteners used to connect the rocket's modules. Data from initial testing provided input for simulation and design.

Finite element structural analysis helped the team optimize the laminate layup. The result for the cylinder is a 34-layer symmetrical layup (0°/±15°/±45°/90°). Following manufacture of the module, TUM conducted full-scale testing. To meet flight qualification loads, the module underwent vibration testing from 0-300 Hz at a frequency level of 0.083 $g^2$/Hz. It also underwent a bending test, which demonstrated successful performance under the qualification load of 14 kNm.

■ **Assembled payload**

CFRP module, here covered with a thermally insulative cork layer, is assembled with REXUS 23 full payload. Source | Technical University of Munich

## More improvements to come

The REXUS 23 mission was originally scheduled for March 2018, but was postponed due to difficulties during a previous REXUS mission. The launch is now scheduled for late February or early March 2019 from Kiruna, Sweden. The TUM team took advantage of the additional time by building a second module that it tested and qualified in autumn 2018. In this new unit, instead of press-forming the load input rings, the team had the rings centrifugally casted by Elekem Ltd. (Lancashire, UK). The raw materials are the same, Engelhardt says, and the original module with the press-formed rings met all flight qualifications. But the new module advances ring performance from an acceptable level closer to an ideal level. "The press-forming process still needs some optimization," Engelhardt says, "but it is very promising."

A future goal, Engelhardt reports, and the reason TUM will return to press-forming in the future, is to make the rings from scrap material from the AFP process. "We will take cutouts and material left over on a roll, shred it, then use those small pieces to press-form the rings," he explains. With limited data and experience related to this recycling process, TUM was unable to implement it within the time and budget restrictions of its Mission 23 work. The hope is to build and qualify the rings made from recycled material for a near-future space flight.

Once the mission is completed, TUM will use the FOS data to develop a more detailed picture of thermal loads on the module during flight. Such knowledge may lead to modifications of material choice as well as module design and dimensioning. "Thermal simulations were performed based on previous measurements, but we will soon have actual data," Engelhardt points out. "We may find that we don't have to have PEEK's glass transition temperature ($T_g$) of 143°C," he says. "A lower $T_g$ means we could possibly use a cheaper polymer."

Both a less expensive polymer and the use of recycled materials will contribute to the space industry's overall goal of decreasing the cost of space transport by orders of magnitude. But the biggest contribution of TUM's REXUS effort undoubtedly is the 40% weight reduction already achieved. CW

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**ABOUT THE AUTHOR**

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