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Carbon fiber wheels: READY TO ROLL

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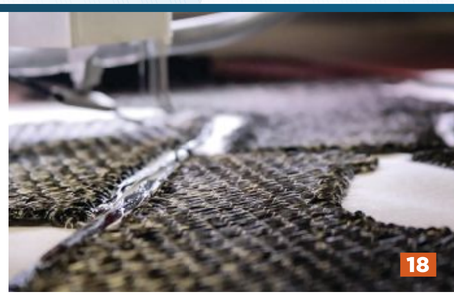
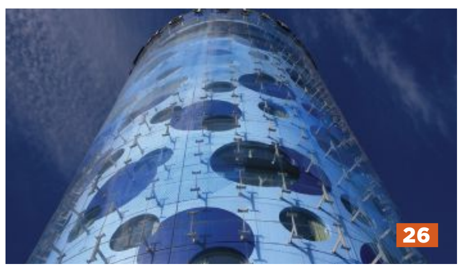
COLUMNS





FEATURES

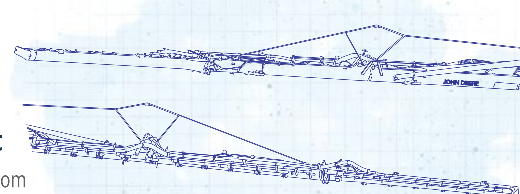
» DEPARTMENTS

» ON THE COVER

ESE Carbon Fiber's E2 line of composite wheels uses tailored fiber placement (TFP) and a proprietary compression resin transfer molding (RTM) process to produce a one-piece, all-carbon fiber wheel.
See p. 18.

Source / ESE Carbon Fiber Co.

FOCUS ON DESIGN



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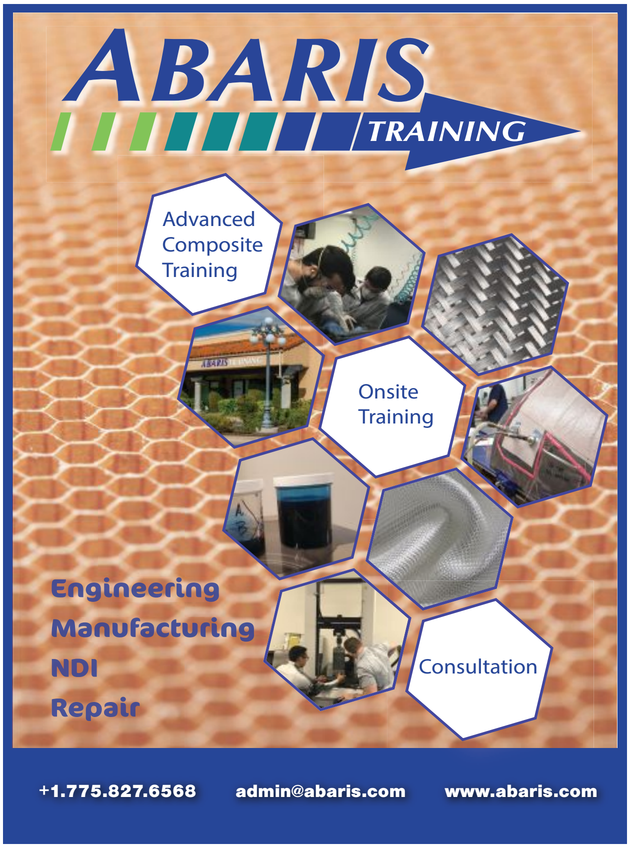

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We have a dog. His name is Leo, and he's a Golden Retriever. Actually, Leo is our son's dog, but our son is away at college, so Leo is on loan with us for a few years. Most days Leo gets two walks, during which I listen to podcasts and recorded books. One of my go-to podcasts is *Freakonomics*, hosted by Stephen Dubner.

> If you have a creative solution to share, I want to hear about it.

In an early December 2019 episode of *Freakonomics*, Dubner explores the hidden innovation economy. Dubner argues that although large firms, universities and government institutions get much (deserved) credit for the products and technologies that emerge from their research and development (R&D) work, there is another group that also innovates, but does so with little or no recognition. This group, called household innovators, is composed of garage inventors, tinkerers and problem-solvers whose homemade creations and solutions go largely unnoticed.

Eric von Hippel, a professor at the Massachusetts Institute of Technology (MIT) Sloan School of Management, estimates that Americans invest more than $41 billion annually in household innovation — an investment that is unrecognized by traditional economic measuring tools. Further, von Hippel says this represents about half of what large organizations invest in R&D.

All of this got me to thinking about innovation in the composites community. If you are a subscriber to and reader of the CompositesWorld *Today* newsletter, you know that it's not unusual to occasionally learn of the establishment of an R&D or technical center by any of the larger firms that work in the composites industry. These include fiber manufacturers, resin suppliers, large fabricators, OEMs, governments or academic institutions.

Such technical centers are typically created to build a critical mass of talent, creativity and expertise focused on developing and commercializing technology that solves customer problems. These efforts, and the innovations they produce, are vital and necessary to the evolution and maturation of composites.

However, in the same way that household innovators go largely unrecognized in the broader economy, it's fair to say that there is also composites innovation that goes unrecognized. In our reporting on the materials and technologies shaping the composites industry, I and other editors on the *CW* staff often visit composites manufacturing facilities. On our plant tours, we of course see and hear much about how people and operations are managed — everything from equipment deployment to material inventory management to process and quality control. One big source of pride for many fabricators is the quality of their product, usually expressed in QC pass rate, on-time delivery or a similar metric.

We also hear anecdotal stories, about how operators, engineers, designers and other workers have solved problems. These are not the grand problems that challenge the industry, but the irritating, frustrating day-in/day-out problems that plague workflow and harm product quality — problems that are solved by employees who are given the trust and freedom to explore creative solutions. These innovations range from a minor modification to an existing tool or piece of machinery, to software or code that enhances a process.

Such innovation is rarely done by people trained to innovate, but by everyday employees who are passionate about what they do and, just as important, work in an environment that encourages their intellectual investment in the tasks they perform. The result is a willingness to seek and develop solutions that help make that plant a little more efficient and the products a little bit better.

I am sure that you are aware of such innovation where you work, and perhaps you yourself have innovated. It's also a pretty good bet that your innovation, as important as it might be to you or your employer, has gone unrecognized by the larger composites industry. Perhaps this is OK, but it's also possible that your innovation has application beyond the world in which you work. In any case, if you have a creative solution you want to share with the world of composites, I would like to hear about it. Email me at jeff@compositesworld.com and tell me how you have innovated on the job to solve a taxing problem. We will aggregate the innovations and publish the notable ones here in *CW*.

JEFF SLOAN — Editor-In-Chief

IACMI: driving innovation in the advanced composites industry

»Since its launch in 2015, the Institute for Advanced Composites Manufacturing Innovation (IACMI — The Composites Institute, Knoxville, Tenn., U.S.) has built a network of industry, academic institutions and federal, state and local governments that are working together to improve the United States' energy and economic security through composites technology development. This consortium includes more than 160 members in 31 states, more than 130 companies and 17 academic institutes. Launched as the fifth Manufacturing USA Innovation Institute and supported by the U.S. Department of Energy's Advanced Manufacturing Office, IACMI has proven its capabilities over the past five years to accelerate development in five technology areas: composite materials and processes; compressed gas storage (CGS); vehicles; wind turbines; and design, modeling and simulation.

IACMI works to strengthen the advanced composites manufacturing workforce.

At the Institute's launch, these areas were identified as those in which more cost-, material- and energy-efficient composite manufacturing could have significant impact. Since then, the composites community within IACMI has grown to support expanding markets such as infrastructure, defense and transportation to enhance U.S. security needs.

In 2016, IACMI led the development of a roadmap to guide the advancement and commercialization of low-cost, energy-efficient composites within the five technology areas. Developed with engagement from industry stakeholders, the roadmap identified promising R&D needed to reduce technology implementation risk and to develop a robust supply chain for the advanced composites industry. The roadmap outlined more than 200 technology pathways for achieving IACMI's stated technical goals of 25% reduction in carbon fiber-reinforced polymer (CFRP) cost, 50% reduction in CFRP embodied energy and 80% recyclability or reuse into useful products.

A collaborative innovation network

Over the past five years, the roadmap has provided the catalyst for IACMI and its members to launch collaborative technology demonstration efforts. More than $70 million has been invested in more than 50 industry-led R&D projects, with participation from 90 member companies. These funded projects align with the roadmap's highest priority activities to both address IACMI member needs and make tangible progress toward its technical targets. As 2020 begins, we reflect on recent project examples across our technology areas.

Composites materials and processes: Fast-curing resins and adhesives help manufacturers reduce cycle times needed to achieve high-volume production of composite parts. Additionally, products made from recovered discontinuous carbon fibers demand a fraction of the energy needed to produce virgin material with only minor reductions in mechanical properties. Ashland Performance Materials (Columbus, Ohio) and partners demonstrated a novel compression-molded automotive hood inner using diluent-free vinyl ester prepregs that reduced manufacturing cost by 22%, reduced embodied energy by 33%, prolonged shelf life stability, eliminated the need for refrigerated storage, significantly improved resin-fiber interfacial strength and enabled reuse opportunities for prepreg scrap. The American Composites Manufacturers Association (ACMA, Arlington, Va.) and project partners, Continental Structural Plastics (CSP, Auburn Hills, Mich.), CHZ Technologies (Austintown, Ohio), A. Schulman (Fairlawn, Ohio) and Oak Ridge National Laboratory (ORNL, Knoxville, Tenn.), are also developing a scalable, low-heat pyrolysis method to recover valuable materials from dedicated or mixed-stream composite waste.

Modeling and simulation: Modeling and simulation tools help designers predict structural behavior, reduce production steps, optimize design and manage product testing and prototype development for composite products. IACMI's own Composite Virtual Factory HUB (cvfHUB) provides members with secure, web-based access to commercial simulation tools to solve design, manufacturing and performance issues of composite materials. DuPont (Troy, Mich.), Fibrtec (Atlanta, Texas) and Purdue University (West Lafayette, Ind.) used predictive modeling tools to demonstrate how Fibrtec's flexible carbon fiber/polyamide composite towpreg materials and DuPont's Rapid Fabric Formation (RFF) processing technology could reduce cost and carbon fiber waste by 30% and embodied energy by 40%.

Vehicles: Fiber-reinforced composites help automakers maximize vehicle mass reduction opportunities, but their implementation is constrained by high costs, long production times, unreliable joinability, low recyclability and an underdeveloped supply chain. Highly automated composites molding technologies for near-net shape composite intermediates can enhance design flexibility while also reducing manufacturing cycle times and waste. Toray Composites (Tacoma, Wash.) partnered with prepreg supply chain experts to develop and optimize a rapid carbon fiber prepreg molding technology that reduces the cost of targeted automotive components by 15%. Meanwhile, Ford (Dearborn, Mich.) with DowAksa (Marietta, Ga.), Dow Chemical (Midland, Mich.), ORNL, Michigan State University (Lansing, Mich.), University of Tennessee (Knoxville, Tenn.) and Purdue University developed a novel epoxy resin system as well as a chopped carbon fiber sheet molding compound (SMC) suitable for high-volume production in excess of 100,000 automotive parts per year.

Compressed gas storage (CGS): Composite materials help meet the growing demand for compressed natural gas vessels — and eventually, hydrogen storage tanks — as a low-emissions alternative to gasoline and diesel. Thermoplastic-based composite CGS tanks can improve end-of-life recyclability characteristics, while automation strategies can permit low-cost, high-volume production for implementation by automotive manufacturers. DuPont with Steelhead Composites LLC (Goldon, Colo.), Composite Prototyping Center (CPC, Plainview, N.Y.) and the University of Dayton Research Institute (UDRI, Dayton, Ohio) designed a new fabrication process and thermoplastic-based resin system that reduces component weight, improves recyclability, increases damage resistance and reduces production costs by up to 20%.

Wind turbines: While lighter and longer wind turbine blades are needed to increase power generation efficiency and capacity, today's composite blades are time-consuming to produce, economically challenging to recycle and increasingly difficult to transport from factory to field. TPI Composites (Scottsdale, Ariz.), Arkema Inc. (King of Prussia, Pa.), Johns Manville (Denver, Colo.), Huntsman Polyurethanes (Auburn Hills, Mich.), Strongwell (Bristol, Va.), DowAksa USA, Chomarat North America (Williamston, S.C.), Composites One (Arlington Heights, Ill.), SikaAxson (now Sika Advanced Resins, Madison Heights, Mich.), Creative Foam (Fenton, Mich.) and Chem-Trend (Howell, Mich.) successfully demonstrated a full-scale 9-meter wind turbine blade and introduced a new vacuum-assisted resin transfer molding (VARTM) process for thermoplastic composites that reduces production costs and improves recyclability compared to thermoset-based composites. In addition, Arkema and partners including Electric Glass Fiber America LLC (Shelby, N.C.), SAERTEX USA LLC (Huntersville, N.C.), General Electric Co. (Boston, Mass.), TPI Composites Inc., University of Tennessee, the National Renewable Energy Laboratory (NREL, Golden, Colo.) and the Colorado School of Mines (Golden) developed a novel non-adhesive thermal welding method for thermoplastic composites that reduces manufacturing defects compared to adhesive bonding methods and lays the foundation as a potential solution for on-site assembly of longer wind turbine blades.

These and other IACMI collaborative projects are driving commercialization; more than 10 new products are now commercially available because of IACMI collaboration outcomes, and include reduced costs through rapid curing, extended product longevity and efficient manufacturing technologies.

World-class R&D facilities, resources and workforce development

In addition to collaborative projects, one of IACMI's key differentiators is its production-ready environments for innovation, strategically located throughout the country. For example, IACMI's Scale-Up Research Facility (SURF), located in Detroit, Mich., offers more than 50,000 square feet of collaboration space, production-scale composites manufacturing equipment and analytical and material preparation spaces. SURF is the nation's only pilot production-scale composite manufacturing facility open to industrial, government, and academic partners.

The Composites Laboratory at UDRI in Ohio features full-scale manufacturing work cells and small business incubation. UDRI has partnered with more than 20 Ohio-based IACMI members to advance rapid-curing prepreg and SMC materials, vinyl ester resins, additive manufactured tooling for large composites aerostructures, carbon nanotube production technologies and more.

Working in conjunction with NREL's design, analysis and structural validation capabilities, the Composites Manufacturing and Education Technology Facility (CoMET) provides a 10,000-square-foot facility in Colorado. At CoMET, industry partners and university researchers can design, prototype, test and manufacture megawatt-scale wind turbine blade materials and components, including pultruded carbon fiber spar caps, specialized fiberglass sizings and novel thermoplastic resins.

Finally, in partnership with Purdue University, the Indiana Manufacturing Institute recently opened its new Composites Manufacturing and Simulation Center. The center serves as a testbed for its state partners to take advantage of next-generation Industry 4.0 technologies and develop comprehensive simulation tools for modeling composites structures from manufacturing to end-of-life product cycle.

In addition to conducting R&D, IACMI works to strengthen the advanced composites manufacturing workforce. So far, IACMI has:

- trained more than 2,000 participants in hands-on workshops,
- engaged more than 9,000 K–12 students in STEM activities and opportunities, and
- hosted more than 100 interns — 100% of whom have graduated with an industry job offer or graduate program acceptance within six months of graduating.

This column is the first in a series highlighting the work of IACMI and its partners. We at IACMI are committed to the future of advanced composites manufacturing and are actively catalyzing industry efforts to develop a robust supply chain, reduce technical risk for manufacturers and foster the next-generation composites workforce. But our success depends upon the participation of the composites manufacturing community, as well as a continuous stream of projects to feed the pipeline of innovation. CW

ABOUT THE AUTHOR

Uday Vaidya serves as director of the University of Tennessee's Fibers and Composites Manufacturing Facility (FCMF), IACMI's chief technology officer, and is the University of Tennessee-Oak Ridge National Laboratory governor's chair in advanced composites manufacturing. Vaidya is an expert in manufacturing and product development of fiber-reinforced polymer composites. Vaidya serves as the editor-in-chief for Elsevier's Composites B: Engineering journal. He engages a broad range of undergraduate and graduate students in experiential learning with composites technologies.

Estimating composite properties using data from similar materials

In my January 2019 column, I discussed methods to determine whether properties obtained from mechanical testing of composites are correct — or even reasonable. One of the methods focused on comparing test results in question to those available in public databases for similar composite materials. However, test results for similar materials cannot always be found. In this column, we consider using available data from similar composite materials to estimate properties when no test results are available.

The need for mechanical property estimates is common when performing initial design and analysis of composite structures. Often only a limited set of properties is available from the material supplier's data sheets. Additionally, testing may be performed to determine the most important properties for the intended application. However, when performing finite element analyses (FEA), a complete set of three-dimensional stiffness properties must be input, including in-plane and out-of-plane properties for the modulus of elasticity, *E*, Poisson's ratio, ν, and shear modulus, *G*. When such lamina stiffness properties are not available, the natural tendency is to try to estimate them, often using available data from similar composite materials. Once the lamina stiffness properties of a composite material with either unidirectional or woven fiber forms are known, stiffness properties for any multidirectional laminate of interest may be calculated using laminated plate theory[1].

There exist multiple publicly-available databases for a variety of polymer matrix composites.

In addition, strength properties are required to predict failure and establish margins of safety. Unlike stiffness properties, however, many strength properties cannot be accurately predicted for laminates with multidirectional fiber orientations, and therefore must be obtained from mechanical testing. The reason? Progressive matrix damage in multidirectional composite laminates, which can significantly affect laminate strength, is difficult to predict and account for using laminated plate theory. Additionally, predicting these strength properties using progressive-damage FEA is currently an active research area. As a result, there's also a need to estimate laminate strengths based on laminate test results from similar composite materials.

Even if all of the required stiffness and strength properties are available, it's often necessary to know the material's properties at non-ambient environmental conditions. The most common environmental conditions for polymer matrix composites are hot/wet conditions, at which the matrix material begins to lose stiffness and strength, and cold temperatures, at which the matrix material

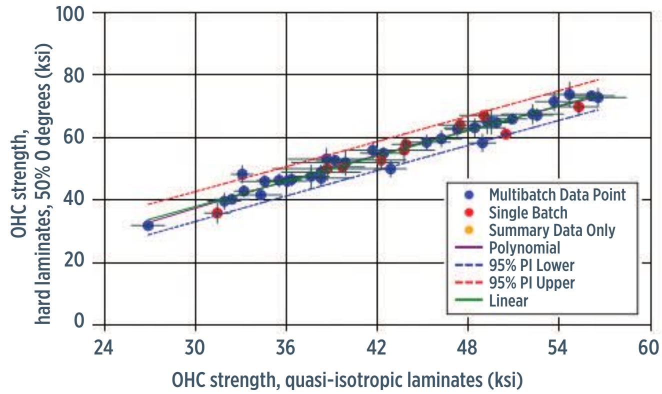

FIG 1 D-TEST plot of open-hole compression (OHC) strength of hard laminates (50% 0 degrees) versus quasi-isotropic laminates for unitape carbon fiber /epoxy materials.

begins to lose ductility. The need for mechanical properties at these non-ambient conditions increases even more the need for available data from similar materials to provide reliable material property estimates.

While it was once a challenge to find published data for similar materials, there now exist multiple publicly available databases for a variety of polymer matrix composites, including:

- the Advanced General Aviation Transport Experiments (AGATE) database[2], developed for commonly used composites of use in the general aviation industry;
- the National Center for Advanced Materials Performance (NCAMP) database[3], initiated in 2005, and
- the Composite Materials Handbook (CMH-17)[4], which includes polymer matrix composites of general interest.

As a result, it is often possible to obtain datasets for similar composite materials that include lamina stiffnesses and strengths, as well as some properties at non-ambient environmental conditions. Additionally, stiffness and strength properties of selected multidirectional composite laminates are often available. The most common laminate tested is a quasi-isotropic laminate (25% 0-degree layers, 50% ±45-degree layers, 25% 90-degree layers). However, properties from other "hard" laminates (40-50% 0-degree layers) and "soft" laminates (8-10% 0-degree layers) are sometimes available as well.

Once the desired mechanical properties have been identified for similar composites, they can be used to estimate properties for which no test results are available. One method of doing so is by establishing ratios of properties for similar materials, and applying this ratio to the material of interest. For example, if the shear modulus G_{23} is needed for the material of interest and G_{12} is available, the ratio of G_{23} to G_{12}, or G_{23}/G_{12}, is calculated for the similar material and used to estimate G_{23} for the material of interest using the equation:

$$G_{23} = G_{12}\left(\frac{G_{23}^{similar}}{G_{12}^{similar}}\right).$$

At this point, the reader may be asking what is a *similar* material? For starters, *similar* implies that the composite material has the same type of fiber (for example, carbon fiber), the same type of matrix material (for example, epoxy), and the same fiber form (for example, unidirectional tape or woven). Further, it's important to assess whether the desired mechanical property is considered a "fiber-dominated" property or a "matrix-dominated" property, and use material properties with the same characteristic for establishing property ratios as described here. Considering unidirectional tape fiber forms as an example, the fiber-direction (0-degree) stiffness E_1 and tension strength S_1^+, are fiber-dominated properties, whereas the 90-degree stiffness E_2 and tension strength S_2^+ are considered matrix-dominated properties. Note that in the example above, both the in-plane shear modulus G_{12} and the interlaminar shear modulus G_{23} are matrix-dominated stiffness properties.

Recent efforts to use material databases to estimate properties of composite materials have led to the development of the analysis tool D-TEST[5,6] (Database-Trend Evaluation and Synthesis Tool) by Materials Sciences LLC. D-TEST uses a database-driven knowledge base to provide comparisons of test results and statistical analyses from similar composite materials for use in estimating mechanical properties. Users can access D-TEST at materials-sciences.com/d-test. The current D-TEST database consists of lamina and laminate properties for both carbon fiber and glass fiber polymer matrix composite materials obtained from the public databases listed above, as well as a significant number of U.S. government-funded programs. D-TEST allows the user to generate plots comparing mechanical properties of composites that are selected based on a consistent fiber type, resin type and material form. Such plots are used to identify consistent property correlations and establish the appropriate factors from which mean values of unmeasured properties may be estimated. In addition, the same methodology may be used to estimate these properties at the non-ambient environmental conditions mentioned previously.

Since quasi-isotropic laminates are most commonly tested, laminates with other percentages of 0-degree, ±45-degree, and 90-degree layers may be estimated using test results from similar materials. Additionally, coupon-level structural properties of composite laminates, such as open-hole and filled-hole tension and compression strengths (commonly referred to as notched laminate strengths) as well as laminate-bearing strengths may also be estimated. As an example, Fig. 1 shows a D-TEST plot of the open-hole compression (OHC) strengths for "hard" laminates (50% 0-degree layers) plotted versus the OHC strength for quasi-isotropic laminates for unitape carbon/epoxy composites. From this plot, the OHC strength of a "hard" laminate could be estimated for a similar composite material based on OHC test results from a quasi-isotropic laminate.

In general, results to date indicate that general property trends, including ratios between coupon-level structural properties and similar laminate strength tests performed using the same composite laminate, are consistent across similar composite materials[5,6]. CW

REFERENCES

1 Gibson, R. F. "Principles of Composite Material Mechanics," 4th Edition, CRC Press, 2016.
2 Advanced General Aviation Transport Experiments (AGATE) database, www.niar.wichita.edu/agate/
3 National Center for Advanced Materials Performance (NCAMP) database, www.niar.wichita.edu/coe/ncamp.asp
4 Composite Materials Handbook - 17 (CMH-17), Volume 2: Materials Properties, SAE International, Rev. H, 2018.
5 Meyers, C.A., Cicalese, M.J, and Caiazzo, A.A., "Innovative Methodology For Composite Structural Allowables and Analytical Validation, Proceedings of CAMX 2015, Dallas TX, Oct. 26-29, 2015.
6 Rousseau, C.Q, Meyers, C., and Storage, T., "Use of Historical Data Trends for Accelerated Structural Design Allowables Development," Proceedings of CAMX 2018, Dallas TX, Oct. 15-18, 2018.

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Composites 4.0: Future or fad?

» In March 2015, I penned a column against incremental thinking in moving composites forward, proposing that we focus on developing processes with inherent measuring capability to identify materials variability in situ, and modify layup or molding conditions on the fly to improve consistency. In February 2016, I envisioned an idealized future where such upstream process sensing was sent in real time to end-to-end simulation tools that could make automated, intelligent decisions and make process changes without human intervention. At the time, terms like the Industrial Internet of Things (IIoT), digital twins, machine learning and artificial intelligence were starting to enter the lexicon of manufacturing and linking to one another under the banner of "Industry 4.0." I just wasn't using it yet.

> Is Industry 4.0 just a fad, or is it truly the future of composites manufacturing?

In April 2016, I attended the Hannover Fair in Germany, which I believe to be the center of gravity of all things Industry 4.0 each year, and saw the possibilities of this, the fourth industrial revolution. My July 2016 column, titled "Get ready for Composites 4.0," recounted what I saw in Hannover and why composites manufacturing, perhaps more so than centuries-old industries like steel and textiles, stood to benefit greatly from implementing Industry 4.0 technologies.

A quick rewind is in order here as a reminder of why we use the term Industry 4.0. The first industrial revolution was based on water and steam power, the second on the moving assembly line and electricity, and the third on robots and computers. This fourth revolution uses smart sensing, which is low in cost and ubiquitous, connected to a network, often wirelessly, where virtual copies (digital twins) make decisions based on big data and history (machine learning), cooperating with humans and other systems in real time. Products have a pedigree, called a *digital thread,* that is stored and can be retrieved when needed. Properly executed, Industry 4.0 offers the potential to improve product uniformity, reduce end-of-line inspection and reduce costs.

In January 2018, I pointed to IIoT — and by extension Industry 4.0 — as a technology to follow for that year. Indeed, significant progress has been made worldwide in implementing the "composites factory of the future," as evidenced by a panel session led by *CW*'s Ginger Gardiner on the topic at the *CW* Carbon Fiber conference in Knoxville, Tenn., U.S. in November 2019. One of the panelists, Michael Kupke of DLR/German Aerospace Center in Augsburg, Germany, noted that "Composites 4.0 needs Research 4.0."

I won't debate who coined the termed "Composites 4.0," knowing I first used it in mid-2016, but I do like that the term is being used to describe Industry 4.0 as applied to composites. While much of what has been implemented in composites production is related to materials tracking and camera-based inspection of automated tape laying (ATL) and automated fiber placement (AFP), there are test beds springing up in Europe, the U.S. and Australia to demonstrate new technologies related to composites manufacture.

In looking at what is happening, I'm reminded of previous initiatives related to manufacturing. Remember when OEMs began insisting their suppliers adopt ISO 9001, and further yet, become certified? The automotive and aerospace industries added requirements to ISO 9001, creating custom versions for their supply chains. For many smaller companies, getting ISO 9001 (and extended versions) certified was a substantial financial burden. In the end, the pain was mostly worth it and is today embedded in more than a million facilities around the world. Definitely not a fad. One group that truly fared well were the consultants that companies engaged to get through the process!

How about Six Sigma? First developed by Motorola in the 1980s, based on statistical process control techniques developed by W. Edwards Deming, it became highly popular once adopted by Jack Welch and General Electric in the mid-1990s. It introduced us to "green belts" and "black belts," and by 2000 around two-thirds of the Fortune 500 had some version of Six Sigma aimed at reducing costs and improving profits. Attempts to apply Six Sigma to sales and product development functions became overreach, stifling innovation. Today, many view Six Sigma as a fad, although some aspects remain in place on the factory floor. Consultants in Six Sigma made a lot of money, though.

Is Industry 4.0 just a fad or is it truly the future of composites manufacturing, and how will it be implemented democratically? Will big OEMs demand it of their suppliers, or will it earn its way via ROI measures? Will small companies be able to afford it? All questions yet to be answered. No doubt there will be consultants that can help. 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.

Composites Index improves on employment, new orders

November 2019 – 49.4

» Registering 49.4 for November, the Composites Index moved higher for a second month, moving closer toward a reading of 50. Index readings above 50 indicate expanding activity, while values below 50 indicate contracting activity. The further away a reading is from 50, the greater the change in activity. Gardner Intelligence's review of the data found that employment led the improvement in the Index, followed by new orders and backlogs. Conversely, contractionary readings for production, exports and supplier deliveries pulled the Index — which is calculated as an average of its components — lower.

November saw the continuation of a trend in total new orders and exports that was previously reported in October's reading. Expanding total new orders coupled with contracting exports implies increasing domestic orders activity. Bolstering this inference was November's expansionary backlog reading, the first above-50 reading since June.

Supplier deliveries data continue to complicate the picture of the industry's health. November's supplier delivery reading marked an all-time low despite positive new order and backlog readings. The supplier delivery reading could be a reactionary response to the period between July and September during which new orders temporarily but steeply contracted while production expanded. If this is the case, then supplier delivery activity can be expected to improve. CW

ABOUT THE AUTHOR

Michael Guckes is the Chief Economist/Director of Analytics for Gardner Intelligence, a division of Gardner Business Media (Cincinnati, Ohio, U.S.). 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.
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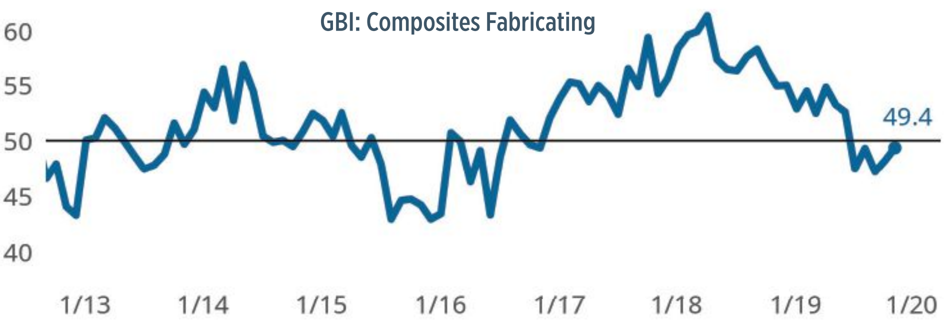
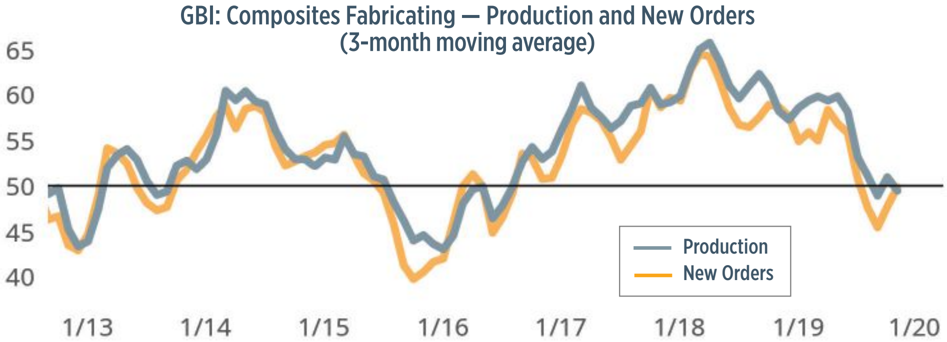


Expanding employment, new orders, backlogs

November's Index data reported expanding activity in employment, new orders and backlogs. An all-time low supplier delivery reading prevented the Index from otherwise rising above 50.



Backlogs increase on implied growth in domestic orders

November's Index data implies that the industry has been experiencing growing domestic orders. This inference was bolstered by the Index's first expansionary backlog reading since June.

This month's composites industry trends include a Q&A with John McQuilliam from Prodrive Composites, the latest developments in composite aeroelastic aircraft wings, research into making PAN precursor from algae and more.

Q&A with John McQuilliam, chief engineer at Prodrive Composites

In a recent interview with CW senior editor Scott Francis for the CW Talks podcast, Prodrive Composites' (Milton Keynes, U.K.) John McQuilliam discusses the company's primary-to-tertiary (P2T) carbon fiber composite recycling process. To listen to the full interview, go to **composites-world.com/podcast** *or download the CW Talks podcast on iTunes or Google Play.*

CW: Back in March, I visited Prodrive Composites and got to see a little bit of your P2T process, which stands for primary to tertiary.
JM: That's right. The first stage is the manufacture of the primary component, and that is the majority of the work we currently do. So these are parts that require virgin fibers, a specialty resin or particular type of thermosetting resin for whatever reason. So they're what I would call traditional composite parts … they're parts that we wouldn't particularly change the design of or the manufacture of, but we would certainly change them to make them more readily recyclable.

CW: And those are typically the more high-performance kinds of parts?
JM: Yes. So they would be made out of thermoset … What we would do is simply change the design of them to allow the waste material from making the parts and ultimately the part of the end of its life to be recyclable so that we can reuse the carbon fibers contained within those parts. So the thermoplastics come in during the second stage … the initial stages can be thermoset or thermoplastic, but the important thing is that it allows us to reclaim the fibers. So to reclaim the fibers from the primary parts, as touched on, we certainly change the design materials to something that is easier to reclaim the fibers from, so what we're really talking about is an increased use of non-crimp fabrics, more unidirectional materials, things where the production waste and the component when they go through for the fiber reclaiming process will give a better yield of longer high-quality fibers.

CW: Can you describe a little bit of the reclaiming process that happens for that primary component?
JM: Yes. So the recycling or the reclaiming process for the primary parts is an incineration type of process. So the waste prepreg — the offcut prepreg — or the end-of-life parts go into a furnace and all of the resin is burned off leaving the carbon fibers behind. And those carbon fibers, through a series of processes, are turned into a nonwoven mat of consistent thickness and random orientation — so it ends up being able to make a quasi-isotropic plaque.

CW: Is this the process that ELG [ELG Carbon Fibre] is doing for you? Are they handling the pyrolysis?
JM: Yes, ELG does that portion of it. So, we send them our waste offcuts and some component parts and then they turn it back into one of the precursors, one of the parts that we use to make our secondary parts.

CW: Can you tell me a little bit about those secondary parts and what characterizes them?
JM: For the secondary parts, the reinforcement is mainly made out of the reclaimed carbon fibers with a discrete use of virgin fibers if required in certain areas. But the majority of the reinforcing is reclaimed fibers. And then we introduce a reactive thermoplastic. This is a liquid resin that we infuse the reinforcements with. Then there's a curing type of process and we get a finished component. This process is done at relatively low temperatures and atmospheric pressure, and the result is a good component.

(continued on page 14)

(continued from page 13)

CW: Part of what enables P2T is resin system that you've described as a "reactive thermal plastic resin." Can you explain a little bit more for our listeners what you mean by that?
JM: Reactive thermoplastic in some ways very similar to a thermosetting resin. We mix it up immediately before making the component, and there are two or three liquid components going to the mixture. And when they combine with time and a little bit of temperature, they actually polymerize into a true thermoplastic. It's the thermoplastic properties that allow subsequent recycling. An advantage of it being a reactive thermoplastic rather than a traditional thermoplastic is the fact that we're effectively creating a thermoplastic at the same time we're surrounding the reinforcing fibers. It is very low viscosity, so it can be formed in a normal or traditional thermosetting type processes. It doesn't need the high temperature and the high pressures that you will get with either injecting a molten thermoplastic into a fiber preform or taking a thermoplastic prepreg where the thermoplastic and the fibers have already been combined and then remounting them at high temperature and pressure, typically in metallic molds. So we're avoiding the complexity and cost of the mold tools required to process thermoplastics above the melt point and avoiding the difficulties due to the high viscosity of molten thermoplastic with distortion and movement of the reinforcing within the mold cavity.

CW: I'm guessing that translates into cost and time savings?
JM: You've got it, yes. The production method is akin to what we do in the traditional thermosetting industry, but the tooling cost is way lower than will be required for processing a traditional thermoplastic. And that's a big advantage for most of our customers. You don't want to make the upfront investment in thermoplastic mold tools — or mold tools —simply for thermoplastics.

CW: So are you seeing this as an enabler for more high-volume production?
JM: Certainly. Cycle times can be shorter than their traditional thermosetting, in that it doesn't require a ramp up to a processing temperature, a dwell and then a cool down again before you can turn around the mold. So we're seeing rate advantages by using this process compared to our traditional oven or autoclave cured components.

CW: And of course, one of the exciting things is that from there, you can recycle this secondary part yet again. So what characterizes this tertiary part in the life cycle of this material?
JM: So I'd say the secondary part, being a true thermoplastic, can be reformed into other shapes and typically would be cut up into small pieces, and then put into the cavity between the heating mold and pressed into a new shape. There is a possibility to take all of the redundant secondary parts, all of the production waste from the secondary parts, and to reform them into another fiber-reinforced plastic component or fiber reinforced polymer component.

CW: And from there, these tertiary parts aren't necessarily the end of the road for that material, correct?
JM: That's correct. … So we think that these tertiary parts, because they're thermoplastic, can be reformed almost an infinite number of times. The process of cutting them up into molding palettes — should we say molding pieces — does have an attritional rate on the fiber … so some of the mechanical properties would drop, but other mechanical properties such as the stiffness, the thermal expansion rate and the distortion temperature would pretty well be retained. You still get a high-quality fiber-reinforced component — not with the original strength of the continuous fiber component or even a relatively long fiber component — but certainly there's still the advantages in terms of stiffness, thermal expansion and the distortion temperature that makes it very worthwhile reprocessing the tertiary parts time and time again.

BIZ BRIEF

Specialty chemicals giant **Solvay** (Brussels, Belgium) and carbon fiber manufacturer **SGL Carbon** (Wiesbaden, Germany) have entered into a joint development agreement (JDA) to bring to market the first composite materials based on large-tow intermediate modulus (IM) carbon fiber. These materials, which help address the need to reduce costs and CO_2 emissions, and improve the production process and fuel efficiency of next-generation commercial aircraft, will be based on SGL Carbon's large-tow IM carbon fiber and Solvay's primary structure resin systems.

The agreement encompasses thermoset and thermoplastic composite technologies. It builds on Solvay's position as a supplier of advanced materials to the aerospace industry and SGL Carbon's expertise in high-volume carbon fiber manufacturing.

Solvay says this partnership represents an opportunity to lead the aerospace adoption of composite material based on 50K IM carbon fiber, resulting in more affordable high-performance solutions.

Composite materials for aerospace applications represent a multi-billion-dollar market that is expected to grow strongly in the coming decade. Solvay and SGL Carbon are uniquely positioned to develop solutions to address the needs of this market.

CARBON FIBER

Technical University of Munich researchers explore using algae to make carbon fiber

Technical University of Munich (TUM, Munich, Germany) researchers have been working to develop a process that uses halophilic algae — algae that thrive in high salt concentrations — to remove CO_2 from the atmosphere and subsequently to make carbon fiber.

According to Thomas Brück, who heads the project along with a team at the Algae Cultivation Center of the Technical University of Munich, the process converts atmospheric CO_2 into biomass, an organic material used as a renewable energy source, and, in a subsequent stage, algae oil. The algae oil is produced by a nutrient-depletion phase where nitrogen is limited in the cultivation medium, triggering the accumulation of lipids.

"We then hydrolyze the algae oil so that we actually split the free fatty acids from the glycerol backbone," explains Brück. The fatty acids are then used to generate biofuels, chemicals for the lubricant industry or thermoplastics, he says. The remaining glycerol residue is turned into acrylonitrile, which is polymerized to yield polyacrylonitrile (PAN), the precursor for approximately 90% of today's carbon fiber production.

While the PAN precursor can be pyrolized via standard means, TUM has also developed a pyrolysis process that carbonizes the PAN fibers using parabolic solar reflectors — curved solar mirrors — in order to yield carbon fibers in a CO_2-neutral manner.

"We do the pyrolysis in focused glass tubes in the center of those mirrors," says Brück. "There you can actually generate temperatures up to 3,000°C, and with that technology, you're completely emission-free and also cheaper because you're using sunlight."

According to Brück, the carbon fiber created using the algae-based PAN has the same chemical composition as classical carbon fibers currently in use today, and the same physical properties as those carbon fibers that come from petroleum resources.

"And since we can combine the thermoplastics that we generate from the fatty acid part with the carbon fiber, we can actually now do 3D printable carbon fiber composites," says Brück. TUM is also currently working with a partner to develop CO_2-negative building materials such as carbon fiber composite-reinforced granite from the algae-based carbon fiber.

AEROSPACE

FLEXOP project develops novel wing designs

As part of the European Flutter Free FLight Envelope eXpansion for ecOnomical Performance improvement (FLEXOP) project, researchers from German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt; DLR, Göttingen, Germany) and the Technical University of Munich (TUM, Munich, Germany) have developed new technologies for lighter yet extremely stable aeroelastic wings. The new wings made their first flight on Nov. 19, 2019, at Oberpfaffenhofen airport (Weßling, Germany).

According to the researchers, wings with longer spans and lower weight generate less drag, and are therefore more energy efficient. The limiting factor for the construction of such wings, however, is the aerodynamic phenomenon of flutter. Wing oscillations increase due to drag and wind gusts.

"Flutter causes material fatigue and can even lead to the failure of the wing attachment to the fuselage," explains Sebastian Köberle, a researcher at the TUM Institute of Aircraft Design.

Although any wing will begin to flutter at sufficiently high speed, shorter and thicker wings have greater structural stiffness, and hence greater stability. Building wings with longer spans that are just as stable and stiff would make them much heavier. In the FLEXOP project, researchers from six countries are working on new technologies to control flutter while allowing wings to be made lighter.


Source | DLR

The partners in the EU FLEXOP project are the Hungarian Academy of Sciences (MTA SZTAKI, Budapest, Hungary), Airbus Group Innovation (Ottobrunn, Germany), Airbus Group Ltd. (London, U.K.), FACC Operations GmbH (Ried im Innkreis, Austria), INtegrated Aerospace Sciences Corp. (INASCO, Athens, Greece), Delft University of Technology (Delft, Netherlands), the German Aerospace Center (DLR), the Technical University of Munich, the University of Bristol

(Bristol, U.K.) and RWTH Aachen University (Aachen, Germany).

TUM researchers are responsible for the design and execution of the flight tests that demonstrate the behavior of the two novel wings developed by the project — the aeroelastic wing and the flutter wing. The TUM team first built the 3.5-meter-long and 7-meter-wide flight demonstrator and integrated the various systems provided by the European partners.

A particularly light wing, which has now been flown for the first time, is an aeroelastically optimized wing constructed from carbon fiber-reinforced composites. It was developed by DLR, in collaboration with Delft University of Technology. The researchers were able to influence its bending and torsional behavior through a special alignment of the fibers during the construction of the wing.

"When the wing is bent by aerodynamic forces, it rotates simultaneously and thereby reduces airflow-induced loads," says Wolf-Reiner Krüger of the DLR Institute of Aeroelasticity in Göttingen.

With the help of the reference wings, the TUM researchers worked in advance to have the flight demonstrator automatically fly predefined flight test patterns. They devised optimum settings and developed manuals and checklists for the flight tests.

"The flight demonstrator has to fly fast enough with the new wings that they would theoretically have to flutter," explains Köberle. "We have to be sure that nothing goes wrong at such high speeds."

Another super-efficient wing developed in the project is the flutter wing. This is a TUM design and is made of fiberglass. If fluttering occurs, the outermost flaps are extended and act like dampers.

"The active flap control developed at DLR considerably increases the possibilities for a much lighter design," says Gertjan Looye of the DLR Institute of System Dynamics and Control in Oberpfaffenhofen, which manages DLR's share of the project.

A second flight control system is being developed by the Computer and Automation Research Institute of the Hungarian Academy of Sciences (MTA SZTAKI).

Project Manager Bálint Vanek of MTA SZTAKI says, "Such a wing would make it possible to transport 20% more cargo or to reduce the required fuel by 7%."

The technology is particularly complex, so tests on this wing will take place at a later date. Both variants of the super-efficient wing have already been evaluated during static vibration tests conducted at the DLR site in Göttingen.

The wings will not only be used on a flight demonstrator. In a further step, the results of the project will be transferred to configurations for transport and passenger aircraft.

One-piece, one-cure, infused carbon fiber wheel is ready to roll

ESE Carbon Co.'s new carbon fiber wheel uses tailored fiber placement and custom presses to minimize waste and improve scalability.

By Scott Francis / Senior Editor

One piece, one cure

ESE's E2 line of composite wheels uses tailored fiber placement (TFP) and a proprietary compression resin transfer molding (RTM) process to produce a one-piece all carbon fiber wheel.

Source | ESE Carbon Co.

» Carbon fiber wheels offer a range of benefits by reducing rotational inertia and the combined mass — known as the unsprung mass — of a vehicle's wheels, suspension and other directly connected components not supported by the suspension. This reduction in rotational inertia and unsprung mass, which can be as high as 50%, typically results in faster acceleration with less effort, reduced braking distance, improved handling thanks to good road contact (mechanical grip) and reduced road noise.

But the price tags on carbon fiber wheels — both hybrid and all-composite — have kept them out of reach for many consumers. With the most affordable priced at more than $10,000 for a set, the wheels are likely to only be found on very high-end sports cars and luxury vehicles. Several wheel companies, however, recognize the market potential for a lower-priced carbon fiber wheel and are working toward finding a solution. Approaches vary from the materials used to the way wheel components are manufactured and combined. Some combine carbon fiber components with aluminum for a hybrid wheel. Some create wheels from prepreg.

ESE Carbon Co. (ESE, Miami, Fla., U.S.) was founded in 2011 with the goal of making carbon fiber wheels available for a broader segment of the driving population. The company has added a five-axis CNC precision machining team, advanced structural composite parts capabilities, tailored fiber placement machines and robotics to automate production. The company aims to release its E2 line of one-piece, one-cure, all-carbon-fiber composite automotive wheels in the coming year. Weighing only 17 pounds, ESE's wheel is designed to a 3,850-pound axle rating, making it capable of supporting vehicles up to a 6,800-pound gross vehicle weight rating. According to ESE's CEO Carlos Hermida, traditional aluminum wheels capable of handling the same weight would weigh more than 30 pounds.

The E2 uses a five-spoke design based on a universal sport aesthetic with a concave, deep-bowl look. Hermida says the company was inspired by the design of an aluminum Porsche wheel, which was then optimized for carbon fiber. The wheel uses a high-temperature epoxy system with good clarity, and offers custom finish solutions including clear gloss, clear matte and custom colors.

ESE's carbon fiber wheel is 80% of the way to certification under the existing Society of Automotive Engineers (SAE, Warrendale, Pa., U.S.) Recommended Practice, which applies to all wheels currently manufactured, including metallic wheels. What's more, Hermida says the company is likely to have the first one-piece wheel on the market that is certified under a new composite wheel recommended practice, SAE J3204, which has just been approved for publication by the SAE. Like the metal wheel's SAE recommended practice, this new recommendation for composite wheels addresses durability through various fatigue and impact tests. It also adds new requirements to account for environmental effects that are unique to composites. Dr. Michael Hayes, ESE's vice president of product development, has been actively involved in the task force for this new recommended practice, sharing data and providing prototypes for developmental testing by the SAE committee. Internally, ESE's engineering team is working to ensure that E2's performance exceeds the minimum SAE recommendations. Years of prototype testing and physics-based simulation have led to the current E2 design.

"There have been years of work by the SAE task force to create the composite wheel practice," says Hermida. "A lot of our testing data and knowledge has been shared with SAE to help get the practice to the finish line, and while the new SAE practice will be more rigorous than current wheel practices, we welcome it in the name of consumer safety."

Turning to TFP

ESE's wheel is created using tailored fiber placement technology (TFP), which the company says allows fast-paced, high-volume manufacturing of carbon fiber components with good mechanical properties. TFP works by arranging fiber bundles, positioning them where they are needed for structural performance, and stitching them into position on a compatible base layer. The procedure is used in place of the conventional approach of cutting woven fabrics to a required shape. ESE uses industrial-grade carbon fiber tow from Hyosung Advanced Materials (Seoul, South Korea) and TFP technology from ZSK Stickmaschinen GmbH (ZSK, Krefeld, Germany) to *stitch* plies, creating preforms of near net shape.

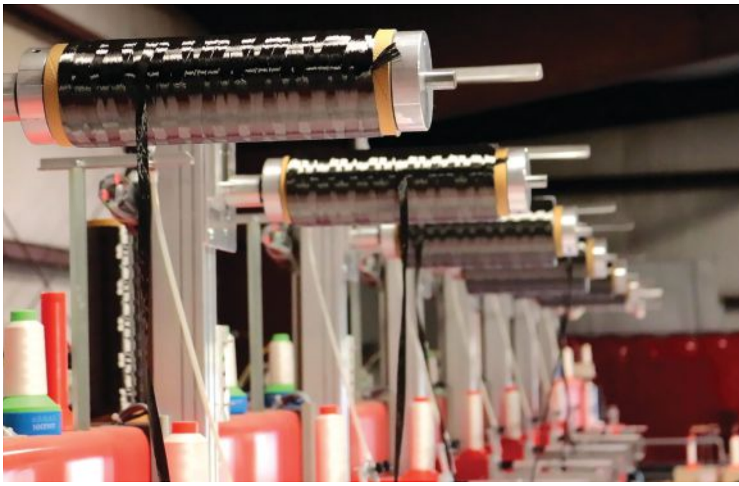
"By controlling the path of the tow material as it is stitched into the desired geometry, material is only placed where it is needed in the final preform," explains Topher Anderson, Ph.D, manager of technical embroidery application for ZSK. "Areas of fabric that would have to be cut out in traditional laminate design are simply left unstitched. This process reduces both the initial waste produced when cutting woven fabrics to shape, and also reduces post-processing waste due to the ability to conform to complex geometries."

Originally working with traditional carbon fiber fabrics before transitioning to TFP, ESE claims the technology has allowed the company to reduce plies by up to 50%, thereby creating a simplified layup process and minimizing waste. According to Hermida, carbon fiber waste was reduced from around 40% with traditional carbon fiber fabrics to less than 10% by adopting TFP. In addition, the technology has led to improved layup quality, optimized fiber orientation and increased design flexibility.

"There's a lot of curvature in our spokes, which complicates the plies. With traditional fabrics, the orientation of your carbon fiber plies is limited," explains Hermida. "With TFP, there is an »

Tailored fiber placement

ESE's carbon fiber wheel is created using ZSK Stickmaschinen GmbH's tailored fiber placement technology (TFP). Source | ESE Carbon Co.



Aerospace grade tow

ESE uses carbon fiber tow from Hyosung Advanced Materials for the E2.

Source | ESE Carbon Co.

Braking heat

ESE Carbon says Huntsman's Araldite has improved production rates and increased rim strength, even at the elevated temperatures to which wheels are exposed during braking.

CW photo | Scott Francis

almost unlimited ability to create straight or curved patterns in any direction, allowing you to design plies that are optimized to manage loads and stresses more effectively than possible with traditional fabrics."

One of the most significant cost savings for ESE's wheel comes from these layup improvements. Hermida says that prior to the switch to TFP, layup was a manufacturing bottleneck for the company. He claims the reduction in plies improves efficiency and reduces layup time by nearly 50%. More parts per mold can be made each day, improving the overall investment of time, labor and equipment per wheel.

In all, ESE says TFP has simplified its process and contributed to improved scalability. Hermida says there is also an added cost advantage of consolidating the supply chain by purchasing tow as opposed to fabric.

All-infused, one-cure wheel

In addition to its investment in TFP technology, ESE is moving away from autoclave processing for its wheel as it pushes for improved production rates. The E2 is produced by a proprietary compression resin transfer molding (RTM) process using custom presses designed by ESE's engineering team. Hermida says achieving an all-infused, one-cure wheel was challenging. A key component of this effort was selecting the right resin system.

"We needed a low-viscosity, high-T_g [glass transition temperature], high-clarity, fast-curing system with robust properties," says Hermida.

The company selected Huntsman Advanced Materials' (The Woodlands, Texas, U.S.) Araldite for its epoxy resin system. According to Huntsman, the system offers low viscosity for faster injection speeds, fiber wet out and ease of processing, as well as flexibility to adjust to different mold conditions and cycle times. With Araldite, ESE says it is able to enhance the production rate and increase the rim strength, even at elevated temperatures to which wheels are exposed during braking.

Araldite combines improved elongation and higher fracture toughness when compared to conventional epoxy resins with a T_g up to 200°C. "Because of brake heat that's generated, that's a critical component," says Hermida.

To reduce time in the mold, the system offers cure at intermediate temperatures, followed by optional post-cure at elevated temperatures outside the mold. The result is a composite rim with good fatigue resistance, which is key to durability in wheels that are exposed to repeated cycling/stresses during vehicle operation.

Huntsman technical representatives worked with ESE's engineering team to determine which epoxy resin system would fit their production needs, as well as the ideal component ratios to attain a work life long enough for injecting multiple wheel molds before the epoxy begins to gel. In addition, the company provided computer-generated, predictive cure modeling analysis and laboratory testing to help support ESE's development efforts.

The wheel keeps on turning

ESE will begin road testing the E2 in Q1 2020. Delivery of aftermarket wheels is expected later in 2020 and ESE says it has begun discussions with OEMs. With the E2 poised for its debut on the market, the question comes back to cost. Most of the carbon fiber wheels on the market today can approximate the cost of some affordable cars.

"Carbon fiber wheel manufacturing is unique in many ways; while current automation technologies benefit us, a large amount of customization and development of automation is still required to get to the wheel price points we want," says Hermida.

With its addition of TFP, ESE is making strides in the automation of its process. Hermida says the company has also been able to automate post-processing of the wheel, and the company is currently working to advance its automation of such tasks as trimming, robotic pick and place layup and preforming.

LEARN MORE

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

"It comes down to ESE making carbon fiber wheels attainable," says Daniel Canavan, ESE's vice president of business development. "We are diligently working to reach a point where carbon fiber technologies can be applied to the greater populous."

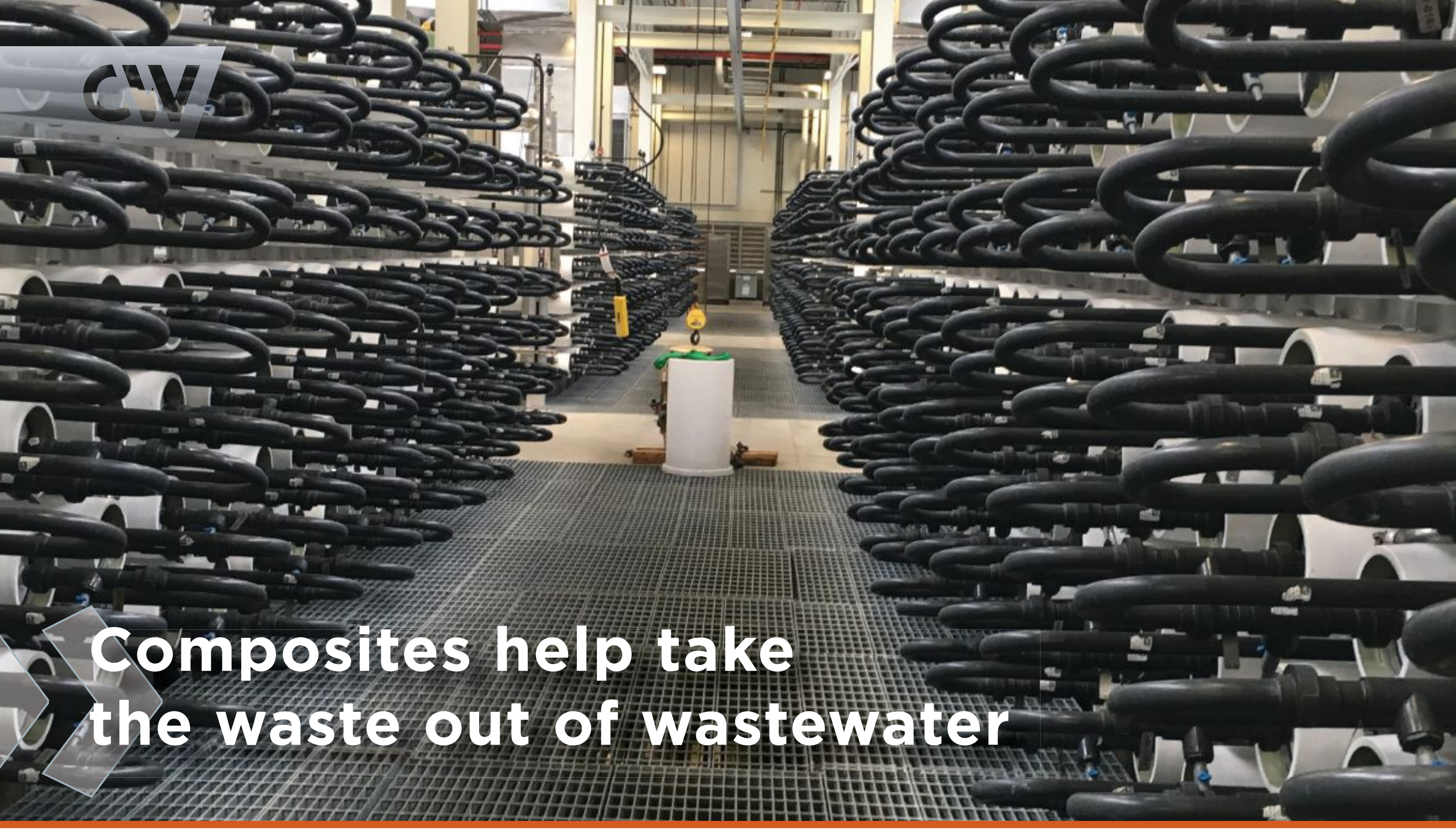
ESE's E2 aims to be more than just a competitive wheel on the market. The initial goal is to offer a set of four wheels for less than $9,900. While this may still sound expensive, it's definitely a step in the right direction, and Hermida says the company's automation projects will help trim the costs to reach beyond the luxury/performance market.

"Our ambitions go way beyond that," says Hermida. "This is just a starting point. Our goal is to set prices that are within striking distance of forged aluminum wheels." Comparable forged aluminum designs range between $5,000-$7,000.

"We see a bigger picture of doing this in mass production," says Canavan. "We're thinking of electric vehicles and other markets where we can share efficiency and [users] can experience the benefits of unsprung weight — performance, speed and safety. There are so many advantages to this technology where we can truly make a difference." CW

ABOUT THE AUTHOR

Scott Francis, senior editor for *CompositesWorld,* has worked in publishing and media since 2001. He's edited for numerous publications including *Writer's Digest*, *HOW* and *Popular Woodworking*.



Composites help take the waste out of wastewater

The role of composites in wastewater recycling to help California meet its 21st century water needs.

By Donna Dawson / Senior Writer Emeritus

Adequate water resources in the state of California are a matter of some urgency, creating new opportunities for composites. California's seven-year drought, which officially ended in March 2019, heated already simmering water wars between farmers, citizens in cities, technologists, manufacturers and environmentalists.

The respite from drought notwithstanding, California's Governor Gavin Newsom ordered key state agencies to develop a blueprint for meeting California's 21st century water needs: to ensure safe and resilient water supplies, protect against floods and maintain healthy waterways for the state's communities, economy and environment.

The state has several operations and ideas to accomplish this, notably: 1) increased water storage infrastructure; 2) digging one or two tunnels under the Sacramento-San Joaquin Bay Delta — called *WaterFix* — for better-controlled conveyance of water from the Sacramento River to some 27 million people in Southern California; 3) wastewater recycling; 4) seawater desalination; and 5) improved recharging of aquifers (groundwater).

Composite materials do or will play a role in all of these applications, but most particularly in wastewater recycling, groundwater storage and seawater reverse osmosis (SWRO) desalination. This summary explores wastewater recycling and groundwater storage efforts. You can find a detailed assessment of composites use in seawater desalination systems at **short.compositesworld/SWRO**.

FIG. 1 Composite pressure vessels enable cleaner water

California's Orange County Water District (OCWD) Ground Water Replenishment System (GWRS) Reverse Osmosis stage currently holds 3,150 fiberglass pressure vessels, each 25 feet by 8 inches in diameter and manufactured by Protec-Arisawa. GWRS has produced more than 287 billion gallons of purified water.

CW photo | Donna Dawson

Composites as an enabling technology

The composite materials and processes in question are filament wound fiberglass-reinforced plastic (FRP) pressure vessels, which have proven to be an enabling technology for production of clean water via municipal wastewater recycling and SWRO (see Learn More). The greatest beneficiary of composite materials in the water treatment process is reverse osmosis, which depends on pumping pretreated feed water (wastewater or seawater) under pressure through a series of semipermeable RO membrane elements, which are encased in FRP composite pressure vessels. Standards established by the Boiler and Pressure Vessel Code of the American Society of Mechanical Engineers (ASME) make certification for specified pressures possible—up to 1200 psi and even higher. A group of pressure vessels — all connected to a common pressurized header — is called a *train*, and the trains are arranged in racks.

Doug Eisberg, director of business development for Avista Technologies, a Kurita Co., in San Marcos, Calif., explicates the process:

"The pressure forces the small water molecules in the feed water through the membranes, leaving larger and unwanted molecules and larger particles behind. RO sends all the purified water to a common collection point, and sends the bacteria, viruses, salt and other undesirables on through to the next membrane, where further separation occurs." Eisberg calls it a *separation* process, rather than a filtration process, "as it does not collect impurities in the way a common filter does, but rather separates the water streams — one purified and the other not." Avista supplies specialty chemicals and technical support services for the membrane separation industry.

Advantages of wastewater recycling

SWRO is, arguably, the best known method for purifying drinking water, but a close second is wastewater recycling, which uses purification systems similar to those used for SWRO. The difference is the lower pressure required (~300 psi) for wastewater recycling because of the near absence of salt in wastewater.

Richard Chmielewski, sales manager for Protec-Arisawa (Vista, Calif.) explains: "Because the salts are much more dilute, we don't have to run at SWRO's high pressure. The salt concentration of Pacific Ocean seawater is 3.5%, resulting in osmotic pressure of around 400 psi. In contrast, since a community's waste is composed of mostly water (plus various contaminants from kitchens, laundry and bathroom), the salt concentration and consequently the osmotic pressure is much, much less — typically less than 0.2% salts. The resulting operating pressures are thus much, much lower." (See Fig. 4, p. 24.)

Making pressure pipes for wastewater recycling is therefore much less expensive, and RO operation is less expensive and less energy intensive, as well. Southern California can especially benefit because its sizable population relies heavily on imported water from the Colorado River and Northern California, exposing its population to cost increases, drought and other forces not under local control.

Standards and regulations

Under the Safe Drinking Water Act (SDWA), the U.S. Environmental Protection Agency (EPA) has authority to set the standards for drinking water quality and to oversee state, localities and water suppliers that implement those standards. The EPA has set maximum levels and/or treatment technique requirements for more than 90 contaminants in public drinking water. In California, Title 22 of California's Water Recycling Criteria offers state guidelines for how treated and recycled water is discharged and used. The standards also require the state's Department of Health Services to develop and enforce water and bacteriological treatment standards for water recycling and reuse.

Significantly for the environment, without recycling, secondary treated sewage water is typically discharged directly into the ocean, affecting marine life (as well as surfers and swimmers).

Recent legislative actions in California include SB 332, the Local Water Reliability Act, introduced in February 2019 by California legislators, which, though currently held by the committee, would call on wastewater treatment facilities to step up recycling, conservation and efficiency to reduce the amount of treated wastewater »

FIG. 2 Expanding capacity

GWRS' final expansion in progress will bring capacity to 130 mgd in 2023.

CW photo | Donna Dawson

FIG. 3 A closer look at the vessels

Each vessel is loaded with seven RO membrane elements made of a semipermeable polyamide polymer (Dow Filmtec, from DuPont). *CW* photo | Donna Dawson

FIG. 4 Filament-wound pressure vessels

Protec-Arisawa is a major supplier of fiberglass epoxy pressure vessels, including 130-to-450-psi vessels for wastewater recycling and 600-to-1,200-psi vessels for SWRO desalination. Its filament winding facility in Vista also winds pressure vessels up to 1800 psi for the oil and gas industry.

Source | Protec-Arisawa

dumped in estuaries and the Pacific Ocean by 50% before 2030, and 95% by 2040. Nationally, four western U.S. Senators have introduced bipartisan drought legislation that would extend the Water Infrastructure Improvements for the Nation (WIIN) Act, including $100 million for water recycling projects.

Cool, clear potable water from wastewater

Southern California's Orange County Water District (OCWD) Ground Water Replenishment System (GWRS, Fountain Valley, Calif.) proved the technology of wastewater recycling to meet state and federal drinking water standards and is one of the largest such facilities in the world. Mehul Patel, executive director of operations for GWRS, explains: "The GWRS project takes secondary treated wastewater and converts it to ultrapure water for replenishing our local groundwater aquifer as well as protecting it from seawater intrusion." The project went online in January 2008 with a capacity of 70 million gallons per day (mgd) and was expanded in 2015 to 100 mgd — 36.5 billion gallons per year — enough water for 850,000 people. Final expansion, currently in progress, will bring capacity to 130 mgd in 2023.

FIG. 5 Skin-like membranes for microfiltration

Scott-Roberts compares the membrane to our skin, "which holds in bodily fluids but allows sweat to diffuse." *CW* photo | Donna Dawson

The GWRS process consists of five basic steps:

- Pre-purification. The Orange County Sanitation District (OCSD) treats wastewater, removing organics and the majority of suspended solids before it reaches GWRS.
- GWRS microfiltration. Treated wastewater is directed through ~25,000 hollow polypropylene microfilters with a 0.2 micrometer pore size (about 1/300th the diameter of a human hair), to remove more suspended solids, protozoa, bacteria and some viruses. Microfiltration produces non-potable water that is suitable for irrigation.
- Reverse osmosis. Water is forced through RO membranes under pressure, removing remaining dissolved solids/chemicals, viruses and pharmaceuticals. The fiberglass pressure vessels that house the RO membranes are qualified for 130-220 psi.
- Ultraviolet (UV) light. Water is exposed to UV light with hydrogen peroxide to destroy trace organic compounds. This results in distilled water that is drinkable but "not really healthy," notes Sandy Scott-Roberts, program manager of Orange County's GWRS, "because it doesn't have minerals." Calcium hydroxide is therefore added after a decarbonation process that uses large composite decarbonators.
- Water delivery. The final product water is pumped through a pipeline to groundwater recharge basins in Anaheim, where it percolates through a layer of sand into the aquifer. Orange County's Groundwater Basin provides about 77%

FIG. 6 Purifying brackish groundwater

The Robert W. Goldsworthy Groundwater Desalter in Torrance produces 5 mgd, to supply 15,000 households. Feed water is actually from seawater intrusion into the groundwater, which occurred in the 1950s and 60s when too much freshwater was extracted from underground reservoirs. The desalter depends in large part on RO as its core treatment technology — with its essential fiberglass pressure vessels. Further expansion of brackish groundwater desalting is anticipated in the next few years.

Source | WRD

of the potable water supply for 2.5 million people.

Of the 100 mgd of wastewater GWRS produces, about 65 mgd are pumped to the recharge basins. The remaining 35 mgd is pumped into injection wells, where it serves as a seawater intrusion barrier to counter the threat of saltwater from the ocean contaminating Orange County's aquifer.

Though the first and arguably the largest, Orange County's plant is by no means the only wastewater recycling plant in California. Pure Water San Diego is the City of San Diego's phased, multi-year wastewater treatment program that will provide one-third of San Diego's water supply by 2035. San Diego Mayor Kevin Faulconer calls the Pure Water Project "one of the most important infrastructure projects in city history."

Using a process similar to GWRS, a demonstration facility has produced 1 mgd of purified water since June 2011, using for its RO step 37 fiberglass pressure vessels rated for 300 psi, made by Protec-Arisawa. Phase 1 construction of a full production facility in the North City area will be completed by 2023. An additional 1,400 pressure vessels will be installed for Phase 1, which will produce 30 mgd. Phases 2 and 3 in the Central Area and South Bay of San Diego are designed to provide another 53 mgd by 2035, which will also require pressure vessels for their RO step; the actual quantity, though, has not yet been determined.

In addition, San Diego's East County has announced that it expects to generate up to 11.5 mgd of new drinking water through its Advanced Water Purification Program. While still being planned, this system is designed to provide 30% of current drinking water demands for residents in the Padre Dam and Helix service areas. Four advanced water purification steps will produce water that is near-distilled in quality. Purified water will then be blended with water in Lake Jennings and treated at the R.M. Levy Water Treatment Plant before being distributed as drinking water.

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Meanwhile, in Los Angeles...

Southern California's sprawling Los Angeles County also has invested in wastewater recycling. The West Basin Municipal Water District (WBMWD, Carson, Calif.) has 1,238 fiberglass pressure vessels, nearly all rated at 450 psi, for RO processing at recycling facilities in El Segundo, Torrance and Carson. The District recycles municipal wastewater using RO for boiler feed water, for groundwater recharge and the seawater barrier.

The recycled product water West Basin produces for groundwater recharge meets drinking water standards and is delivered to the Water Replenishment District (WRD, Lakewood). WRD manages and protects local groundwater for 4 million residents over a 420-square-mile region of southern Los Angeles County and is the largest groundwater agency in California. The 43 cities in its service area use ~225 mgd (~82 billion gallons/year), accounting for about half of the region's water supply. WRD was said to be on track to becoming completely independent from imported water by the end of 2019.

LA Sanitation (Los Angeles), for its part, operates four water reclamation plants that serve more than 4 million people over 600 square miles. The *Los Angeles Times* reported in February 2019 that Mayor Eric Garcetti has vowed that Los Angeles will recycle all of its wastewater by 2035 through its Hyperion Water Reclamation Plant. The proposed water project could cost $8 billion, take 16 years to complete and provide as much as one-third of the city's supply. CW

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Plant Tour: Holland Composites, Lelystad, Netherlands

Balancing performance with affordable production, this industry veteran continues to explore composites' infinite possibilities.

By Ginger Gardiner / Senior Editor

» Located in a 4,500-square-meter building, less than an hour's drive from Amsterdam, Holland Composites (Lelystad, Netherlands) focuses on four markets: marine/offshore, architecture, renewable energy and special projects. Holland Composites uses a mix of prepreg carbon fiber-reinforced polymer (CFRP) and Nomex honeycomb for highly loaded parts, and resin infusion and glass fiber for the building industry and lower-margin projects. "We are still able to pull off high performance even with these more cost-effective constructions, and we maintain low overhead for the parts using advanced materials," says Sven Erik Janssen, Holland Composites' co-managing partner, along with founder Pieterjan Dwarshuis. "This is unique."

Foiling catamarans, building facades and more

Located less than an hour's drive from Amsterdam, Holland Composites pursues a wide variety of highly technical projects in its 4,500-square-meter facility.

Source, all images | Holland Composites

The company also operates the brand DNA Performance Sailing, producing foiling multihull sailboats, including the 5.5-meter F1X catamaran, the 11-meter TF10 trimaran and 14-meter F4 catamaran. The 12-meter G4 catamaran is no longer in production, "but it showcases our capabilities for advanced composite yacht building and high performance," notes Janssen. "This boat is a dual-purpose foiling racer and family cruiser with berths, kitchen and head, yet achieves a speed of more than 35 knots. The ability to foil with more than 4,000 kilograms in weight and only a six-person crew — there is still no competition in this field short of multi-million-dollar America's Cups yachts."

FIG. 1 OOA-cured structures

Large carbon composite structures for its DNA Performance Sailing brand of foiling multihull sailboats are cured in flexible ovens (left) comprising insulated panels with heating and air circulation computer-controlled from an exterior unit (below).

Marine to road and air transport

Before the tour begins, Janssen gives a history of the company and the composite structures it produces. Holland Composites was formed in 1992 by Janssen and Dwarshuis, who were, at the time, students at the Technical University in Delft (TU Delft, Netherlands). They built carbon fiber masts for Hobie sailing catamarans, an 18-meter yacht tender using CFRP and Nomex honeycomb in 1993, and a 100-foot sailing yacht using resin infusion processing in 1994. "By that time, everything we were building was made from carbon fiber using prepreg or infusion," recalls Janssen. However, he adds, because the business was subject to the typical ups and downs of the marine market and one-off projects, "we looked to diversify, but wanted to stay in advanced composites versus FRP [meaning less advanced, more commodity glass fiber and polyester resin]."

The company began exploring lightweight solutions for road transport, producing 35 truck trailers featuring a glass/carbon fiber composite monocoque chassis, which cut weight by 3,500 kilograms. "The trucks were carrying dense loads, like potatoes, and would max out in weight before filling their volume," Janssen explains. Holland Composites also made refrigerated trailers, he adds, "But we were a bit too early; the market was not yet ready."

At about the same time, VRR (Rotterdam, Netherlands), a supplier of custom air cargo solutions, approached the company. "They were doing work for Airbus, Boeing and the airlines," recalls Janssen. "We developed a featherweight container with a carbon/aramid fiber composite monocoque, which is still not matched in low weight today," he says. Though Holland Composites made a few thousand of these, the market quickly became saturated with low-cost FRP products.

Marine remains a core strength

In 1999, the Dutch Navy approached Holland Composites to produce solid glass fiber composite sonar domes for submarines. "These were traditionally built in two halves, which were bonded together," says Janssen, "but the seam causes a disruption in the field of 'view.' We were asked to build these in one piece. These sonar domes are large — 11.5 by 3 by 3 meters, and 45 to 110 millimeters thick — and difficult to infuse, comprising 5,000 kilograms of vinyl ester/epoxy hybrid resin supplied by Romar-Voss Composites (Roggel, Netherlands). The finished structure weighs 6,500 kilograms. They must be rigid and resist slamming loads because they are located at the forward section of the hull. "We also have to match the density and sonar transparency of water," says Janssen. "We do this for destroyer-type vessels for quite a few naval forces around the world."

At the other end of the weight spectrum are the DNA performance foiling multihulls. "Our small boats were the first foiling » catamarans in competition," says Janssen. Holland Composites also produces the composite hydrofoils for record-setting racing yachts like *MOD70's Team ARGO* and *Beau Geste*. "We have a technique in-house that can create really highly loaded parts without failure, and a unique one-shot production method for these very high-performance foils," he adds. "We work with the best sailors in the world to reach the next level of foiling performance and produce all of the foils for the NACMA17 Olympic class boats."

The lightweight CFRP deckhouse that Holland Composites produces for Windcat Workboats wind farm service/support vessels (see Learn More) uses resin-infused CFRP foam sandwich construction for stiffness to achieve a large, open span without pillars inside the cabin. "The monocoque deckhouse is lightweight enough that we can put it on good dampeners to isolate [it] from engine and wave vibration in the hull," says Janssen. "Windcat is known for its really quiet ride, and the boats are well-liked by the large wind turbine OEMs. All of these wind farms must be maintained, so there is a new market for high-speed catamarans of 50 to 60 feet in length."

Entry into architecture

In the early 2000s, facing a shortage in university student housing — with 3-4-year waiting lists — the Dutch government began a search for alternative solutions. "We had developed a composite capsule for another customer and thought if we enlarged it to be a standalone living unit, we could stack these and provide a solution," says Janssen. This became the Space Box, a 6-meter-long by 3-meter-wide by 3-meter-high modular building unit that was an instant success.

"Delft University of Technology initially trialed 125 units," says Janssen. "They were a funky shape, and we made them in bright colors. They were also very energy efficient." Holland Composites sold 2,000 units but quickly found itself in new territory: "We didn't know anything about the building industry," he says, "but we had to arrange the electricity, sewer — the whole bit. All of a sudden, we were the main contractor."

Gaining notice from architects, Holland Composites was chosen in 2004 to work on the Life Sciences building for the University of Groningen (Groningen, Netherlands). The nine-story building reportedly used the first structural composite facade of its size, covering 9,220 square meters. "The original design was very heavy, but we were able to save weight," notes Janssen. "Also, there were instrumented labs that faced south, so thermal insulation was an issue. If you build in big panels, you can reduce thermal leakage, but you need greater stiffness and load-carrying capability, which composites can provide."

Holland Composites made the 3.6-by-3.3-meter by 200-millimeter-thick curtain wall facade panels using glass fiber-reinforced polyester hybrid resin and foam core. Janssen contends that "when using a metal frame plus cladding construction approach, you can never really hit the R-value [thermal resistance] theoretically possible. But with cored composites, which integrate the structural frame and cladding into a single panel, we not only hit that theoretical value but exceeded it."

Holland Composites also succeeded in aesthetics, matching the building's theme and

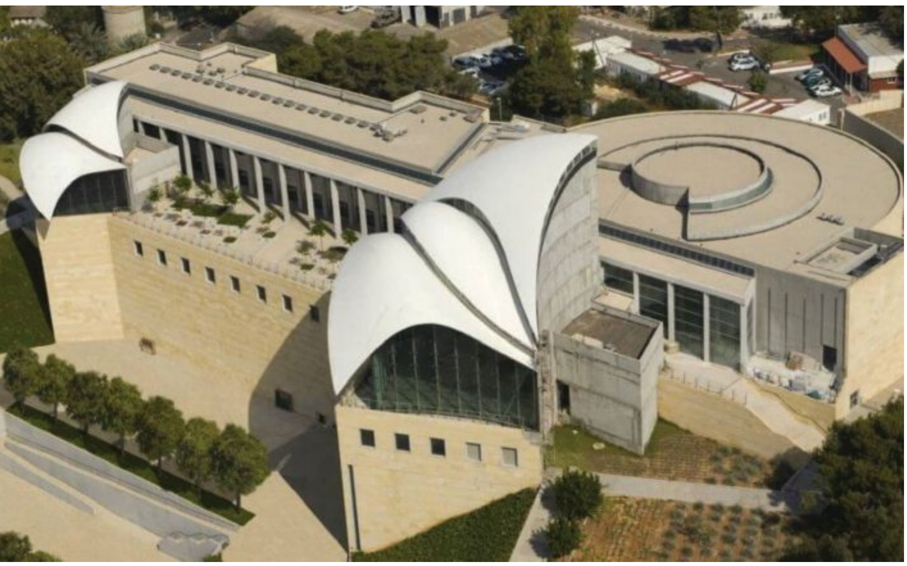

FIG. 2 Highly technical architecture

The Yitzak Rabin Centre (above) and Fletcher Hotel (below) are examples of the challenges Holland Composites pursues, providing lightweight and durable solutions that enable architects' designs without blowing the budget.

natural setting with its translucent RAFICLAD composite panels, which feature glass fiber reinforcement in a plant-like, fibrous form. Being translucent, these green-tinted bio-inspired exteriors allowed light to transmit into the building's interior. RAFICLAD is also used to produce photoprint facades and unusual designs, highly valued by architects and their clients (see images of this and more in the online version of the article, **short.compositesworld.com/Tour_HComp**).

"Everything we do is structural"

For the Yitzak Rabin Centre (Tel Aviv, Israel), the company was asked to build wing-like roof structures that would be too heavy if made from concrete (see Fig. 2, opposite). "Again, we made the largest sections possible," says Janssen. The company resin infused 75 40-by-60-meter sections using glass fiber and epoxy-based vinyl ester resin, and then shipped them to Israel. On site, these were laid upside down into jigs in order to laminate them together into "wing roofs" with a maximum span of 31 meters. Janssen notes that the project was very challenging structurally. "These panels are 200 to 300 millimeters thick and hold the glass facade together, including an 11-meter cantilever section. The composite material can withstand all of the forces, giving you the possibility to design such free-hanging roof spans."

The Fletcher Hotel tower is another such project, completed in 2012-2013 (Fig. 2, opposite). It began as a shopping mall next to a highway but required substantial acoustic attenuation in the structure after the decision was made to convert the building to a high-end hotel. "The concrete skeleton could not cope with much additional load, so we were called to provide a lightweight solution," says Janssen. Holland Composites devised 8.5-by-3-meter composite panels to which the plate glass facade could be fastened. "The glass actually hangs onto our panels, which helps to handle the load," he points out. "We then fastened our panels to the concrete skeleton. This combination of the glass in front of the composite sandwich panels with the airgap in between creates an enormous acoustic barrier." Each composite panel was paint-ready for interior walls on one side and finished with UV-resistant coatings on the glass-facing, exterior side.

"This was also a very fast way to mount cladding to a round-shaped building," says Janssen. "We mounted the complete facade in one step and achieved an insulation R value of 8, which is twice the rating of normal building exterior materials." Expanding on this idea, Janssen says he believes energy neutrality is critical to future building construction. "Not much energy is needed to heat the buildings that use our structural composite cladding, so our approach is very efficient to achieve a net-zero footprint. BREEAM »

FIG. 3 Tidal turbine blades

Holland Composites builds blades for tidal turbine generators using carbon fiber prepreg, cured in an autoclave, to handle the large loads placed on these low-speed, high-torque structures.

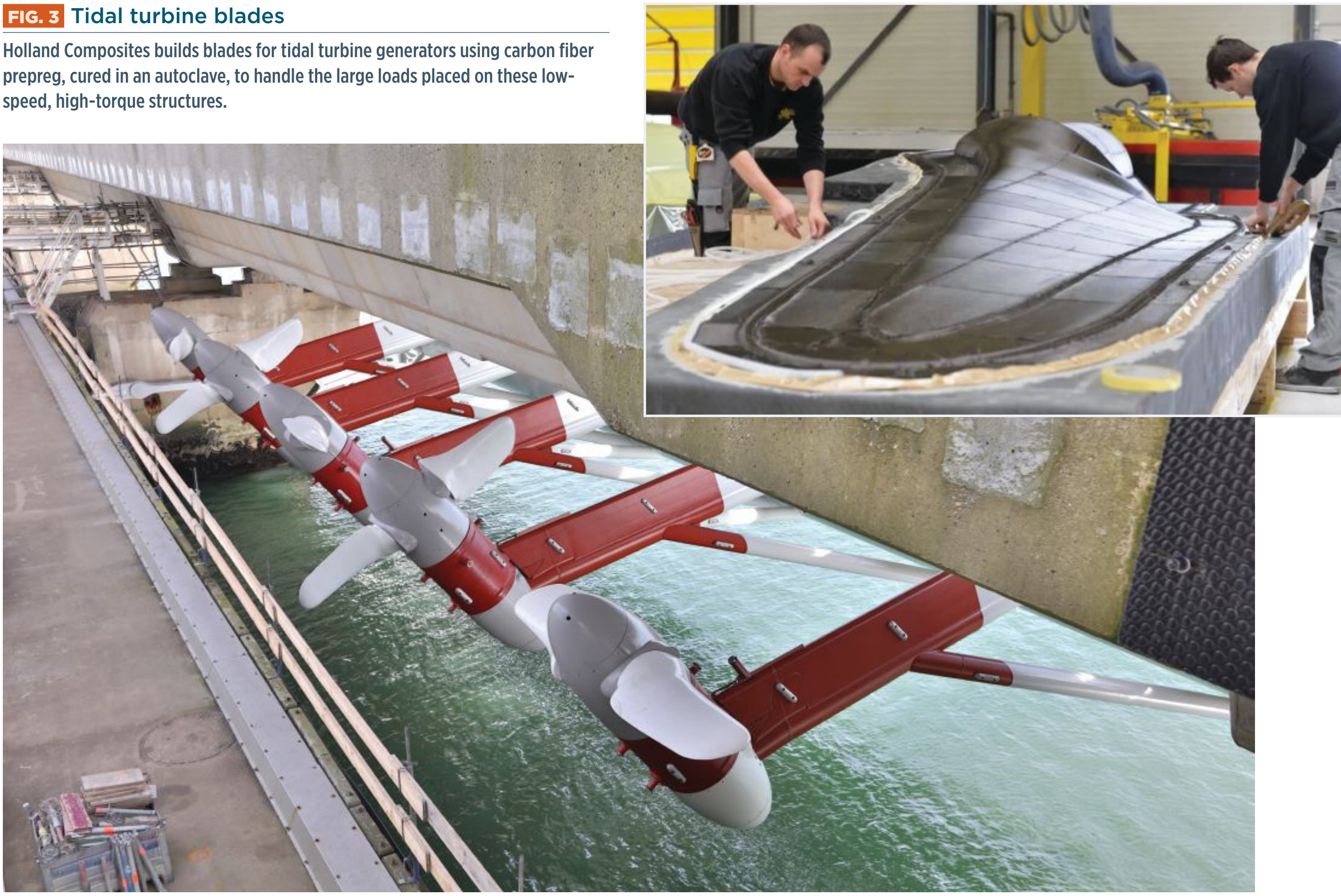

FIG. 4 Increasing automation

The Zünd automated cutter in the foreground supplies cut reinforcements and foam to the layup area, which can be seen in the back, at right, with the materials storage on the mezzanine above. The enclosed tooling area lies behind the yellow roll-up door, seen here behind the side of the CMS machining center, which is next to the Zünd cutting table.

is the Dutch certification for energy efficiency, and the first two buildings that achieved this use our composites."

Janssen singles out the Stedelijk Museum of contemporary art in downtown Amsterdam as the pinnacle of Holland Composites' technical building projects (see Learn More). "It was an extreme exercise in managing thermal expansion and illustrates what we do." Holland Composites has also pioneered earthquake-proof structural facades, which are now required in certain parts of the Netherlands, Janssen explains, because the soil has been destabilized due to hydraulic fracturing (fracking). The Wiebenga building in Groningen features an earthquake-proof facade that can move 30 centimeters without failure. "Typical steel and concrete cannot handle this type of movement," he adds.

> "For what we do in composites, we see many opportunities in the future."

Though balancing the myriad requirements with cost and schedule is a challenge when building structures, Janssen notes the largest issue currently is fire resistance. "Wrong implementations of composites have brought the composites industry a bad name in this regard," he explains. "We now use only fire-resistant materials on these building projects and complete fire testing per approved regulations."

Offshore and renewable energy

Holland Composites also has long-term contracts in the offshore oil and gas industry. "Composites here offer not just light weight and corrosion resistance, but also easy repair," says Janssen. "Offshore rigs and vessels are not allowed downtime. However, repair to metal structures requires welding and sparks, so production has to be stopped due to fire hazard. We can patch composites without this disruption." The company has new clients requesting such products for a variety of offshore constructions.

Holland also has manufactured blades for tidal turbines (see Fig. 3, p. 29). The harvesting of tidal energy is still new, says Janssen, but the first projects have been completed and the results are impressive. "Tidal turbines offer a reliable energy source," he explains. "The tides are always there, compared to wind and solar, so you can reliably predict the power output, which is key for power companies." Holland Composites uses autoclave-cured carbon fiber prepreg for these blades because the loads are enormous. "The blades move at low speed but with high torque," says Janssen. "You want the maximum translation of rotor speed into the motor to produce power, so the turbine manufacturers need strong but efficient structures that are shaped to get as much energy as possible out of tidal movements."

Each turbine has two 3-meter-long blades that are 18 millimeters thick. There are five turbines per tidal generator. "The load on these turbine blades is described as equal to a 13,600-horsepower tugboat going forward in full power," says Janssen, "but the customer also needs blades that are stiff, lightweight and low-maintenance with good fatigue resistance for durability. Steel would have been too heavy, making the generators less efficient." Holland Composites makes only the blades; fairings, nose cone and non-structural cladding are made by other fabricators.

Future-oriented facility

The tour begins in the layup area, which features a large layup table, parts for the DNA performance sailboats and a variety of CFRP foils being readied for installation. The ceiling is low here because of a mezzanine for materials storage. This opens onto a high-ceilinged

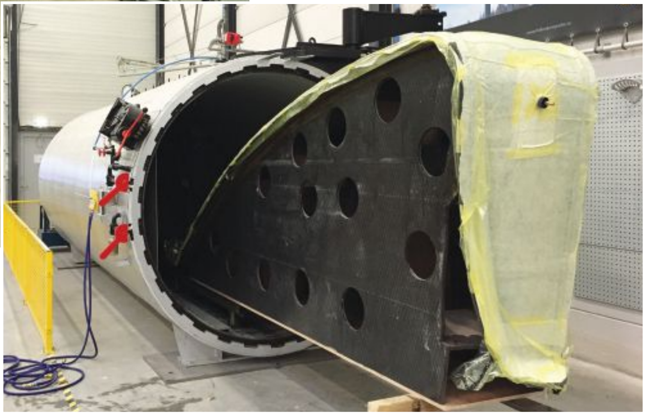

FIG. 5 **Full process chain**

The CMS machining center is situated between the cutting table (out of view, at left) and the autoclave (far right in image at left). The autoclave is also seen below with a CFRP tool (note holes for air ventilation) and large CFRP foil being cured under vacuum bag for a high-performance multihull sailboat.

production floor, featuring a Zünd (Altstätten, Switzerland) automated cutting machine just beyond the layup area (see Fig. 4). The cutter has a 5.7-by-2.8-by-0.3-meter cutting range to process prepreg, dry fiber and foam materials up to 25 millimeters thick.

Turning around from the Zünd cutter, we walk to a glass-enclosed tooling room that abuts the layup area. Entering through a yellow roll-up door, there are multiple tools in process and parts are being cured under vacuum bags. "We make our own molds," says Janssen. "For CFRP parts, we use CFRP or aluminum for the tooling, as well as ventilation holes for air circulation within the tools, which helps to ensure even curing across the part."

Coming back out of the tooling room, we pass the 5-by-2-by-1.8-meter 5-axis CNC milling center (CMS SpA, Zogno, Italy) and can see the 6.5-by-2.2-meter autoclave (Tankbouw Rootselaar, Nijkerk, Netherlands). "We typically cure at 125°C with a pressure of 6 bar," Janssen notes (see Fig. 5).

The wall beside the autoclave cuts the production area into two halves, running the length of the building along the tooling room. We turn around and pass through a door to the second half of the Holland Composites facility, which contains a waterjet cutting machine (8-by-2-by-0.5-meter cutting range), several ovens sized up to 15-by-10-by-3.5 meters, and the company's 19-by-12-by-3.5-meter paint booth. "Currently, we are producing large panels for a project in Qatar and a series of CFRP deckhouses for the Windcat boats," says Janssen.

LEARN MORE

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

Read more about the Stedelijk Museum project | short.compositesworld.com/Stedelijk

Read more about CFRP deckhouses for Windcat | short.compositesworld.com/Windcat

Holland Composites' latest installation is a Massivit 3D (Lod, Israel) 1800 Pro printer with a build volume of 145 by 111 by 180 centimeters. "We are partners innovating 3D printing of molds using three printheads, where two are printing the skins of a sandwich and the center nozzle prints the infill or lattice structure in between," Janssen explains. "We will use fiber-reinforced material in future developments, but for now, we can print accurate tooling with minimal milling needed. We use much less material and see very fast mold production times. We now have a complete process chain, with the ability to go from design to molds to painted parts in a short time period."

He notes that the company is still exploring how to increase its use of automation to further advance its products, but without driving up cost. "It comes down to ingenuity. We are drawn to highly complex problems that few others dare to tackle, but as boatbuilders, we have always had to be very creative with limited resources. For what we do in composites, we see many opportunities in the future." CW

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Overmolded hybrid parts open new composites markets

A process that combines continuous carbon fiber-reinforced PAEK with chopped fiber/PEEK overmolding is making inroads in the aerospace market. Parts that previously could not be produced cost-effectively from composites can now be made at *less* cost than their metal counterparts.

By Karen Mason / Contributing Writer

Complexity and strength

Components like the B bracket for aircraft storage bins exhibit both high complexity and a requirement for high strength — a combination for which the hybrid overmolding technique is especially suited. Source, all images | TxV Aero Composites

» Often in the aerospace market, an OEM is willing to pay more for a composite component, knowing that the investment will return dividends in fuel savings due to the component's light weight, a longer life due to less wear and tear, or other reductions in operational and maintenance costs. This "product lifecycle" view has opened many markets and applications to composites. More unusual is a composite component for which the acquisition cost itself is less than that of the metal version. But this is changing. Some new automated composites fabrication processes are starting to tip the scale in favor of composites, and among these is a hybrid overmolding process developed by TxV Aero Composites (Bristol, R.I., U.S.).

A joint venture of Tri-Mack Plastics Manufacturing (Bristol, R.I., U.S.) and Victrex (Thornton Cleveleys, U.K.), TxV has advanced its hybrid overmolding technique to the point of commercial production status. The company has partnered with SFS intec Aircraft Components (Althengstett, Germany) to redesign and commercially produce an aircraft storage bin bracket previously made from aerospace-grade aluminum. A success story of its own, the bracket also demonstrates the potential of hybrid overmolding and VICTREX AE 250 unidirectional carbon fiber/polyaryletherketone (PAEK) tape for valuable weight and cost savings in numerous aerospace applications — advantages achieved by replacing a subtractive metal machining process with a composites process in which material is added, not subtracted.

From subtraction to addition

Machinists and machine shops that produce metal components on CNC machines have nicknamed themselves "chipmakers," for the obvious reason that their processes cut away unneeded material from metal blanks to make components, creating scrap metal chips. These chips represent a costly aspect of metal machining, whether they are disposed of, sent to a recycler, or reprocessed in-house. In the case of SFS intec's overhead storage bin bracket, 60 to 70% of the aluminum becomes scrap during the several milling steps required to machine it.

This high scrap rate renders the raw material cost for a net-shape or near-net-shape composite version of the bracket potentially lower than the metal material cost. "We can compete against less expensive (per pound) aluminum because of the chips; if the buy-to-fly ratio is 8:1, most of the aluminum purchased becomes scrap," notes Jonathan Sourkes, TxV senior accounts manager. "Another factor is the time each component spends being milled. We can make [composite] parts in minutes, not hours."

Beyond raw material costs, composite versions of components like the bracket — featuring a complex geometry and requiring high load-bearing performance — have not been economically feasible using historically available manufacturing options. On the one hand, if the components were made with low-cost, chopped fiber reinforcement in a high-speed, low-touch process like injection molding, the component would not achieve sufficient load-bearing performance. On the other hand, if it were made with higher load-bearing, continuous fiber reinforcement via a low-speed, high-touch process, typically involving some manual layup, production would be too slow and/or impose manufacturing costs that would make the end product too expensive.

Because of these roadblocks to new composites applications of this type, the composites industry as a whole has devoted significant resources to developing automated processes that can produce such components at suitably high production rates and with sufficient load-bearing capability to meet aerospace customer needs and specifications. With an eye toward commercial production of such composite components, TxV came into being in 2017 specifically to accelerate the commercial adoption of innovative manufacturing processes for polyketone-based composite applications throughout the aerospace industry.

TxV's overmolded hybrid solution incorporates two key advancements to the state of the art in composite component fabrication. First, it automates the production of those parts of the component that require the strength or stiffness of continuous fiber reinforcement. Second, it leverages the speed of injection molding to complete the component's complex geometries. More specifically, it produces a tailored laminate to handle loads, which is then overmolded to functionalize and create final part geometries. The hybrid technique, according to Sascha Costabel, head of innovation at SFS intec Aircraft Components, "is a good option for components that must withstand high levels of mechanical stress and geometries that require multiple processing steps where conventional machining is used."

Partnering with SFS intec has been a great choice, Sourkes says. "As a global leader in system attachments, SFS is always doing something really interesting. They are very innovative and willing to invest in new technologies," he notes. SFS intec also has a strong relationship with its aircraft customers, he adds, and they possess the capability to perform qualification processes — key to aerospace industry adoption of a redesigned component.

The aircraft storage bin bracket, specifically referred to as a "B bracket," was chosen as the first attachment component for composites redesign because it is representative of components that are challenging to design and produce. Following collaborative engineering, part conceptualization and design, and modeling of performance via an Altair (Troy, Mich., U.S.) finite element analysis (FEA) tool, the project team iterated from the first article to validate, test and prove out the model. Design for manufacture was central to the development of the composite bracket, which leverages the manufacturing advantages of automated tape laying for the continuous fiber-reinforced elements and high-speed injection molding for the chopped fiber-reinforced elements.

Virtual prototyping

Using proprietary data developed to characterize the relationship between the laminate and overmold, TxV iterated the layups and ply orientations without having to manufacture and test a physical prototype. Iterations continue until the visible stresses, as depicted here, are within the range of load cases provided.

Building B brackets

One key aspect of the hybrid overmolding process is the use of distinct polymers of the same class. PAEK serves as the matrix resin for the continuous fiber composite portions of the bracket, while polyetheretherketone (PEEK) is used in the overmolded areas. VICTREX PAEK and PEEK boast superior fatigue, chemical and corrosion resistance; excellent smoke, flame and toxicity resistance; rapid formability; and weldability. VICTREX AE 250, a lower-melting PAEK (LM PAEK), offers a melt temperature 40 degrees C lower than PEEK's. "When molten PEEK flows over the surface of the LM PAEK composite, the lower melting temperature allows for a strong attachment," Sourkes explains.

Specific raw materials for the B bracket are VICTREX AE 250 unidirectional carbon fiber-reinforced PAEK tape (58% carbon fiber) in widths of two inches; and short carbon fiber-filled VICTREX PEEK 150CA30 (30% carbon fiber). These materials feed the hybrid overmolding production work cells, which create the »

1 A Dieffenbacher Fiberforge 2000 automated tape laying system (bottom) produces tailored laminate blanks (top).

2 Tailored blanks are consolidated in an automated bespoke consolidation cell, which features two sets of platens that are kept at temperature (one hot, one cold) to speed this step.

brackets through the following multi-step process.

First, the carbon fiber/PAEK tapes are laid down in a tailored blank using a Dieffenbacher (Eppingen, Germany) Fiberforge 2000 tape laying system (Step 1, above). “This machine is currently one of the fastest tape-laying systems in the world,” Sourkes attests. It is outfitted with robots to load and reload tape spools, so that it can run uninterrupted, minimizing manual touch time. Layup is designed so that gaps between tapes are minimized. Each ply of the B bracket tailored blank is inspected before the next ply is laid down. The process is performed in an environmentally controlled area to minimize the potential for foreign objects and debris (FOD).

The tailored blanks are then consolidated in an automated bespoke cell that requires minimal manual handling to load and unload the laminates (Step 2). In the cell, matched heated platens press-consolidate a panel, eliminating voids. Matched cold platens then cool the panel. The two sets of platens, kept at temperature, are much more efficient than a static press with one set of platens. “The result is a drastically reduced cycle time measured in minutes versus hours,” Sourkes says.

The consolidated laminate preforms are then further processed in a proprietary work cell to form the primary shape of the bracket (Step 3). The final carbon fiber/PAEK inserts are then cut from the formed blanks using a Flow International (Kent, Wash., U.S.) waterjet cutter (Step 4).

In determining the size of the tailored blank, Sourkes points out that a tradeoff must be deliberated for each project. “We can size the laminate so that we can zip out three or four rectangles from a single square blank. By laying up as large a blank as you can, then cutting it into preforms, you maximize the buy-to-fly ratio; but cutting the preforms means more time for waterjet cutting operations.” In the B bracket project, each consolidated laminate is cut into multiple preforms.

Next is the overmolding step, which is performed with an Engel (Schwertberg, Austria) high-temperature injection molding machine (Step 5). The inserts are placed in an injection molding cavity that is filled with molten PEEK, which melts the top layer of

3 A proprietary work cell forms the primary shape of the bracket.

5 An Engel injection molding machine optimized for PEEK hybrid overmolding completes the composite part by overmolding the inserts.

4 A Flow International waterjet cutter cuts the carbon fiber/PAEK inserts from the formed blanks. Two of these inserts are used in each bracket.

6 The final B bracket, produced with a cycle time of just 3 minutes, has a buy-to-fly ratio of 1.06:1 and offers weight savings of 30 to 40%.

the VICTREX AE 250 laminates to create a strong melt-bonded component.

When required, a component is finished via machining to net shape. "While it is our aim to mold near-net parts," Sourkes admits, "oftentimes some minimal level of machining is required after the fact to clean up process geometry." Machining may be performed with a waterjet or CNC machines.

Groundbreaking results

In manufacturing the bracket, the TxV hybrid overmolding process achieves cycle times of three minutes, and a buy-to-fly ratio of 1.06:1 (Step 6). "It is the efficient use of materials and rapid manufacturing process that allows us to produce value-added thermoplastic composite parts, and that makes possible the system cost reductions over the incumbent metal designs," Sourkes emphasizes. "Effectively we are replacing a lower-cost raw material with a high buy-to-fly ratio and significant processing time with a highly engineered material solution." The result is weight savings in the 30 to 40% range and cost savings in the 20 to 30% range in a like replacement — that is, a replacement part that follows the same geometric and operational specifications as the existing component. "Weight savings in particular can be as great as 60% when we are afforded the opportunity to completely redesign a part system," he notes.

The carbon fiber/PAEK/PEEK bracket has also consolidated part count: TxV and SFS agreed to injection overmold a spreader nose onto the bottom of the part in the same operation used to functionalize and add other features. Previously, the spreader nose was made from PEEK and then held in place by two rivets. Thus, the consolidation results both in a reduced part count and in the elimination of an assembly step.

Expertise from the two companies that launched TxV undoubtedly has enabled the success of hybrid overmolding. Sourkes explains that, after developing the PAEK material and processing technology, Victrex first explored opportunities with existing business partners. "However, companies with injection molding » expertise didn't have the expertise to work with continuous fiber-reinforced composites, and vice versa." Victrex and Tri-Mack partnered for several years before forming TxV in 2017 and building the venture's purpose-built polyketone composite center of excellence, which is highly automated and designed for high-rate serial production.

Asked to compare the TxV process and results with a conventional manufacturing approach, Sourkes notes that the B bracket is not amenable to standard approaches: "This would be very challenging without machining the bracket from a composite billet — which would be cost-prohibitive."

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Qualify then fly

Taking advantage of SFS intec's ability to run qualification, the two companies have proceeded with certification through "point design," which means that only this particular part geometry gains flight approval. Parts were produced and subject to the tests laid out in the qualification document. "Given the part is an overhead bin bracket, the operational loads are fairly easily achieved," Sourkes notes. "However, the performance requirements go beyond those typical loads and must cover some extreme takeoff and landing maneuvers." As *CW* goes to press, the qualification package has been submitted and is awaiting final signoff from the specification custodian. TxV and SFS intec expect the part to be flying early in 2020.

Once the B bracket is qualified, TxV will scale to production volumes. While the company is using its existing hybrid overmolding line to produce these brackets, Sourkes emphasizes that the company has a dual mandate — both to make parts with the technology and to support industry manufacturers interested in adopting the technology themselves. In other words, composites manufacturers may adopt this technique in their own facilities.

Composite brackets like the SFS intec product have the potential to take over a fairly large market for these kinds of components. Commercial aircraft use thousands of brackets and system attachments, accounting for significant cost and weight contributions to the overall aircraft. "We are convinced that thermoplastic composite components will play an increasingly larger role in the manufacture of aircraft," Costabel anticipates. CW

ABOUT THE AUTHOR

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Tech Table: Aerospace structural adhesives

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

The bonding of aerostructures is becoming increasingly important as airframers seek solutions for next-generation aircraft that enable increased lightweighting. The ability to assemble and unitize structures and minimize use of mechanical fasteners is critical to efficient, high-rate commercial aircraft manufacturing. That said, bond application control and bond quality assurance are still maturing, and thus have not yet supplanted mechanical fasteners in aircraft assembly.

Still, manufacturers have brought to market a wide array of adhesives designed to mate structures of all types of materials, including metal and composite laminates and honeycomb cores. This is the first of a series of Tech Tables that *CW* will publish in 2020, each designed to provide as comprehensive a list as possible of suppliers, their products and selected product specifications.

This table of aerospace structural adhesives, which includes film and paste adhesives, was built with data provided by suppliers. It should be noted that not all of the same data were provided for each adhesive by each supplier. Further, each supplier conducts different tests to characterize the adhesive; one test, however, was conducted more than others, and that is the single lap shear test, also known as ASTM D 1002. Based on data *CW* received, most of the single lap shear strength data were derived from tests with metallic adherends, or the adherend was not specified at all. A minority of single lap shear strength data were derived from tests with composite adherends.

Look for two more Tech Tables in 2020: Mold release agents (July) and compression molding machines (December). CW

TECH TABLE: ADHESIVES

Supplier	Product	Format	Type	Areal weight(s), gsm (film only)	Cure temperature, °C	Cure time	Glass transition temperature (Tg), °C	Service temperature, dry, °C	Single lap shear strength, RT, Mpa*
3M	Scotch-Weld AF 143-2	Film		463-537	177	1 hour		-55 to 177	
	Scotch-Weld AF 502	Film		294	121	1-2 hours	118		
Barrday	FA EP255SP	Film	Epoxy	293	113, 135	1-2 hours			
	FA EP259	Film	Epoxy		113, 135	1-1.5 hours			
Click Bond	CB200	Paste	Acrylic		RT	24 hours		-55 to 121	30.3
	CB359	Paste	Epoxy		RT-82	1 hour-7 days		-55 to 93	31.0
	CB394	Paste	Epoxy		RT-65	1 hour-5 days		-55 to 177	30.0
	CB420	Paste	Acrylic		RT	24 hours		-54 to 121	21.0
Henkel	Loctite EA 7000 AERO	Film	Epoxy	146-391	121, 177	1-2 hours	145	150	28.0*
	Loctite EA 9309.3NA AERO	Paste	Epoxy		RT, 82	1 hour-5 days	61, 81		32.8, 34.5
	Loctite EA 9377 AERO	Paste	Epoxy		RT, 82	1 hour-7 days	67		36.9
	Loctite EA 9380.05 AERO	Paste	Epoxy		82-104	2 hours	106	121	35.0
	Loctite EA 9394 AERO	Paste	Epoxy		25, 66, 93	1 hour-5 days	78	177	28.9
	Loctite EA 9394.2 AERO	Paste	Epoxy		25	24 hours	70	121	33.9
	Loctite EA 9396.6MD AERO	Paste	Epoxy		25, 82, 93	1 hour-7 days	64-112	149	18.6
	Loctite EA 9658 AERO	Film	Epoxy	290-490	177	1 hour	200	177	35.9, 36.5
	Loctite EA 9686 AERO	Film	Epoxy	146-415	121, 177	1-1.5 hours	121-124	-55 to 149	40.7, 43.0
	Loctite EA 9695 AERO	Film	Epoxy	171-244	121, 177	1-1.5 hours	122, 150	149	31.7, 34.5
	Loctite EA 9696 AERO	Film	Epoxy		107, 129	1-1.5 hours	123	121	34.8-42.0

TECH TABLE: ADHESIVES (continued)									
Supplier	Product	Format	Type	Areal weight(s), gsm (film only)	Cure temperature, °C	Cure time	Glass transition temperature (Tg), °C	Service temperature, dry, °C	Single lap shear strength, RT, Mpa*
Henkel	Loctite EA 9814 AERO	Paste	Epoxy		127, 177	1-1.5 hours		177	
	Loctite EA 9820 AERO	Paste	Epoxy		121, 177	1-1.5 hours		177	
	Loctite EA 9824 AERO	Paste	Epoxy		127, 177				
	Loctite EF 562 AERO	Sheet	Epoxy		121, 177	1 hour	149	-55 to 177	
Hexcel	HexBond 200 Series	Sheet	Epoxy		121, 177	1 hour		-55 to 220	
	HexBond 308	Film	Epoxy	293	171	1 hour		121	46.9
	HexBond 319	Film	Epoxy	176-391	177	1-4 hours		-55 to 149	31-45
	HexBond 322	Film	Epoxy	244-381	177	1 hour		199	21, 22
	HexBond 340U(SP)	Film	Epoxy	50-150	175	1 hour		180	31, 32
	HexBond ST1150	Film	Epoxy	750-1500	120-180	1 hour			
	HexBond ST1480	Film	Epoxy	75-292	180	1.5-4 hours	180-193	-55 to 150	32.6, 33.8*
L&L Products	L-0010	Sheet			RT, 50		133		27.8-30.7
	L-9000	Sheet			121-177				
	L-9001	Sheet/ Beads			140	1 hour			
	L-9003	Sheet/ Beads			140	1 hour			
	L-9100 Series	Paste	Epoxy		15-30				
	L-9107	Paste	Epoxy		23, 65	15 min-5 days		-55 to 135	
	L-9115	Paste	Epoxy		15-30				
	L-9150	Paste	Epoxy		15-30				
Lord	LORD 403/406/410	Paste	Acrylic		RT, 66	24 hours		-40 to 149	13.3-20.7
Magnolia	Magnobond 6162 A/B	Paste	Epoxy		RT, 52, 82	1 hour-7 days			34.5
	Magnobond 6166 A/B	Paste	Epoxy		RT, 52, 82	1 hour-7 days	100		27.6
	Magnobond 6168 A/B	Paste	Epoxy		RT, 82, 121	1 hour-7 days			27.6
	Magnobond 6380 A/B	Paste	Epoxy		RT, 77, 104	1 hour-3 days			31
	Magnobond 6388-3 A/B	Paste	Epoxy		RT, 127	1 hour-7 days		-55 to 149	22
	Magnobond 6389 A/B	Paste	Epoxy		RT, 60	4 hours-5 days		-55 to 149	20.7
	Magnobond 6392-2 A/B	Paste	Epoxy		RT, 66, 121	1 hour-7 days			31
	Magnobond 6398 A/B	Paste	Epoxy		RT, 66, 122	1 hour-7 days			32.4
	Magnobond 6448 A/B	Paste	Epoxy		RT	8 hours			27.8
	Magnobond 7500 A/B	Paste	Epoxy		RT plus 93	20 hours			27.6
Renegade	RM 1005	Film	Polyimide	293-488	177	2 hours	327		17.2*
	RM 1010	Film	Polyimide	293-488	357	2 hours	371		19.3*
	RM 1014	Film	Polyimide	293-488	293	2 hours	316		20.0*
	RM 3006	Paste	Bismaleimide		227	12 hours		-54 to 204	13.8
	RM 3007	Paste	Bismaleimide		227	12 hours		-54 to 204	
	RM 3011	Film	Bismaleimide	293	232	13 hours	310	204	

TECH TABLE: ADHESIVES (continued)									
Supplier	Product	Format	Type	Areal weight(s), gsm (film only)	Cure temperature, °C	Cure time	Glass transition temperature (Tg), °C	Service temperature, dry, °C	Single lap shear strength, RT, Mpa*
Solvay	FM 209-1	Film	Epoxy	150-490	121, 177	1.5 hours	132	121	31.4, 34.7
	FM 300	Film	Epoxy	146-391	177	30 min	109	-55 to 149	29.8-40.3
	FM 300-2	Film	Epoxy	146-489	121, 149	1.5 hours		-55 to 149	14.8-30.0*
	FM 309-1	Film	Epoxy	146-391	177	1.5-2 hours	182	177	30.5-41.2
	FM 450-1	Film	Bismaleimide	147-488	191	4 hours		232	23.0
	FM 57	Film	Polyimide	293, 488	177	1.5 hours		-55 to 288	24.3*
	FM 73	Film	Epoxy	100-420	121	1 hour	76	-55 to 82	39.8-47.2
	METLBOND 1515-4M	Film	Epoxy	158-390	121, 177	2 hours	170	148	14.8-32.8
Toray	EF8020	Film	Epoxy	100, 300	70-120	.5-8 hours	116	121	27.0, 38.0
	EX-1516	Film	Cyanate ester		121		126		29.7
	EX-1543	Film	Cyanate ester	146	177-218		191, 236		16.8, 17.9
	MicroPly EF72	Film	Epoxy	100-300	120	1 hour	112		25, 32
	RS-15H	Film	Epoxy		80-93	6.5 hours	99		21.0
	RS-4A	Film	Cyanate ester		177		195, 238		28.3
	TC263	Film	Epoxy	70-293	121	2 hours	110-115	93	19.6-33.8
	TC310	Film	Epoxy	171, 293	121, 177	2-3 hours	157		31.1-37.1
	TC4015	Film	Cyanate ester	171-288	177, 232	2 hours	321	538	15.2, 17.9*

Composite material specified by supplier as adherend in single lap shear test

New Products

Source | Haydale

» PREPREG MATERIALS

Graphene-enhanced prepreg improves lightning strike protection

Haydale (Ammanford, U.K.) has developed a range of graphene-enhanced prepreg materials for lightning strike protection, using functionalized nanomaterials to improve the electrical conductivity. The material can be used for structural components or for enclosures for electronic avionics systems.

According to Haydale, the material also has potential applications for unmanned aerial vehicles (UAV), commercial aviation, space applications or offshore wind turbine blades.

The material has been developed in collaboration with Airbus UK (Bristol), BAE Systems (Farnborough, U.K.), GE Aviation (Evendale, Ohio, U.S.) and Element Materials Technology Warwick Ltd. (Warwick, U.K.), within the U.K.'s National Aerospace Technology Programme (NATEP)-supported GraCELs 2 project, where the first iterations of materials were developed and subjected to lightning strike tests. The consortium is now looking to manufacture a demonstrator component using the developed materials, to establish composite manufacturing protocols for commercial purposes.

An electrically conductive masterbatch is also commercially available, and the Haydale team has been working with customers to test its capability, reporting significantly better results compared to existing materials. **haydale.com**

Source | Toray Advanced Composites

» PREPREG MATERIALS

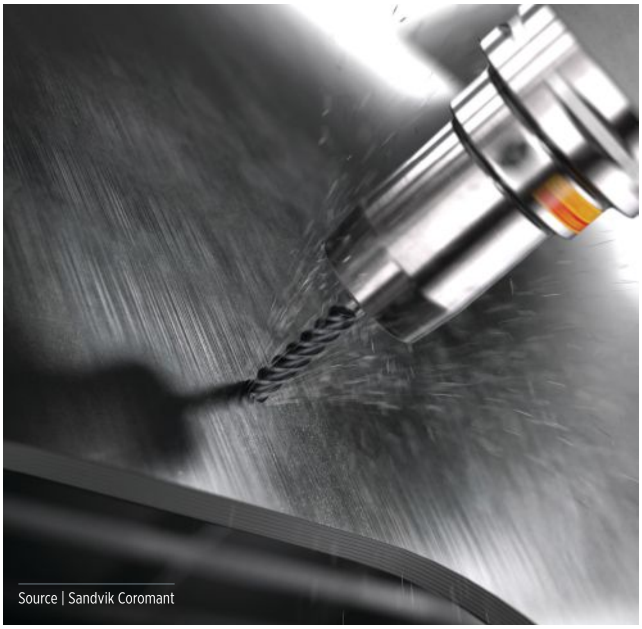
Structural resin system developed for high-end motorsports

Toray Advanced Composites' (Morgan Hill, Calif., U.S.) Toray TC346 is a new prepreg resin system engineered for the high-end automotive and motorsports market.

Toray Advanced Composites has provided high-performance structural and tooling materials to the high-end motorsports market for more than 30 years and says that its proprietary new TC346 resin system complements its existing portfolio of products. TC346 is said to be a new flagship structural composite material for applications that demand exceptional mechanical properties, while still being user-friendly and easy to process.

The Toray TC346 resin system reportedly has the highest combined T_g (>200°C) and high-temperature mechanical property retention available for the motorsports market. In addition, it is said to demonstrate best-in-class elevated temperature dry (ETD) mechanical properties, including compression strength, interlaminar shear strength and fracture toughness. It reportedly has a superior surface finish that is said to be suited for parts that need to be structurally tough but maintain an aesthetic appeal. The material's controlled flow system is said to simplify layup and cure processes for easy handling during production.

Additional features are said to include optimal out life and storage life, flexible cure cycles and good handling/tack/drape characteristics. TC346 can be manufactured as unidirectional tape or fabric in a variety of weights and fibers. **toraytac.com**


Source | Sandvik Coromant

» MACHINING ACCESSORIES

Solid carbide drill designed for aerospace composites

Cutting tool and tooling system specialist **Sandvik Coromant's** (Fair Lawn, N.J., U.S.) has introduced the CoroDrill 863 solid carbide drill with 863-A1-O geometry, designed to improve consistency and performance during hole-making operations on composite aerospace workpieces. The drill is said to extend tool life and achieve high hole integrity, and has been specifically designed to combat potential delamination issues caused by drilling. The substrate is based on a new grade, O1AD, which is said to improve wear resistance. A high axial rake angle is included for reduced delamination in unidirectional carbon fiber-reinforced plastic (CFRP).

According to Sandvik, tool life is improved significantly when using the CoroDrill 863 drill, with increases in material drilled, often measured in meters. As a result, fewer tool changes are needed.

Composite applications include aircraft frames, wingboxes, fuselage sections, stabilizers, floor beams and flaps. The assortment is available from 4xD to 5xD, in diameters from 3-10 mm (0.118-0.393"). **sandvik.coromant.com/us**

» ADDITIVE MANUFACTURING

Fixed-gantry options for large-scale additive manufacturing

Thermwood's (Dale, Ind., U.S.) LSAM MT, the latest model of its large-scale additive manufacturing (LSAM) machine, features a single fixed gantry mounted over a moving table (MT stands for "moving table"). Available with either a 10 × 5-ft. or a 10 × 10-ft. work station, this configuration is intended to provide a lower-priced option compared to dual-gantry/fixed-table LSAM systems.

According to Thermwood, the LSAM MT is a robust industrial production machine capable of reliable, day-in and day-out production. Both "Print and Trim" and "Print Only" versions of the system are available. Thermwood says the "Print Only" configuration was designed for companies that do not need to add machining capacity with their additive system.

The 10 × 10 machine includes a 10 × 12-ft. table with a 10 × 10-ft. working area. The extra 2 feet are used to mount an optional vertical layer print table, meaning the machine can make parts up to 10 ft. wide × 10 ft. deep × 5 ft. high using traditional horizontal layer printing, or 5 ft. wide × 10 ft. deep × 10 ft. high using vertical layer printing.

The print technology and print heads used on the MT are the same as used on the larger machines, enabling the same throughput, print quality and layer-to-layer fusion. As with the larger systems, the MT can process high-temperature polymers suitable for autoclave-capable tooling or compression molds.

Thermwood recommends its smaller, less expensive MT option for use with parts, regardless of size, made from bondable materials like reinforced thermoplastic composite materials for room- or low-temperature


Source | Thermwood

applications such as foundry patterns, boat plugs, boat and yacht molds, and building structures. According to Thermwood, it can be faster to print these types of parts in sections, which allows more time for each individual section and layer to cool, followed by bonding of the final part using industrial adhesives. The smaller MT machine can also accommodate smaller, high-temperature parts.

Thermwood recommends its larger MT machine for materials that cannot be bonded effectively — such as PSU, PESU, PEI and Ultem — that are either resistant to solvents or used at temperatures too high for adhesives to withstand and must therefore be printed in one piece. The larger machine configuration also enables printing and trimming the part at the same time. **thermwood.com**

MANUFACTURING SUPPLIERS

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ADVERTISING INDEX

Demand for longer sprayer boom arms enables composites in agricultural equipment

Shift from steel to carbon fiber/glass fiber composites extends sprayer boom arm width, reduces weight and enhances productivity.

By Peggy Malnati / Contributing Writer

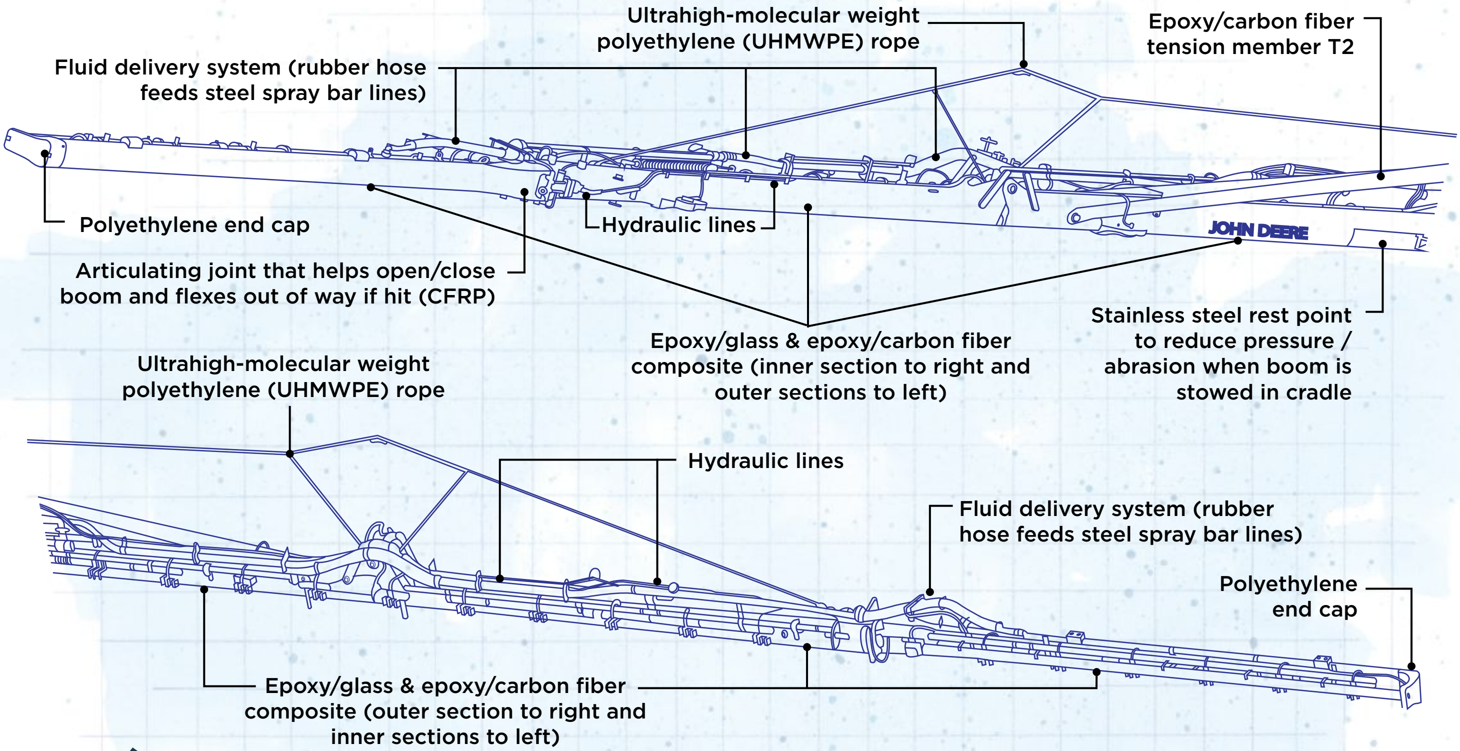
Meeting agricultural demand

Boom arms for self-propelled spraying equipment, used to apply liquid chemicals to crops, are a growing composites application in agricultural equipment. Source | Deere & Co.

» As contiguous agricultural fields in areas such as North America, Argentina and Brazil have grown larger thanks to consolidation, and as no-till farming increases in certain geographies, farmers want sprayer systems with longer boom arms to reduce the number of passes needed to cover increasingly larger fields. This also reduces soil compaction and increases productivity and crop yields.

In response to this need, the Argentinian arm of King Marine S.A. (Valencia, Spain), whose core business, ironically, was fabricating composite boat parts using aerospace-grade carbon fiber-reinforced plastic (CFRP), used its composites expertise in other markets to develop new sprayer boom arms for self-propelled spraying equipment. In use, the boom arms unfold and extend perpendicular to the main axis of a tractor and permit farmers to apply liquid chemicals (e.g., insecticides, herbicides and fertilizers) to crops. After use, they refold and stow along the tractor body to avoid tangling with fence posts and to permit farmers to drive on roads.

Booms have long been produced in steel, but as length increases, larger support structures are required to keep arms from bending under torsional and fatigue loads and during unintended impacts with fences, trees and other structures. (High fatigue loads are why booms never transitioned to aluminum.) In turn, the move to longer



DESIGN RESULTS | **Carbon fiber composite sprayer boom arm**

- Autoclave-cured carbon and glass fiber/epoxy composite replaces stainless steel, reducing mass and costs and improving tractor fuel economy.
- Composite booms reduce corrosion, greatly increase damage tolerance for longer service life, reduce maintenance and operating expense, and facilitate field repairability.
- CFRP's high strength and stiffness/weight ratios enable composite booms to be made longer without needing weight-intensive support structure, so farmers can treat a given field in fewer passes and with fewer machine trails, increasing harvest volumes.

booms with bigger support structures necessitates that farmers purchase larger tractors to carry heavier spraying equipment and larger tanks holding greater volumes of liquids. However, in solving one problem, the heavier equipment leads to increased soil compaction and, as a result, reduced crop yields. In addition, many agricultural chemicals corrode metals, and longer booms require more elaborate folding mechanisms for boom stowage. Steel booms have, effectively, reached a practical limit of approximately 36 meters (120 feet) side-to-side. Still, the market — particularly in the Americas — wants longer booms.

Recession provides opportunities

The Great Recession of 2008 was catastrophic for both individuals and businesses. Twenty-year-old, family-owned King Marine, which has manufacturing facilities in Picassent, Spain, and Campana, Argentina, entered 2008 with a booming business producing CFRP components — particularly masts — for high-performance yachts.

"That's when the worldwide economic recession started, and the luxury marine market took a huge hit," recalls Natalia Dacko, European administration chief and internal audit at King Marine. "Our sales dropped dramatically and we stopped building boats. We were in crisis mode because our company was in jeopardy. We had a large staff of technicians, engineers and specialists — all of whom were experts in carbon fiber [composites]. The big question was, 'What are we going to do now?'" King Composite S.L. was created to explore non-marine CFRP applications.

In 2009, an unexpected solution to the company's concerns came from an Argentinean whose own company manufactured agricultural sprayer systems. The man was frustrated about problems plaguing his metal booms. "He told us he'd like for booms to be lighter, longer, free of fatigue, corrosion-proof and easy to repair," recalls Dacko. Although King Composite had no previous agricultural equipment experience, a team built a CFRP prototype, and the Argentinean company loved it, kickstarting King Composite's growing business with agricultural equipment OEMs in Argentina. King Composites would eventually be renamed King Agro SL.

As business in composite sprayer booms grew, King Agro became known for its innovative and quality products. After a few years, its success was noticed by an agricultural equipment leader fighting its own sprayer boom battles. Engineering team members »

The limits of metal

Traditionally produced in steel, sprayer boom arms had reached their practical structural and width limits owing to the large support structures required to keep arms from bending under torsional and fatigue loads.

Source | Deere & Co

from Deere & Co. (Moline, Ill., U.S.) met with King Agro in 2015 to discuss opportunities, and soon King Agro was producing and distributing CFRP booms for the John Deere brand.

New generations, new permutations

"We started with King Agro's designs and recommendations, plus what Deere had developed, and found they were pretty applicable," explains Phillip Ferree, King Agro general manager. "First, our joint team made some changes to improve reliability and durability for the South American market and launched those products in 2015. Simultaneously, we started designing second-generation products for North America and Europe. To meet local regulations, we needed different functionality in things like durability and impact, which required translating metal specs into composite designs." Those products were commercialized in 2017.

"During our first meeting, we spent three hours just discussing different features of sprayers in North and South America," recalls Thomas Bartlett, Deere sprayer product engineering supervisor. "Not only do they use different folding patterns — there are 20 different ways to fold these systems depending on market and regulations — but farming conditions are also different. In Brazil, they use no-till farming. In North America, it's more limited till with different farming practices and more regulation. Europe has further differences and much smaller farms. They keep their chemicals centralized, so sprayers are brought to the depot for refills rather than taking chemicals out to the fields for refills as we do in the Americas." Additionally, in some geographies plumbing carried liquids from the tank to nozzles through the arms, but in other locations, plumbing ran beneath the arms. Still another challenge was how long to extend the booms, as adding another meter here or there wouldn't necessarily provide a workable solution. Instead, engineers had to consider how crops were planted in each geography and the distances between and within rows.

The booms feature multiple composite tubular structures with square cross-sections that, in turn, are connected via special "ends" that connect to the fluid delivery systems. Specially designed features molded into the main structures provide components with required functionality to hydraulically open/close and carry fluids under high pressures. "With the hydraulics, we were able to integrate lots of features that we needed so we could put things together and create a more simplistic design overall," adds Bartlett. Deere requires that

Easier usage and storage

Composite booms feature the ability to extend (below) and fold (left) to facilitate travel between fields and equipment storage.

Source | Deere & Co.

booms deploy/stow in less than 1 minute and that fluid be delivered within two seconds of starting the pump.

All composites use an epoxy matrix and are vacuum bagged and autoclave cured. A combination of carbon and glass fiber reinforcement is used depending on whether components need higher strength or higher impact. Most of the carbon fiber is 24K tow but in a variety of formats, ranging from unidirectional to twill weave, the latter for aesthetic appearance layers with clear-coat finish. In joints and locations where hydraulics interact and more strength and stiffness are needed, heavier structures with more plies are used. Depending on model and market, production volumes range from 100 to 1,000 systems annually. King Agro estimates that in 2017, the total global market for self-propelled sprayers was 14,000 units/year.

"Going into this program, our targets were to extend booms to 40 meters but at 30% lower mass, since weight was very important," notes Jonathan Nelson, Deere composite sprayer boom design engineer. "When you hang a large mass off the front or back of a machine, you're battling inertia, so it's a lot harder to balance loads between front and rear axles. We also wanted to improve corrosion resistance, but also had to consider galvanic corrosion in the presence of carbon fiber. Another requirement was for higher impact because you just never see a sprayer that hasn't hit something. We carried over standardized tests developed for metals that involve running booms into fence posts for several hundred cycles." Working loads and fatigue on parts are surprisingly high, as equipment travels at 24-30 kilometers per hour [15-19 miles per hour] and plumbing sees spraying pressures of 276-414 KPa [40-60 psi].

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Lighter, better, faster

After three years, the collaboration proved so fruitful that in 2018, Deere acquired King Agro, which now builds booms at its facilities and ships them to John Deere factories in Des Moines, Iowa, U.S., and Horst, Netherlands, for final assembly. The deal reportedly allows King Agro to retain its brand name, trademark and commercial relationships.

Converting to composites has enabled booms to extend beyond 36 meters (120 feet) to 40 meters (132 feet). Compared to steel, CFRP is six times stronger, 5.5 times lighter, provides higher impact and doesn't corrode. Lighter booms mean better fuel economy, lower maintenance, greater working width, longer service life, lower operating costs and better efficiency with fewer machine trails for greater harvest volume. Another benefit is repairability. "Our dealers can take a catastrophic failure, cut the component in half, add some resin, clamp it and let it cure and they're good to go," adds Nelson. "It's actually easier to fix than welding steel."

The benefits of lighter booms

Lighter booms mean better fuel economy, lower maintenance, greater working width, longer service life, lower operating costs, easier field repairability and better efficiency with fewer machine trails for greater harvest volume.

Source | Deere & Co.

"The best part is the customer benefits," adds Bartlett. "With carbon fiber products, they can be more productive. They can go wider without a weight penalty, cover more acres, experience less soil compaction, and the reduction in ground pressure positively affects yield."

Ferree agrees: "From a design standpoint, composites enable us to do things we couldn't do with current materials, which were at their structural and width limits," he explains. "We've had a solid transition from our steel offerings to our premium CFRP offerings — particularly in the Americas — because we bring higher productivity, which in this segment is greater width. Lighter, wider booms can be installed on smaller, less-costly tractors. Or, more liquid can be carried on a given tractor while maintaining the same mass. Either way, the loading balance between front and rear axles is improved and the center of mass is closer to the machine's center, improving ride for the operator."

"We do see applications for carbon fiber in other products," predicts Aaron Wetzel, vice president, Deere ag & turf crop care platform. "In the coming years, we'll explore additional opportunities where the light weight and stronger-than-steel capabilities will add additional value to our products for our customers." CW

ABOUT THE AUTHOR

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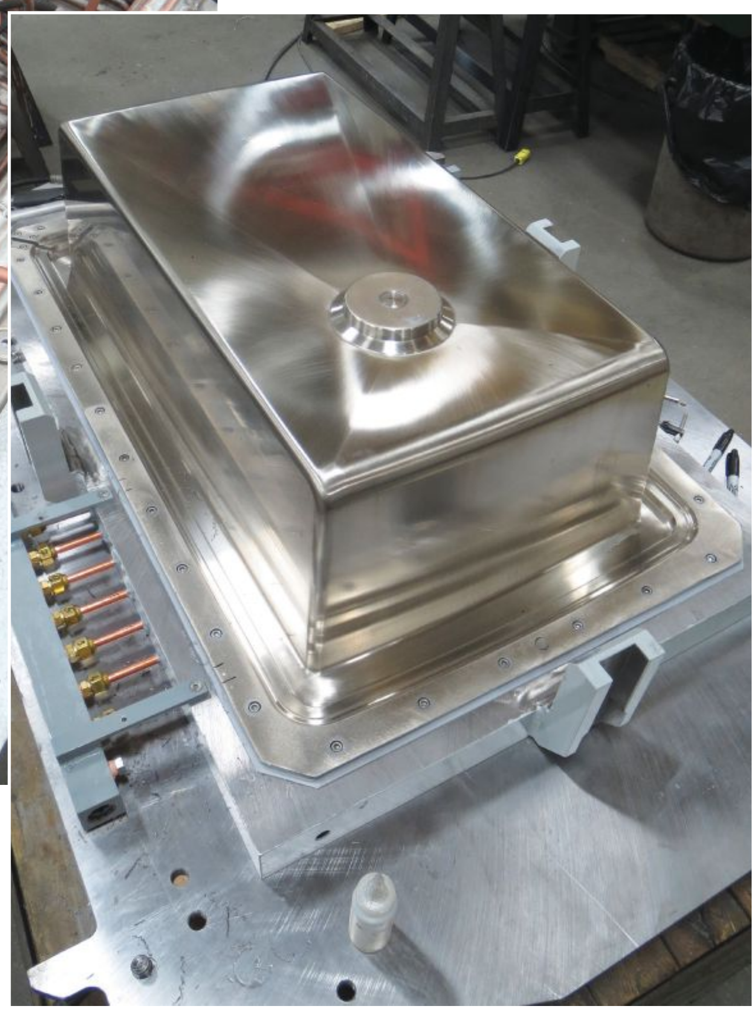
Post Cure

Highlighting the behind-the-scenes of composites manufacturing

Show us us what you have! The *CompositesWorld* team wants to feature your composite part, manufacturing process or facility in next month's issue. Send an image and caption to *CW* Senior Editor Scott Francis at sfrancis@compositesworld.com, or connect with us on Facebook, LinkedIn, Twitter or Instagram.



Inside the mold

Taken during a *CW* plant tour of moldmaking specialist Weber Manufacturing Technologies Inc. in Midland, Ontario, Canada, the B-side of a sink mold (left image) shows the myriad copper heating and cooling tubes lining the tool surface. The A-side of the mold is shown at right. *CW* photo | Jeff Sloan