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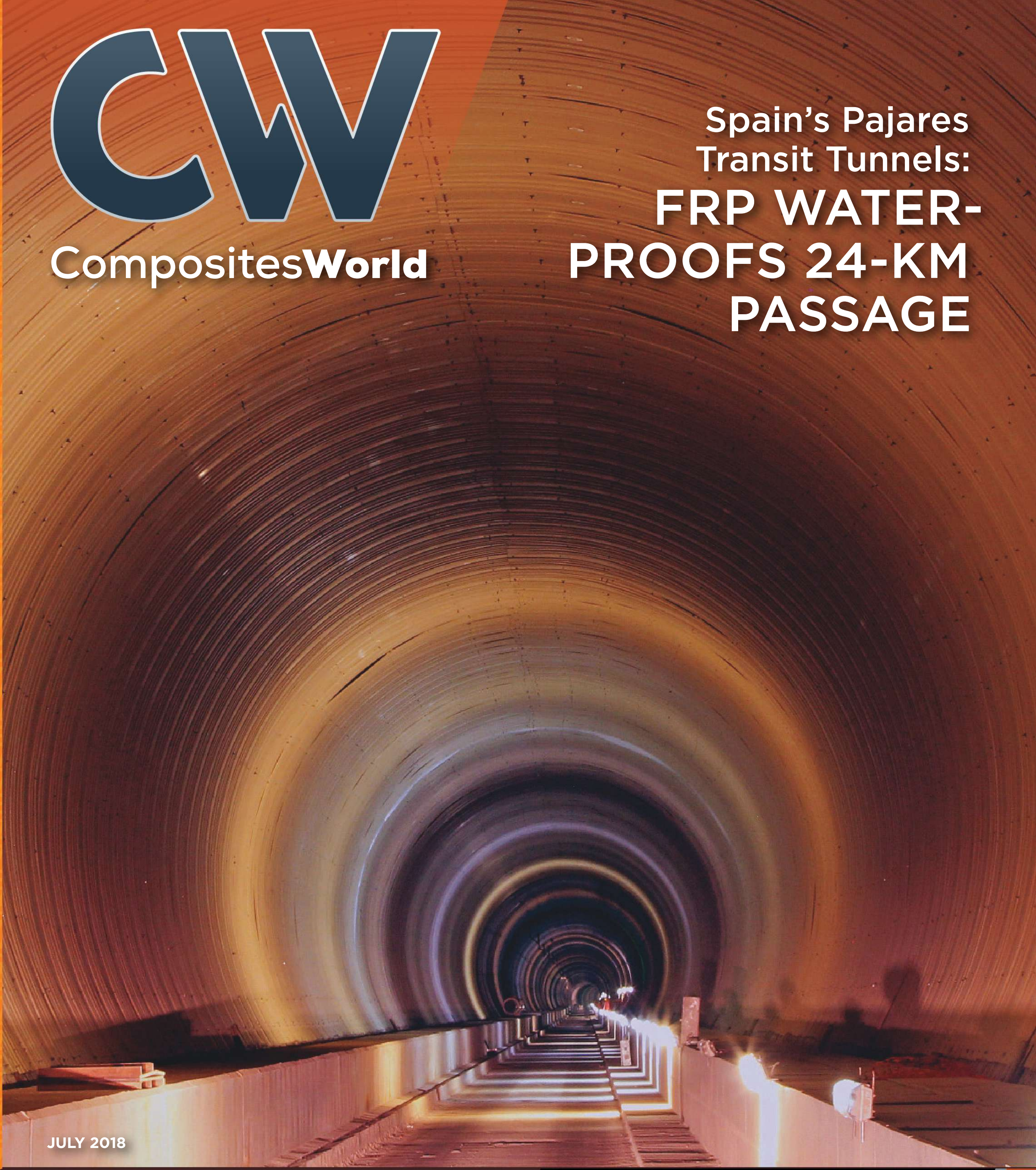

Spain's Pajares Transit Tunnels: FRP WATER-PROOFS 24-KM PASSAGE

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COLUMNS

» DEPARTMENTS

FEATURES

» ON THE COVER

Spain's Pajares Tunnels, intended to facilitate high-speed rail travel between Madrid and Spain's northernmost province, pass beneath extraordinarily wet mountainous terrain. The composite lining that encapsulates the tunnel passage channels large volumes of concrete-wall water seepage down to canals that direct the water out of the tunnel but also makes a rather striking visual impression. Read about it on p. 52.

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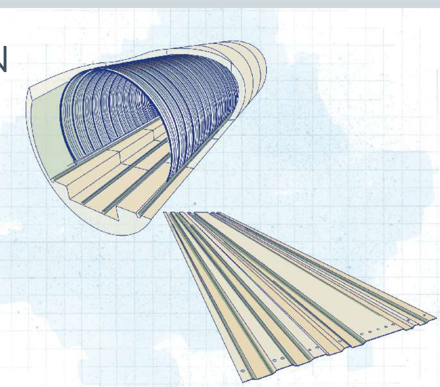

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» It's summer and we all, theoretically, have more time for leisure reading. So, if you are headed to the beach, the back yard or out on a road trip, I have a book for you: *The Innovators: How a Group of Hackers, Geniuses and Geeks Created the Digital Revolution.*

Teamwork, collaboration, creative tension, innovation and the future.

Written by Walter Isaacson, it's a historical review of the teams of people who shaped the digital age. Isaacson's story starts in the 1840s with Ada Lovelace, an English countess, mathematician and, by many accounts, the first world's first computer programmer. From there, Isaacson moves into the 20th and then 21st Centuries, introducing us to a cast of digital revolutionaries, including Vannevar Bush, Alan Turing, John von Neumann, J.C.R. Licklider, Doug Engelbart, Robert Noyce, Paul Allen, Bill Gates, Steve Wozniak, Steve Jobs, Tim Berners-Lee and Larry Page.

Isaacson's theme is that innovation is borne out of collaborative, cooperative teamwork. He evaluates a series of digital milestones (development of the transistor, graphics-based operating systems, computer networking, etc.) and then explores the people who helped us reach those milestones. What he discovers is that the most innovative ideas and technologies were the product of creative tension among two or more people, each of whom had a skill set that complemented the skill sets of others on the team. Such complementary groups developed a *dynamic feedback loop* that propelled an idea forward in a way that could not have been possible had any single team member been working alone.

Reading this book, it's not difficult to imagine what lessons it has for the composites industry, and beyond. Indeed, team-centered innovation is the reason companies and governments create laboratories, technical centers and R&D facilities — throw creative, smart people together, give them tools and materials, and see what results.

The composites industry has benefited for decades from such strategies, developing materials and technologies that speed cure, boost product quality, and offer new ways of fabricating composite parts and structures,propelling composites into end-markets and applications that, 10-20 years ago, were unimaginable.

As we look ahead, I wonder: Where will today's innovators take us? What stands in their way? One of the hurdles Isaacson describes is *inter-team* collaboration (or the lack of it). Early on, an ethos developed in the computer world that said, basically, "hardware is proprietary, software is public." This made it difficult for hardware developers to share knowledge with other teams. Conversely, an open-source philosophy in the software community drove creativity from team to team, thus accelerating innovation, at least, initially. But most programmers eventually got to a point where the value of their work exceeded the value derived from open collaboration.

Similarly, In the world of composites, "intellectual property," "proprietary," and "non-disclosure agreement (NDA)" are some of the first words mentioned when you get two engineers from two different companies together. Protection of the "secret sauce" is paramount, particularly if that secret sauce is tied to a major program or customer. But, if everyone has technology to protect, how do we move technology forward into the future?

IACMI here in the US, and organizations like it in Europe, are working to build multi-company project teams to develop technologies that can eventually be commercialized. But this *inter-team* effort requires some degree of surrender of intellectual property control, which many firms are just unwilling to do.

One force that drives composites creativity is the influence of outsiders. The dynamic, rapidly expanding nature of composites use attracts thinkers and doers from ancillary industries, where composites are known, but not well understood. Such folks tend to look at composites and their application with fresh eyes, from a perspective that shapes new composites paradigms. This is happening perhaps most vividly in the architecture community, where architects are putting composites to work more creatively than ever.

While we wait to see where it all leads, I'll move on to my next book. Enjoy the summer, and let me know what you're reading.

JEFF SLOAN — Editor-In-Chief

Image courtesy of United States Air Force
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Thermoplastic composites in aerospace — the future looks bright

» A significant milestone occurred in thermoplastic composites recently, and hardly anybody noticed. Gulfstream Aerospace (Savannah, GA, US) delivered its 300th *Gulfstream 650* aircraft. This twin-engine business jet, which began production in 2012, is the first commercial airplane to use critical control surfaces made from thermoplastic composites.

Airbus has successfully employed thermoplastic composites on the leading edges of its A300-series aircraft for decades, but these are not critical control surfaces. If a leading edge falls off the plane, then the plane still lands without a problem and everybody stays safe. If a critical control surface fails, then probability of a catastrophic landing increases substantially.

The real impediment to use of thermoplastic composites in critical control surfaces is an education gap.

Thermoplastic composites were not considered for critical or major structural components in aircraft for many years. This was true for several reasons. First, thermosets are in the comfort zone for many — they're structural and stable and have 40+ years of flight-allowable databases behind them. The application of continuous-fiber composites is almost completely structured around thermoset resins. Major composites manufacturers use autoclaves (and now OOA ovens), and other thermoset-driven capital equipment. Along with the thermoset-focused database and capital equipment, most composites engineers have lived in the thermoset comfort zone for their entire careers. They've designed or tailored a process around a handful of off-the shelf, flight-certified prepregs. Shop technicians are experts in vacuum bagging, bonding or other processes based on thermoset use. The customers only wanted to use thermosets, because they knew nothing about those "exotic" materials called thermoplastics.

This comfort zone in a necessarily conservative community is a major reason for the aerospace industry's slow progress in exploiting the advantages of thermoplastics. Even when a thermoplastic prepreg starts at less than 0.5% porosity (some of them do), and the AFP part made from the prepreg is at a similar porosity, some still want to put the final part into an autoclave to ensure consolidation. Heck, even some well-versed thermoplastic composites engineers like the security associated with ensuring consolidation via autoclave. If you find a thermoplastic composite in a database, it's likely a PEEK that is autoclave-consolidated. When you do that, you lose the price advantage of thermoplastics.

Back to the *G650*. Its elevator and vertical tail rudder are made with carbon fiber/PPS composite and then assembled using induction welding via an FAA-certified process. That one sentence describes three milestones associated with the parts. First the elevator and tail rudder are critical for maintaining control of the aircraft, and the FAA would not certify them without substantial proof of performance. Second, the use of PPS — not a polyketone — on a critical part, was, when these structures were designed, almost inconceivable. Sure, PPS had been used on leading edges, but the resin only has a glass transition temperature (T_g) of 90°C. On a hot summer day in the Mojave desert, at a location on the plane near the engine exhaust, one can be sure the material surface temperature will come dangerously close to 90°C. Wouldn't design of a critical control surface with such a low-T_g material create unnecessary risk?

Fortunately, PPS (and polyketones) are semi-crystalline polymers. The chain structure within the polymer enables them to retain a significant portion of their strength and stiffness above their T_g. In contrast, when a thermoset, such as epoxy, is exposed to temperatures above its T_g, it decomposes. PPS, in fact, has been used in underhood automotive applications at temperatures of more than 140°C for many years. An older composites engineer (like myself) would have had a hard time selecting a matrix material that could operate above its T_g. But some young, upstart engineer that "didn't know any better" got it to work, and that was a major milestone.

Now for the third milestone. A major advantage of thermoplastics is that they can be welded, thereby eliminating the need for bonding and riveting and the cost and weight issues associated with each of these. For a welded, critical thermoplastic composite to be FAA-certified, it would have to be proven to meet spec every time. KVE Composites Group (The Hague, The Netherlands) developed the welding process for part manufacturer Fokker Technologies (The Hague, The Netherlands) using TenCate Advanced Composites (Nijverdal, The Netherlands) CETEX laminate prepreg. (Guess where? Yes, those A300-series leading edges.) And it was good enough to become FAA-certified. (As a side note, every thermoplastic composite engineer should thank God for the Dutch, but that's a topic for another day.)

So, despite the major technical milestone at Gulfstream that started production more than five years ago, why is the aerospace composites industry still operating in the thermoset comfort zone? One reason is an *education gap*: I sat on a SAMPE panel a couple of years ago with a professor from a major US university that has a heavy composites curriculum. One of his slides claimed there were no critical flight surfaces made with thermoplastic composites in production. When it was my turn, I showed the Gulfstream parts on a slide, and realized that I had lost a potential academic friend. He simply did not know. Had he been from a European university, he probably would have known.

The anti-thermoplastics bias in the US is not just from lack of knowledge, nor is it just because they're outside of the comfort zone. Thermoplastic composites were overly hyped in the 1980s for military applications, and when they failed, as most entry-level technologies do on the first try, they got a real bad rap. Development of high-performance thermoplastic composites in the US was reduced to a crawl. In contrast, Airbus and the Dutch invested heavily in development of thermoplastic composites and began using tons of the material as early as the Airbus A320. By the way, Fokker is now manufacturing a rudder similar to that already in production, intended for multiple Gulfstream aircraft.

Where will thermoplastics take us next? Because thermoplastic prepreg tapes allow for full automation of complex shapes, improved properties and full recyclability (although, not everyone I've talked to is convinced of this) and reduced cost, they are the way to go. I've recently heard industry experts claim that a fuselage made with thermoplastic composites via automated fiber placement will still have to be autoclaved to ensure full consolidation. This perspective neglects two key points. First, some aerospace-grade thermoplastic tape is made with very low porosity (<0.5%, and made in the US) and it's only getting better. Second, given the recent, major advances in artificial intelligence-supported automation, real-time quality management of the AFP process is very real and very close. Why else would Toray (Tokyo, Japan), Boeing's primary thermoset prepreg supplier, invest more than US$1 billion in thermoplastics specialist TenCate Advanced Composites (Morgan Hill, CA, US)? My prediction? The Fuselage of Tomorrow and/or the New Midsized Airplane will be made with thermoplastic composites, and it/they will be built by 2025. CW

ABOUT THE AUTHOR

Michael Favaloro is president of CompositeTechs LLC (Amesbury, MA, US), a team of experts that caters to composites industry technical, business development and market analysis needs. His 38 years in the industry has included work (1980-1999) at Avco Textron (Wilmington, MA, US), GE Aircraft Engines (Lynn, MA, US) and Beacon Power (Wilmington, MA, US). More recently, he supported business development of thermoplastics for Celanese (Dallas, TX, US) and TenCate (Morgan Hill, CA, US) in the oil and gas, aerospace, automotive and medical industries.

Can we achieve global standards for composites?

» During JEC World, this past March, the leadership of seven composites-focused research consortia, or clusters, met to explore creation of a communications network between them and the potential for international collaboration. The meeting, representing countries in European, North American, Asian and Australian regions, was organized by the Institute for Advanced Composites Manufacturing Innovation (IACMI, Knoxville, TN, US). The plan is to grow, adding clusters from other countries and, perhaps, pursue a global composites "roadmap" to drive research into critical industry needs.

The industries we serve are global, and our industrial members operate in multiple countries. Many have asked if such coordination between clusters can help them leverage their industrial contributions to achieve greater results. A significant focus of our discussion, therefore, was to identify pre-competitive areas of research where international coordination can have a major impact on composites adoption. *Every* cluster is attacking the issue of increasing production speed and reducing the cost of composite structures, but looming issues tabbed for collaboration included composites recycling, improved modeling and simulation tools, and drafting international standards for the composite properties necessary for effective part design.

It is the relative lack of such standards that presents one of the highest hurdles to composites adoption, and also is incredibly difficult to address. The problem is variables: Compared to metals, our endless permutations of resin and fiber types, combinations, properties and varieties of manufacturing processes create an almost impossible-to-fathom range of possibilities. With near unlimited options, it's easy to throw up your hands and surrender.

Yes, several segments of the composites industry have developed ways to address this situation. Aerospace OEMs, for example, have for decades, used a *building block* approach that goes from physical testing of coupons to subelements to substructures to full structures. However, the development of design allowables, based upon molding and testing *thousands* of coupons, is so costly that *it creates large barriers to entry for new materials and processes*. Hence, materials and processes qualified more than 20 years ago are used to build current commercial and military aircraft primary structures. These databases are privately held, for the most part, by aircraft OEMs, so they are not generally available for use by others. The *Composite Materials Handbook (CMH-17)*, does have some publicly available systems characterized, and Wichita State University's (Wichita, KS, US) National Center for Advanced Materials Performance (NCAMP) program, headed by the Wichita-based National Institute for Aviation Research (NIAR), has established additional allowables data, mainly for secondary structures and general aviation.

The wind energy industry is working with the International Electrotechnical Commission (IEC) to develop and adopt standards for wind blade construction. Certification bodies for wind turbines, such as DNV GL, have published their own standards as an interim measure until the new IEC standards are adopted. The infrastructure landscape is very fragmented, yet the American Composite Manufacturers Assn. (ACMA, Washington, DC, US) is making steady progress, helping sectors adopt standards for composite rebar, FRP grating, architectural elements and utility poles.

Developing standards for automotive composites, however, appears to be the greatest challenge. Of the markets noted so far, automotive presents the largest set of material and process variables and a very wide range of performance requirements. In the US, the American Chemistry Council (ACC, Washington, DC) has launched a project with IACMI to develop performance standards for carbon fiber composites based on four categories: *crash* critical, *strength* critical, *stiffness* critical and *appearance* critical. The plan is to identify what properties are needed for each category to effectively model performance, agree on the test protocols to generate such properties, and allow suppliers and third parties to certify to these standards. It sounds like a simple task, but securing agreement from *all* parties in the value chain is anything but easy. In Europe, the German trade association AVK is working with industry and the Institut für Verbundwerkstoffe (IVW) in Kaiserslautern to develop test standards for characterizing continuous-fiber thermoplastic composites. ACC and IVW are discussing the possibility of coordinating efforts between these two projects. It's a start.

These projects will need to resolve which of the various international test methods are best suited for a given property, or if several methods can be used. In my February 2016 column, I envisioned an idealized future where *virtual allowables* could be incorporated to reduce the number of physical specimens that must be tested. For these efforts to ultimately succeed — and it will take years, so patience is essential — the global automotive supply chain will need to come together and participate. The world's composites research clusters, working in unison, can provide the leadership to achieve such an ambitious goal. It won't be easy, but it is something we can all agree needs to be done. 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.

Shear testing of high-shear strength composite laminates

» In my October 2015 column, I compared three V-notched shear test configurations used to measure the shear stiffness and shear strength of composite materials: The V-notched beam shear test (ASTM D5379[1]), the V-notched rail shear test (ASTM D7078[2]) and the V-notched combined loading shear test. All three use specimens with 90° V-notches machined into the central test section to produce a region of uniform shear stress.

The primary differences between the three shear test configurations are the size and shape of the test specimen as well as the methods of load application: through the top and bottom specimen edges (ASTM D5379), through the specimen faces (ASTM D7078) or both (combined loading shear test). Here, we'll focus on shear testing of thick, high-shear-strength laminates for which the combined loading shear test method is best suited.

The combined loading shear test fixture (Fig. 1a) is similar to that used in the V-notched rail shear test, but is larger and has bolt-adjustable specimen edge loaders. The specimen is loaded into one fixture half, using an alignment jig to properly position it. The edge loader bolt is tightened to ensure specimen edges are in contact with the fixture. Next, the bolts for the face loaders are adjusted to align the specimen's centerline with the centerline of the fixture half before tightening. The second fixture half is mounted in the same way onto the specimen's other end. Finally, the edge loader bolts for both fixture halves are loosened, then retightened to ensure that no preload is applied to the specimen edges. The assembled fixture is mounted into a universal testing machine via pinned adapters and loaded in tension.

Although the central V-notched region of the combined loading shear specimen has the same geometry as in the V-notched rail shear test, the gripping region's length is increased from 25 to 51 mm, providing twice the area for both edge and face loading. The resulting 127-mm-long by 56-mm-wide specimen (Fig. 1b) has been shown to produce acceptable gage-section failures in relatively thick, high-shear strength laminates that require applied shear loads up to 100 kN[3].

High-shear strength composite laminates are of interest for many structural applications, including the central web region of composite beams, which carry the majority of the shear stress under transverse loading. Unlike tension and compression stresses, which are carried most efficiently by reinforcing fibers oriented in the direction of the stress (Fig. 2a), shear stresses are carried most efficiently when fibers are oriented at ±45° angles (Fig 2b). This concept can be visualized by considering the shear stress element rotated 45°, showing that the ±45° fibers are actually carrying the stresses directly in tension and compression. For this reason, high-shear-strength composite laminates typically have a relatively high percentage of ±45° plies. Note that a quasi-isotropic $[0/\pm45/90]_s$ laminate is expected to have relatively high shear strength, having 50% of its plies in ±45° orientations.

The ability to mechanically test high-shear-strength laminates is especially important because of the challenges associated with predicting their shear strength. Using laminated plate theory analyses with progressive ply failure[4], shear-loaded multidirectional laminates typically are predicted to experience matrix-dominated ply-level damage prior to reaching their

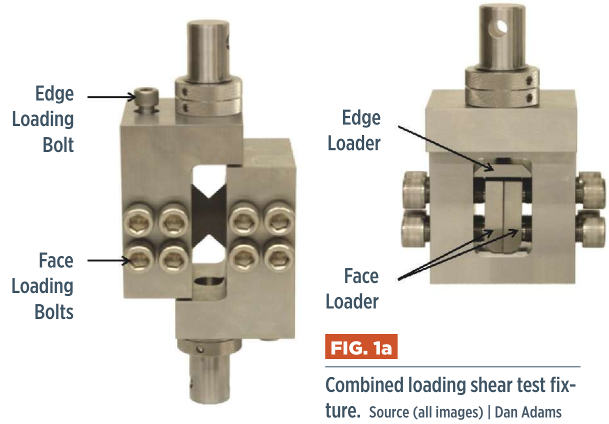

FIG. 1a
Combined loading shear test fixture. Source (all images) | Dan Adams

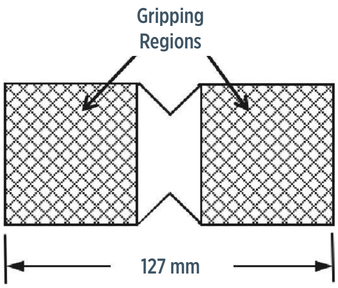

FIG. 1b
Combined loading shear test specimen.

FIG. 2
Efficient fiber orientations for stresses

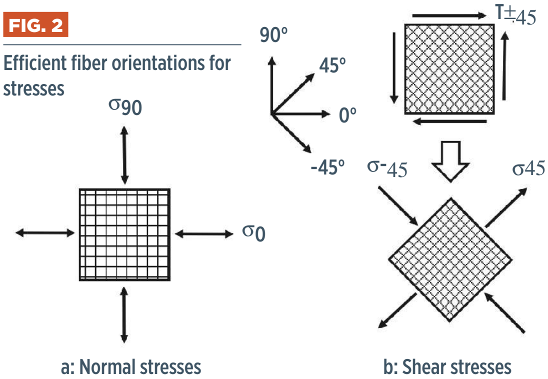

FIG. 3
Failure mode in quasi-isotropic shear specimen.

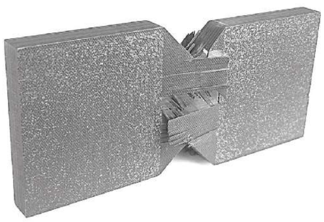

FIG. 4
Failure along 45° planes in epoxy shear specimen.

ultimate shear strength. Additionally, predicted shear strengths are highly dependent on the ply failure theory used.

As an example, combined loading shear testing and laminated plate theory strength analyses were performed using a $[0/\pm45/90]_{4S}$ quasi-isotropic carbon fiber/epoxy laminate. The laminate shear strength was predicted using three ply-failure theories: maximum strain, Tsai-Wu and Hashin. Ply damage produced during incremental shear loading was modeled by reducing associated stiffness properties of the damaged ply[4]. The three failure theories predicted ply-level damage initiating at applied shear stress levels of 250-443 MPa. The ultimate shear strength measured from shear testing was 346 MPa[3], whereas the predicted strengths were 250-564 MPa.

The post-failure condition of the quasi-isotropic shear specimens (Fig. 3, p. 10) showed a complex failure mode, with different failure planes produced in the various ply orientations. Knowing that the maximum shear stress is produced on the vertical plane connecting the V-notches, it is logical to expect that a *proper* shear failure would occur on this vertical plane. However, shear loading of a multidirectional laminate produces a complex, multiaxial stress state that is different for each ply orientation. Thus, the rather complex failure mode observed in the quasi-isotropic shear specimen is less surprising.

Interestingly, isotropic materials also can provide somewhat unexpected failures under shear loading. For example, Fig. 4 (p. 10) shows the post-test condition of a V-notched epoxy shear specimen. The specimen failed along 45° planes, which, as shown previously (Fig. 2b, p. 10), is the plane on which the maximum tensile stress occurs. Thus, even some isotropic materials do not fail on the plane of maximum shear stress when subjected to shear loading. CW

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Composites Index moves lower after setting all-time high

May 2018 – 57.4

» The GBI: Composites Fabricating Index for May registered 57.4, moving lower after having set an all-time record in April. Compared to the same month one-year ago, the Index showed an increase of 4.1%. Five of the six measures used to calculate the Index fell during the month. Only the Supplier Deliveries subindex remained unchanged, near its all-time high set earlier this year.

May's lower readings could suggest that the industry's growth is merely moderating after achieving unprecedented levels of growth earlier in the calendar year. While May's numbers were comparably lower than recent periods, all components continued to register expansionary gains (>50.0 readings) for the month.

The Gardner Intelligence team's review of the underlying data for the month indicates that the Index was pulled strongly higher by Supplier Deliveries. The Index was also supported by Production, Employment and New Orders. But the Composites Fabricating Index — an averages-based calculation — was pulled lower by Backlogs and Exports, both of which indicated slowing growth during the month.

The relatively stronger Production reading as compared to New Orders may explain why Backlogs growth slowed sharply in the May data. In four of the first five months of 2018, Production growth exceeded New Orders. Consistent with the Gardner Intelligence team's understanding of the manufacturing business cycle, fabricators are continuing to adjust and increase production output through improvements to their supply chains and employment levels. The elevated growth in New Orders since 2017 has forced shops to make long-run changes to their operations to accommodate stronger demand for products. CW

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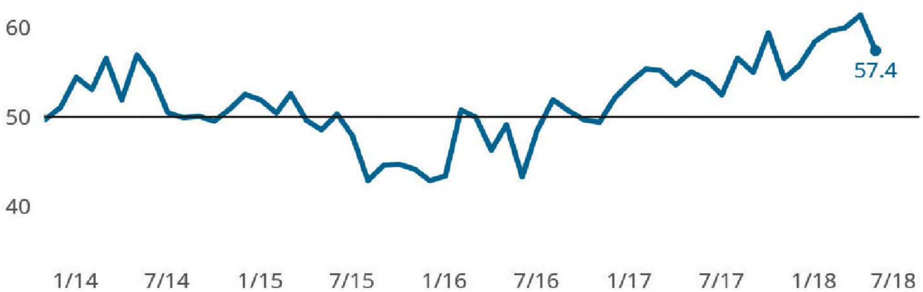
Michael Guckes is the chief economist for Gardner Intelligence, a division of Gardner Business Media (Cincinnati, OH US). He has performed economic analysis, modeling and forecasting work for nearly 20 years in a wide range of industries. Guckes received his BA in political science and economics from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

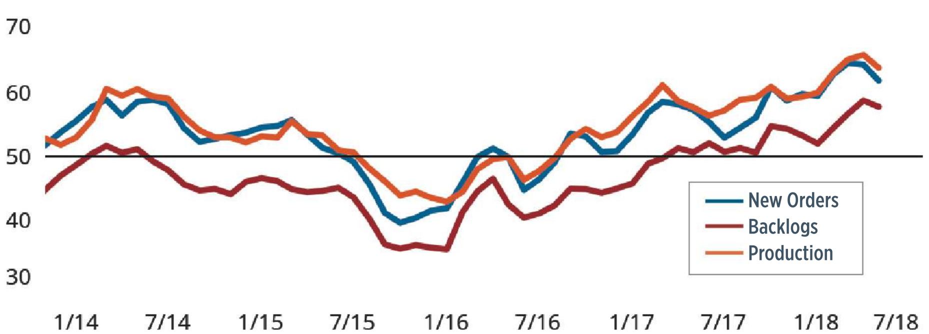
GBI: Composites Fabricating



Still growing, but at a slower pace

The Composites Fabricating Index moved lower in May after recording a record high in April. All components except for Supplier Deliveries (unchanged) indicated slowing growth.

GBI: Composites Fabricating — Production, New Orders and Backlogs (3-month moving average)



Backlogs peaking as Production, New Orders growth slows

Although fabricators have sought to match supply to increasing demand in the latest market upcycle, Backlogs have grown at unprecedented levels. May data indicate slowing growth in New Orders might curtail future Backlogs growth.

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_CW_ Talks with cutting/kitting specialists from Web Industries, notes the debut of commercial PA 6.6 compounds reinforced with recycled carbon fiber, and reports good news in both the boating and aircraft interiors markets.

Q&A: Ashley Graeber and Manish Patel of Web Industries (Marlborough, MA, US)

Editor's note: CW Talks: The Composites Podcast*, recently spoke with Graeber, director of sales and business development (left) and Patel, senior application engineer (right), about Web Industries and its place in the composites supply chain as a slitter of carbon and glass fiber tapes into smaller tows, and as a provider of cutting and kitting services. Patel explores the company's technical expertise, while Graeber reviews the company's commercial presence. What follows is excerpted from the podcast. To hear the complete interview, check out* CW Talks *on iTunes or Google Play, or at* CompositesWorld.com/podcast.

***CW*: Let's talk about Web Industries itself. Where does it fit into composites manufacturing and into the composites supply chain?**

AG: Interesting question. We've played a valuable role in the industry, but outside our immediate customer base, which is fairly narrow, we are not that well known. We spent the last 20-plus years pioneering our product development and working with formatting solutions, mostly with a small group of customers. We're working actively to broaden our market awareness and perception, with expansion of our facilities and services globally.

***CW*: The core of Web's business, its legacy, is slitting of prepregs for automated fiber and tape placement. What are the challenges associated with slitting?**

MP: First, we love challenges, it's true. It's not just about slitting and spooling up on the core. Each carbon fiber and resin mix behaves and processes differently, with a different temperature and humidity needed when we are processing. I would say our biggest challenge concerns projects that use a hand layup product and transitioning that product to automated fiber placement layup .... Hand layup products tend to be overly tacky, and are not optimized for AFP processing.

AG: To add to what to Manish said, the commercial challenge is just that: We just slit fabric, and ... how hard can it possibly be? I've actually heard that quite a few times. But as Manish said, most manufacturers don't understand the value impact that precision-slit, custom-spooled tape can have on their manufacturing process. In the early stages, it can reduce time to market, and during the production lifecycle, it's all about ongoing increased equipment uptime and production throughput.

***CW*: As the two of you look to the future of aerospace composites, what opportunities do you see from a technical and from a commercial perspective?**

MP: Currently we're heavily involved with thermoplastics processing. This is not a new product, but it's going to play a significant role in the future. We believe the market will see more material types being used on future aircraft as engineers optimize the parts based on the material itself — regardless of the material type and processing method. We want to provide a solution path to make parts in the most efficient way.

AG: From a commercial perspective, I'm excited about the prospects, for both Web and the aerocomposites industry, so definitely a bright future — we've opened a thermoplastics center of excellence and are working diligently with our key customers on some various formatting disciplines specific to thermoplastics.

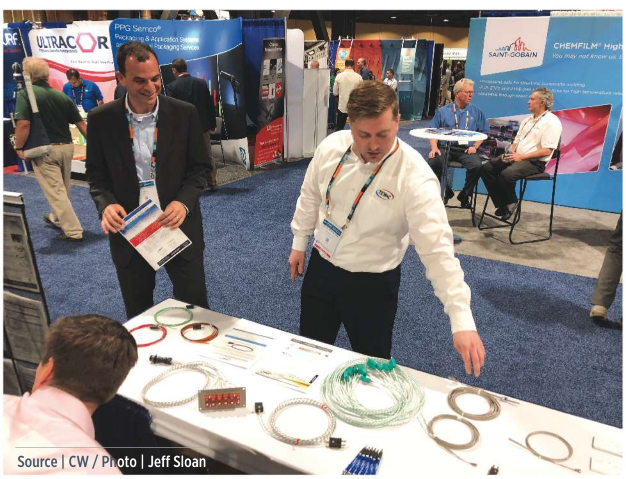
***CW:* As you look over this industry and as you look back on your experience, what is your assessment of the future of the composites industry?**

AG: Our worries are the same as any industry that's healthy, and that's that we have huge production volumes, growth in production volumes, which bring price pressures, supply chain challenges. You mentioned thermoplastics — there's the availability of material to drive that industry, and also the standard competitive pressures ... just looking at the different design options that composites allow, and the growing adoption of composites across all those industry segments ... it's really hard not to be excited.

MP: From the technical side, the dynamic nature of the business is not new. During our 50 years' history in the formatting business, we have seen many changes. We fully expect that the composites industry will continue to evolve and mature with the changes that we *don't* fully see today .... We fully expect that in 10 to 15 years our service model for this market will look very different than what it is today.

TE Wire & Cable, Plataine join forces to develop smart thermocouples

Photo | CompositesWorld



Source | CW / Photo | Jeff Sloan

TE Wire & Cable (Saddle Brook, NJ, US), a manufacturer of thermocouple wire, and Plataine (Waltham, MA, US), a provider of Industrial IoT and AI-based optimization software for advanced manufacturing, announced at SAMPE 2018 a partnership for what the companies are calling Smart Thermocouple solutions.

Plataine president and CEO Avner Ben-Bassat (left) and Vlad Fedorchak, TE Wire & Cable's business unit manager, Aerospace Composites, were on hand at the Plataine booth to greet show visitors (see photo).

The joint solution reportedly integrates IoT, AI and thermocouple technologies to improve efficiencies and quality. TE Wire & Cable's thermocouples are connected to Plataine's IoT-based AI software via a simple hardware infrastructure based on RFID tags and engraved bar-codes. Plataine's software then monitors the thermocouples' location, status and duty-cycles to provide automated, real-time alerts and *(continued on p. 16)*

(continued from p. 15)

recommendations to optimize thermocouple calibration, refurbishment or replacement. A dedicated Web page enables users to plan ahead for efficient thermocouple utilization.

According to Ben-Bassat, the joint solution improves quality compliance, reduces the risk of using thermocouples that are no longer fit for purpose and eliminates the need for manual tracking processes and production delays associated with manual processing steps.

Plataine's software is described as weaving "a web of digital threads from raw-material to end-product," allowing thermocouples to be paired to molds and parts for full traceability in the event of quality issues or audits.

To learn more, visit **plataine.com**

MARINE

NMMA: US boating industry sales highest in a decade

Source | NMMA

Good news for composites manufacturers who work in and serve the North American boatbuilding industry and those who supply their machinery and materials: According to the National Marine Manufacturers Association (NMMA, Chicago, IL, US), US recreational boat sales are at a 10-year high, prompting boat manufacturers to expand to meet demand. Data released on May 22 by the NMMA show that unit sales of new powerboats increased by 5% in 2017, reaching 262,000 — the highest levels the US recreational boating industry has seen in 10 years.

Total marine expenditures were at an all-time high in 2017 at US$39 billion (spending on new boats, engines, trailers, accessories and services), up 7% from 2016. Boat manufacturers are expanding capacity to meet this demand — building new plants and increasing production; supporting recent data from the Bureau of Economic Analysis that US manufacturing gross output increased to US$6.228 trillion in the fourth quarter of 2017.

"As the strong economy continues to bolster new boat sales and boating expenditures, capital spending and manufacturer optimism are at record highs, creating one of the strongest periods on record for the US boating industry," says NMMA president Thom Dammrich. "The growth trajectory recreational boating is continuing to see is healthy and steady as the industry works to bring new buyers to the market across all segments, from small aluminum fishing boats to large cruising yachts."

Abaris to relocate training operation

The Composite Prototyping Center (CPC, Plainview, NY, US), an organization dedicated to providing workforce development, prototype manufacturing and technical training in advanced composites manufacturing, announced June 5 that Abaris Training Resources (Abaris, Reno, NV, US) will relocate its Griffin, GA, US-based advanced composite training operation to CPC's 25,000-ft^2 facility on Long Island.

CPC is also the designated Northeast center for the Institute for Advanced Composites Manufacturing Innovation (IACMI, Knoxville, TN, US) in which both organizations hold membership.

The decision to relocate was reportedly prompted by Abaris' goal to expand beyond its current curriculum.

According to CPC executive director Leonard Poveromo, "CPC has the advanced technology required in manufacturing using composites …." The location is equipped with robotic fiber placement systems, large autoclaves, RTM/VARTM resin injection/infusion equipment and 5-axis CNC machinery. "We're confident our resources will be extremely beneficial to Abaris in meeting its goal to broaden its course offerings."

To prepare for Abaris, Poveromo stated that CPC will be setting up workstations for Abaris' repair training classes. Abaris will initially be using its current instructors, but Abaris president Michael J. Hoke says, "With the addition of new courses over the next year or two, we will be hiring instructors from the Long Island region with strong backgrounds in advanced composite materials, as well as the right teaching skills and personality to engage students in both the classroom instruction and hands-on workshop environments."

IACMI workforce manager Joannie Harmon Heath, MPA adds, "IACMI members, Abaris and the Composites Prototyping Center both play important roles in the continued growth of workforce development in the composites field. The CPC is home to the research of several IACMI projects and being in the Northeast corridor is also close to many IACMI members. Abaris' proximity to the CPC will increase the opportunity for hands-on learning experiences and workforce development initiatives."

Abaris will be setting up at CPC in June, with its first course, the five-day "Advanced Composite Structures: Fabrication & Damage Repair – Phase I," scheduled for Aug. 20-24, 2018.

Green composites: Chicago compounder introduces recycled carbon fiber-reinforced PA 6/6

At the 13th annual Automotive Engineering Plastics Conference (AutoEPCON) organized by the Society of Plastics Engineers (SPE, Bethel, CT, US) and held in the Detroit suburbs on April 30-May 1, a Chicago-based custom compounder and distributor debuted an interesting new pelletized, carbon fiber-reinforced thermoplastic composite.

The material, called FiberX2, from JM Polymers (Chicago, IL, US), is notable for two reasons. First, it uses recycled carbon fiber (CF) from the aerospace and sporting goods industries — but *post-industrial* and *post-consumer* recyclate (PIR, PCR). Second, it uses PIR polyamide 6/6 (PA 6/6) resin from the automotive industry. The combination makes the new product and the parts made from it greener because it takes significantly less energy to collect, clean and repurpose both fiber and resin than it does to make virgin (prime) fiber and resin. In addition to a lower carbon footprint, users of FiberX2 reportedly also reap a 15-20% cost reduction vs. prime resins with the same fiber length and loading levels. The company also says the product offers 1.5- to 1.8-times better tensile strength than long-glass fiber polypropylene (124 MPa for 50% LFT-PP vs. 184 MPa for 20% CF-PA 6/6).

FiberX2 is initially being offered with 20-, 30-, and 40% CF reinforcement. Notably, 30% seems to be the sweet spot because data comparing tensile strength values for virgin CF-PA 6/6 of the same fiber length and loading levels shows that values are the same at 30% loading (both 221 MPa) whereas they are slightly lower at both 20% (184 vs. 190 MPa) and 40% (221 vs. 234 MPa). Similarly, when comparing flexural modulus, the recycled compounds have slightly higher bending stiffness than prime except at the 20% level. The company says it tweaks its own sizing to assure good bonding to polyamide.

According to Josh Ullrich, JM Polymers president and CEO, the company began working with Ford Motor Co. (Dearborn, MI, US) in 2014 to develop the product. Developmental projects are in process and efforts are also underway to develop specifications.

The company next plans to introduce a grade that is reinforced with 15% fiberglass and 5% carbon fiber. That product will offer slightly better impact and lower cost than the all-carbon grades, albeit at lower stiffness and strength.

"As a custom compounder, we've got the ability to tweak our formulations to meet customer requirements, such as when they need to hit a particular shrinkage or impact target," adds Ullrich.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Teijin breaks ground on carbon fiber facility in South Carolina

Source | *CW*

As reported by *CW* in November 2016, Teijin Ltd. (Tokyo, Japan) purchased roughly 440 acres of commercial land in Greenwood, SC, US, to establish a carbon fiber production site, projecting an investment of US$600 million by 2030. Now, 18 months later, Teijin has broken ground on its first TENAX structural carbon fiber plant in the US. It will join the company's established Rockwood, TN, facility, which manufactures Pyromex carbon fiber used in flame-resistant insulation, carbon/carbon brakes and gas diffusion layers for fuel cells.

CW attended Teijin's groundbreaking ceremony on Friday, June 1, 2018, held at the new site outside of Greenwood. Teijin joins a growing list of high-tech manufacturers in Greenwood, located directly across from FUJIFILM Manufacturing USA. Inc. (the North American Manufacturing and R&D headquarters for this wholly owned subsidiary of Tokyo-based FUJIFILM) and Ascend Performance Materials (Houston, TX, US), reportedly the world's largest producer of Nylon 6.6 resin.

Jane Thomas, president of Teijin Holdings USA Inc., began the ceremony, answering the question, "Why Greenwood?" She explained that the decision involved a complex matrix of factors including infrastructure, incentives and an unbeatable coalition via the Greenwood Partnership Alliance, "but mostly it was the people." She described the local culture as a combination of "grit and grace" and noted the unwavering commitment from the city, county and state. "This new facility will produce the most significant manufactured material of our generation," said Thomas, adding that industrial demand for carbon fiber is surging. "This site will create hundreds of jobs and will support families for generations."

Mr. Toshiya Koyama, executive officer of Teijin Limited said, "Carbon fiber is one of Teijin's core businesses. We are building this facility to grow our business footprint in the US and to serve as a global hub for Teijin carbon fiber for the aerospace and automotive industries."

"We look forward to this new chapter of Teijin's expansion in the US," said Yukito Miyajima, president of Teijin Carbon Fibers Inc. (TCF). "We are strengthening its global upstream-to-downstream carbon fiber business." Noting the company's beginning 100 years ago in the summer of 1918, he added, "Our 101st year starts here in

Greenwood. We will integrate Teijin's carbon fiber business with US industries."

After the ceremony, *CW* spoke with Shukei Inui, General Manager Carbon Fibers Business Unit for Teijin. "This new facility will take roughly two years to construct, with production starting in the second half of 2020. The first industry it will support is aerospace, with products such as Teijin's high-tenacity and intermediate modulus 12K and 24K fibers." He notes that Teijin already supplies carbon fiber to the automotive industry and this South Carolina facility will help to grow this market. Inui said that polyacrylonitrile (PAN) precursor for the Greenwood plant will be imported from Teijin's newly completed line in Japan (an expansion announced in November 2017). However, with sufficient growth in the market, Inui suggested that such a line could possibly be built here in the future as well. Although the exact production numbers for the South Carolina plant have not been disclosed, Inui said it will be one of the largest-capacity facilities for Teijin, similar to the 2,700 MT/yr line added to its Mishima Plant in Japan in 2008.

The strong partnership between Japan and South Carolina was highlighted by Takashi Shinozuka, Consul General of Japan in Atlanta, GA. "South Carolina is well-known in Japan as a great place to do business, not just because of incentives, but because of the success achieved by companies here through support at all levels." As of 2017, 190 Japanese companies have a presence in South Carolina, 55 of which are in the Upstate area. Japanese companies have invested almost US$3.4 billion in South Carolina since 2011, and South Carolina companies export over US$1 billion in goods to Japan, according to Upstate Alliance (Greenville, SC). This relationship is strengthened by annual joint meetings of the US-based Southeast US-Japan Association (SEUS) and the Japan-based Japan-US Southeast Assn. (JUSSA Japan).

South Carolina's Secretary of Commerce Bobby Hitt, appointed by Governor Nikki Haley in 2011, observed that 25 years ago, "South Carolina was a textile and tobacco state. Now it is an advanced manufacturing state, including significant activity in the aerospace and automotive industries." He touted the achievements of waht he termed "Team South Carolina," which has recruited approximately US$32 billion in capital investment and more than 118,000 new jobs in world-class companies, such as BMW, Boeing, Bridgestone, Continental, Giti Tire, Mercedes-Benz Vans, Michelin, Samsung, Toray, Volvo Cars and more.

"Still, companies locate in communities, not states," he acknowledged. "FUJIFILM stood tall, one company cordially inviting another to locate across the street. That's very neighborly." This sentiment was echoed repeatedly throughout the ceremony and reflected in press materials in which Teijin said it aims to be an enterprise that supports the society of the future.

AEROSPACE

Composite aircraft interiors market to exceed US$1.8 billion by 2023

Stratview Research (Detroit, MI, US) and PR Newswire (New York, NY, US) announced in a May release a new market research report with the unusually lengthy title, "Aircraft Cabin Interior Composites Market by Aircraft Type (Narrow-Body Aircraft, Wide-Body Aircraft, Very Large Aircraft, Regional Aircraft, and General Aircraft), by Application Type (Floor Panels, Sidewall Panels, Ceiling Panels, Stowage Bins, Galleys, Lavatories, Seating, Ducts, and Others), by Composite Type (Glass Fiber Composites, Carbon Fiber Composites, and Others), by Process Type (Sandwich Construction, Compression Molding, and Others), by End-User Type (OE and Aftermarket), and by Region (North America, Europe, Asia-Pacific, and Rest of the World), Trend, Forecast, Competitive Analysis, and Growth Opportunity: 2018-2023." The report is a study of the use of composites in aircraft cabin interiors during the trend period of 2012-2017, and a forecast based on that study for the 2018-2023 period. As its title suggests, this research report provides detailed insights on this market's dynamics, and is intended to enable informed business decision making and growth-strategy formulation based on the opportunities present in the market.

According to Stratview Research, the aircraft cabin is one of the most discussed subjects in the airline industry today and should continue to be a hot topic because airlines' requirements for aesthetically pleasing, compact, and innovative cabin interiors show no sign of abatement. Low-cost carriers demand aircraft that have maximum space for seating to generate more revenue per journey, but premium airlines that target high-end customers would like to offer extraordinary passenger comfort to emphasize excellence in the customer experience. All major Tier 2 players reportedly are working closely with aircraft OEMs to develop advanced lightweight interior systems. Composite materials are the perennial choice in fabricating structural parts because the materials not only offer lightweighting advantages and high strength-to-weight ratios but also deliver superior aesthetics.

The report claims that the global aircraft cabin interior composites market is projected to grow over the next five years to an unprecedented US$1.891 billion. Organic growth of the aircraft industry is credited as the primary driver of the demand for composites in aircraft cabin interiors. A projected CAGR of 4.7% in air passenger traffic during

2017-2036 will drive the demand for commercial aircraft. This factor is expected to create a sustainable demand for composite parts for cabin interiors globally in the foreseeable future. Increasing production rates of key aircraft programs, market entry of new players, such as Commercial Aircraft Corporation of China Ltd. (Comac, Shanghai, China) and Irkut (Moscow, Russia), introduction of variants of existing best-selling aircraft programs, and increasing demand for cabin retrofit of the large, existing aircraft fleet are likely to offer a sustainable growth platform for composites in these segments in the coming years. North America is expected to remain the largest market during the forecast period, but Asia will also experience growth, due to more assembly plants in China and the introduction of indigenous aircraft in the region.

For more information about the report, visit Stratview Research's Web site | **stratviewresearch.com/332/Aircraft-Cabin-Interior-Composites-Market.html**

CORRECTION

In *CW's* recent Side Story, titled "Wind energy: A worldwide phenomenon," a companion piece to our feature editorial piece on the several competing methods for wind blade inspection, titled, "Service & repair: Optimizing wind power's grid impact" (*CW* July 2018, p. 58), it is noted on p. 62 that the "Pyeongchang 2018 Olympic Winter Games were entirely powered by wind energy." However, our editors erroneously added, "The total generation capacity reached 203 MW, exceeding the Games' required capacity of 194 MW by 104%." An alert reader was kind enough to point out that to exceed the required capacity by 104%, the installed would reach 395.76 MW (194 + 194 x 1.04). The generation capacity, of course, was 104% *of* the required capacity or it *exceeded* required capacity by a more reasonable 4%. *CW* regrets the editorial error.

In Memoriam: Brad Dunstan (1960-2018)

Brad Dunstan, 58, Melbourne, Australia, passed away in the first week of June. Dunstan's career in the automotive industry spanned almost 40 years. He was a leader in developing Australia's high-tech automotive components sector. He also set up the Victorian Centre for Advanced Materials Manufacturing (VCAMM, Scoresby, VIC, Australia) and played an instrumental role in establishing the Carbon Nexus (Waurn Ponds, VIC, Australia) carbon-fiber research facility at Deakin University, where he was director. He was an advocate for the use of carbon fiber, well-known in the international composites industry and will be greatly missed.

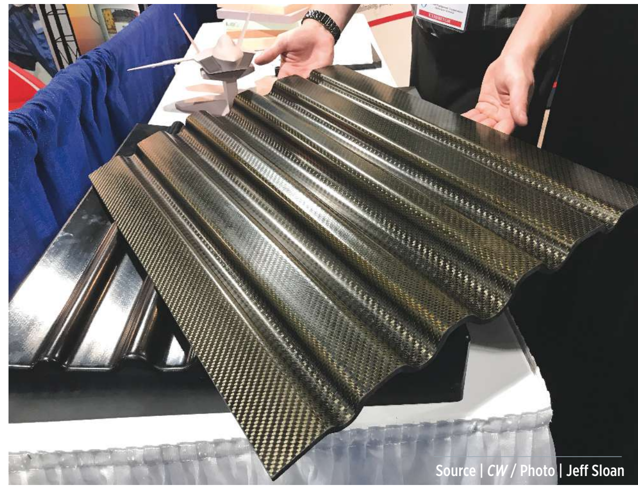
AEROSPACE

SAMPE 2018 exhibitors' showings target next-generation aircraft

The broader aerospace world might be patiently waiting for The Boeing Co. (Chicago, IL, US) to officially announce plans to develop its New Middle-Market Airplane (NMA or 797), tabbed as a replacement for the 757, but suppliers in the composites industry aren't sitting on their hands. The SAMPE 2018 conference and trade show, held May 21-24 (Long Beach, CA, US), revealed that the aerocomposites supply chain has been busy developing new products for next-generation aircraft. Particularly the 797.

CompositesWorld found the following few of the many innovations introduced or in the works:

- **Solvay Composite Materials** (Alpharetta, GA, US) announced FusePly, an epoxy-based film that is designed to co-cure with a prepreg and provide a chemically active surface that reacts with functional groups in adhesives to create a covalently bonded structure. Solvay officials at SAMPE noted that FusePly's chemically active surface differentiates it from traditional composite surface preparations, like peel ply and plasma treatment, which provide mechanical bonding only. FusePly, which Solvay believes will allow aerospace OEMs and fabricators to create reliable bonds and reduce mechanical fastener use, is compatible with 149-177°C amine-cured epoxy prepregs and is designed specifically for secondary or co-bond applications such as stringer-to-skin bonding. It can be processed in or out of the autoclave, is not affected by moisture or out time, and is said to have no mixed-mode failure. Solvay


Source | *CW* / Photo | Jeff Sloan

says that many OEMs are in the process of determining suitable applications for this technology.

- **Hexion** (Columbus, OH, US) introduced Epon FlameX, a halogen-free, nonparticulate, nonadditive chemistry for epoxies that provides strong fire/smoke/toxicity (FST) performance in aerospace, rail and marine interiors applications. It comprises EPON FlameX Resin 9600 cured with EPIKURE FlameX Curing Agent 9700. This self-extinguishing resin meets the following standards: 60-second vertical burn (*FAR25.853*(a)); smoke toxicity (BSS7239); smoke density (BSS7238). Epon FlameX can be used with resin transfer molding (RTM), infusion, filament winding and prepreg-based processes. It cures at 150°C and offers glass transition temperatures of 100°C (entry level), 130°C (intermediate level) and 190°C (advanced).
- **American GFM** (Chesapeake, VA, US) featured in its booth US120/CM10, a highly automated, three-zone marking/cutting/offloading ply-cutting and kitting system. It features an ultrasonic cutter that, American GFM guarantees, does not leave uncut threads. The ply-picking system features a six-axis robot that organizes plies into kits in an indexing drawer system. The entire system is adaptable to a variety of ply lengths; similarly, each of the three zones can be adjusted in length depending on throughput and ply size requirements. In addition, smaller systems can combine the marking and cutting function.
- **DUNA-USA** (Baytown, TX, US) featured the latest iteration of its Black Corintho tooling board, and had in its booth an epoxy-sealed tool made from the material. The tool was used to mold an autoclave-cured part made using **Airtech International's** (Huntington Beach CA, US) Beta Prepreg benzoxazine prepreg (see photo, p. 24).
- Start-up **MITO Materials Solutions** (Stillwater, OK, US) introduced at SAMPE its MITO T-Series, a non-nanotube nanoadditive for use with epoxies, vinyl esters and polyesters to provide a 100% increase in toughness and an 80% reduction in mechanical failure risk. The material, which is loaded into resin at 0.1-0.2 wt%, also offers a thermal resistivity increase of 12-14°C. MITO T-Series is being targeted first toward recreational vehicle sidewalls, which have a poor history of stress cracking, which leads to substantial costs in warranty repairs. Another targeted application is in marine base resins to resist temperature increase caused by gel coat magnification.

SAMPE 2018 keynote looks to the composites future

The SAMPE 2018 general session featured the announcement of the top three papers presented at the conference, and a keynote presented by Carmelo Lo Faro, president, Solvay Composite Materials (Alpharetta, GA, US).

The top three papers were:

- *First place:* "Fabrication of Out-of-Autoclave Prepreg with High Through-Thickness Permeability by Polymer Film Dewetting," Sarah G. K. Schechter, Timotei Centea and Steven R. Nutt
- *Second place:* "Warpage of Thin-Gauge Compression-Molded Panels with Discontinuous Long Fiber Carbon/Polyetheretherketone," Caroline Collins and Pascal Hubert
- *Third place:* "Recycling of Amine/Epoxy Composites Using Chemical Treatment at Atmospheric Pressure," Yijia Ma, Travis J. Williams and Steven R. Nutt

For his keynote, Lo Faro surveyed the materials evolution, from copper in 8700 BC, straw/mud bricks in 2500 BC, steel in 1851 AD, aluminum in 1889, titanium in 1950, to the evolution of composites in the 1950s and 1960s, followed by the growth of aerospace technologies (1970-2010) in commercial and defense-related breakthroughs.

With that as context, he spoke about three 'eras' of composites: The lightweighting era (1970-1995), the manufacturing era (1995-today) and the next era, which he deemed the industrialization and simulation era.


Source | *CW*

He pointed out that automation of manufacturing processes has been a significant enabler of composites construction in the commercial aircraft structures arena. Today's infusion technology enhances affordability and results in a viable manufacturing rate, he added, citing Bombardier's (Montreal, QC, Canada) *C Series* wing, made with high-pot-life resin and non-crimp fabric. He highlighted the CFM LEAP engine fan blade, made using toughened resin and 3D woven preforms; and Moscow, Russia-based Irkut's *MS-21* wing, made via automated fiber placed dry tape infused with toughened resin. "I don't believe aluminum and titanium accomplished as much in their first 30 years as composites have in their first 30 years," he argued.

Can we claim victory? Lo Faro asked. In short, he answered, *no* — a lot more can be done. To grow further, composites must deliver more value, he said. Future challenges and opportunities might include press forming, thermoplastic composites for large structures, additive manufacturing, joining, simulation, managing complexities, and, of course, cost.

LoFaro did inject "a little caveat — the *hype cycle,*" where interest becomes exaggerated enthusiasm (hype), and then, "after a time of disillusionment," finds its place in reality. The future, he said, will be driven by industrial scale and economies; convergence of aerospace and automotive practices; and the increased importance of production systems vs. end-products.

Moving on to thermoplastic composites, Lo Faro discussed PEEK, PEKK, PAEK and continuous compression molding. Thermoplastic composites are not new, he reminded his listeners. Further, he expects growth in the 21st Century to be enabled by maturation of cost-effective, automotive-like manufacturing processes developed in the past 15 years: notably compression molding, continuous compression molding and stamp forming. If the aerospace supply chain is to develop and build large thermoplastic composite structures then it must mature out-of-autoclave molding/forming systems capable of rapid heating/cooling.

Lo Faro also touched on additive manufacturing (AM). Initially, he said, AM can support manufacture of tooling and fixtures. In the future, AM can provide on-demand tool manufacturing, and can improve composites maintenance and repair operations (MRO). Here too, he said, are opportunities to couple AM with machine learning. However, he said, more collaboration is needed between machine and material suppliers.

Lo Faro went on to name three important simulation and modeling needs for the composites industry:

- *Molecular modeling* — informing experimentation and increasing speed to market
- *Artificial intelligence* — applied to materials design and discovery
- *Certification by analysis* — which he called the *Holy Grail*

These technologies have the potential to shorten development time through optimized molecular design for improved properties, changing the way the materials themselves are developed. The future is now, he said, for multi-scale modeling to accelerate composites innovations and adoption and failure prediction.

Lo Faro finished optimistically: "When we look at the next 40 years, I believe composites are a material that will exceed the capabilities of metals."

AUTOMOTIVE

Lightweighting summit: Targeting composites auto powertrain opportunities

Source | Vyncolit NV & Sumitomo Bakelite Co. Ltd.

The Lightweight Composites Solution Conference, held May 17 in Gent, Belgium, focused on materials and designs for reducing automotive powertrain weight. Organized by Vyncolit NV (Gent, Belgium) and parent company Sumitomo Bakelite Co. (Tokyo, Japan), the event brought together more than 50 experts from leading OEMs, suppliers and research institutes in the field of automotive lightweighting, including automakers Nissan Motors (Yokohama, Japan), Volkswagen (Wolfsburg, Germany), Renault Nissan Mitsubishi (Amsterdam, Netherlands) and R&D/design organizations, including FEV Europe (Aachen, Germany), Brembo (Curno, Italy), the Fraunhofer Institute for Chemical Technology (ICT, Pfintzal, Germany), and more.

A key message delivered at the summit, according to a Vyncolit and Sumitomo Bakelite, is that designers and builders of auto powertrains of all descriptions — conventional, hybrid and fully electric — will need to lightweight their products to a greater degree if carmakers are to meet the stringent regulations on carbon dioxide emissions (CO_2) that will come into force in 2025 — and composites will be key to making this happen. For example, the European fleet average emissions requirement for new cars in 2021 is 95g of CO_2 per kilometer. By 2025, this could be reduced further to 75g of CO_2 per kilometer. The average emissions level of a new car sold in 2016 was 118.1g of CO_2 per kilometer. Given that the powertrain accounts for 32% of an electric vehicle's weight, reducing this figure will be a key to enabling these vehicles to travel further on a single charge, thus the use of smaller, less-expensive batteries.

The managing director of Vyncolit NV, Pieter Vanderstraeten, told conference delegates: "All OEMs, have a lot of work to do in the next six to seven years. Lightweighting will be key in hitting these targets, regardless of the drivetrains employed."

Nissan's general manager of planning group, powertrain technology and prototype development department, Kimio Nishimura, outlined the OEM's mid-term plan *"M.O.V.E to 2022"* to accelerate the electrification of its vehicles in order to hit the CO_2 targets. He highlighted the need for compact, efficient and powerful motors, and heat-resistant, thermally conductive and low-permittivity (i.e., the ability to resist an electric field) materials for their construction.

For example, Fraunhofer ICT's Lars-Fredrik Berg talked delegates through the *DEmiL* project, the aim of which is to develop a direct-cooled electric motor with an integrated lightweight housing that delivers power on a consistent basis. A highly filled, low-viscosity epoxy from Sumitomo Bakelite is used to overmold the motor's stator. Channels are formed during this transfer molding process that help to cool the active materials, helping to produce a motor with a very high, weight-specific power output. Further, Vyncolit NV's chief innovation and technology officer Hendrik De Keyser told delegates that the use of phenolic resin for the manufacture of brake pads can cut the weight of the brake systems in a car by 1 kg.

Conference chair, Fraunhofer ICT Institute leader Frank Henning, noted, "Two thirds of all innovations are based on developments in materials science. Materials seem to be old economy, but they are enablers of the new economy."

CW MONTH IN REVIEW

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06/11/18 | short.compositesworld.com/BallyNASA

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The European Composites Industry Assn. expands with the addition of Composites UK, the trade association for the UK composites industry.
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A second office building and manufacturing hall will be added to the prepreg manufacturer's Heinsberg-Oberbruch location in response to business growth.
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Rolls Royce launches Pearl family of engines
They will be used for Bombardier's *Global 5500* and *Global 6500* business jets.
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Arevo's 3D-printed commuter bike supported by Hexcel carbon fiber
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Airbus awards Teledyne CML Composites an A350 Life of Program contract
The package includes a range of composite parts for the Airbus A350-900 and the A350-1000 aircraft wing structures.
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PolyOne acquires PlastiComp
The latter brings its Complēt product lines and design capabilities in long-fber technology (LFT) to PolyOne as part of its Specialty Engineered Materials segment.
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Innovate UK backs Oxford-based automated composite tooling company
Mouldbox has received a grant from the UK innovation agency to develop its machine learning platform and design-to-product composite tooling service.
06/04/18 | short.compositesworld.com/InnoUK

MidAmerican Energy takes aim at 100% renewable goal with Wind XII project
The 591-MW wind energy project is expected to be completed in late 2020.
06/04/18 | short.compositesworld.com/WindXII

Fuselage of the future?

MTorres' (Torres de Elorz, Navarra, Spain) aircraft fuselage demonstrator, made without a removable mandrel or fasteners, is shown here with the crew that created it. A detailed, almost entirely automated factory concept for manufacturing the fuselages was released at the 2018 JEC World exhibition.

Source (all photos/images) | MTorres

A complete paradigm shift in aircraft construction

With its new Torreswing automated system for mold-free, fastener-free composite fuselage and wing construction, MTorres aims to revolutionize aerostructure.

By Sara Black / Senior Editor

» Everyone is talking about "one-minute" cycle times as a means to increase composites' acceptance in the automotive industry. But that drive for shorter production cycles through development of more time-efficient materials and processes is no less important in the aerospace world. As aircraft build rates continue to ramp up, the need to control the cost of aerocomposites is critical as well. Toward that end, changes are underway in design, materials and processes.

A new aircraft structure production concept, called Torreswing, aims to bypass incremental development and, instead, target disruptive change in fuselage and wing fabrication technology by eliminating conventional tooling and the use of fasteners during automated fabrication of large, one-piece monocoque structures. Developed by machinery manufacturer MTorres (Torres de Elorz, Navarra, Spain), this radical departure from the manufacturing norm made its debut in 2017. It was recognized with a JEC Innovation Award in the category Aerospace Process at the 2018 JEC World exhibition in Paris, and was exemplified by a demonstration fuselage (see the opening photo) on display at the MTorres stand.

CW had the opportunity to interview MTorres' Integrated Assembly group's key account manager for the technology, Luis Enrique de la Iglesia y

Gotarredona, and R&D business development manager Iñigo Idareta, and thus got this exclusive look at how the process works.

Factory of the future

Composites' use on commercial and general aviation (GA) aircraft has increased significantly over the past decades, and so has the use of automation in aerospace fabrication. Obvious examples are the use of automated fiber placement (AFP) to make the fuselage barrels of the Boeing 787, the wings of Airbus' A350, the wing spars and wings of Boeing's 777X, and, more recently, the FLEXMONT project's process for robotic assembly of Airbus vertical tail planes (see Learn More, p. 34). That said, a great deal of touch labor is still required to assemble a finished plane.

"The basis of the Torreswing process is a simple and easy-to-automate concept," said De la Iglesia y Gotarredona, while illustrating the Torreswing process using two animated videos on display at the JEC World event, showing manufacturing steps that eliminate nearly all hand labor.

"A series of 'elemental parts' [Fig. 1, bottom right] are made first." He explained. "Those elemental parts then become the molds on which a monocoque fuselage is created." In the case of an aircraft fuselage, those elemental parts include multiple carbon fiber composite frames, or rings, sized to the aircraft, and flat floor panels. Finished frames are butted together, adhesively bonded, and the floors placed inside the rings, to form the fuselage "skeleton" that is overwound via fiber placement to form the outer skin. The concept simplifies manufacturing and eliminates the metal fasteners that would otherwise join fuselage sections, or attach skin to stringers/frames. Wings and tail also would be made in a similar automated process, but no information is yet available for the wing process, which is still under development. "The current concept uses dry fiber and resin infusion, born from our experience in wind blades," says Idareta, but he points out that "it can accommodate prepreg, or thermoplastic materials, as the customer wants."

In the automated factory scenario, a small army of industrial robots and positioners shuttle parts from one station to the next, in a U-shaped workflow. "The factory and manufacturing concepts have increased the level of automation and reduced the number of required tasks, and it's certainly doable today with the MTorres integration machines," claims De la Iglesia y Gotarredona.

Assembling some essentials

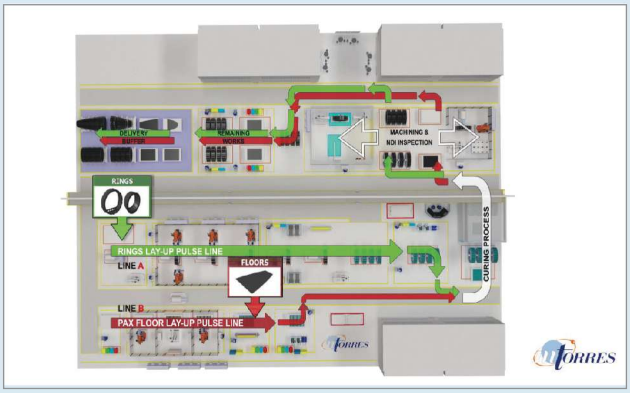
Phase I begins with the elementals. In the ring layup line, which runs parallel to the floor layup line (See Step 1, p. 32), a robot transfers a metallic, collapsible ring mandrel, customized to the customer's aircraft fuselage shape and size, onto a rolling positioner robot, equipped with a rotating headstock. The positioner moves into the next station, between two stationary MTorres AFP heads mounted on robotic arms, that quickly lay dry carbon fiber tape onto the mandrel surface, which is *grooved* on the outside (Step 2, p. 32). More on the purpose for the grooves, below. The layup, as proposed in the concept, has 0°, 90° and ±45° plies, but can be optimized for each application. MTorres has developed its own dry carbon fiber tape for the process, using carbon fiber from a proprietary source, to which it adds a heat-activated thermoplastic binder, which functions both to give the tape some tack during layup and to enable infusion performance.

Note that, on the front and back side of each ring, a flat plate is fiber placed (Step 3, p. 32), to create support for the floor panels. Next, the rings are prepared for resin infusion, with technicians bagging the layups and adding resin feeder lines. After bagging, a robot places the bagged rings on an automated transfer jig, which moves the rings to the infusion station, manned with technicians who oversee the resin infusion and vacuum.

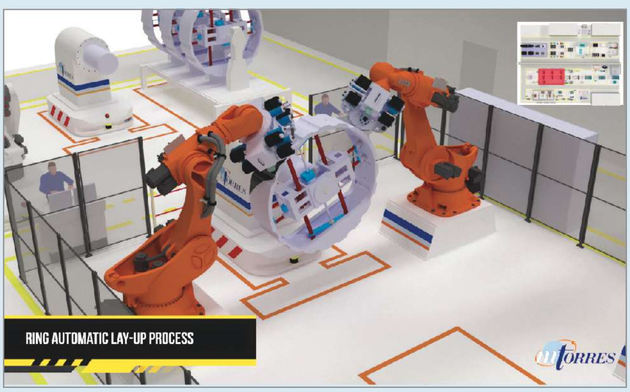
Meanwhile, at the floor layup line, three robotic arms work in concert to produce the flat floor panels. The first robot lays a 0°/90° laminate on a flat table mold, which is attached to a moving floor or jig feed line. The moving line takes that layup to a second station, where a robotic arm equipped with a pick-and-place end-effector places foam core over the laminate. At the next station, a third robot places a 0°/90° laminate skin over the core. The thickness and ply architecture of the panels are customized to the requirements of the application, says the company. Panels are largest, and square in shape for the middle part of the fuselage, »

FIG. 1 Replacing tools and stringers with ride-along rings

"Elemental" parts are fabricated first, including floor panels and frames or in the case of a fuselage, rings, like the one shown here. Such frames and rings, made of carbon fiber composite, are butted together and bonded, taking the place of and performing the same function as a mold or mandrel when the AFP equipment overwinds the fuselage skin.



1 Factory of the future: An overview of MTorres' factory concept for automated production of aircraft, using robots.



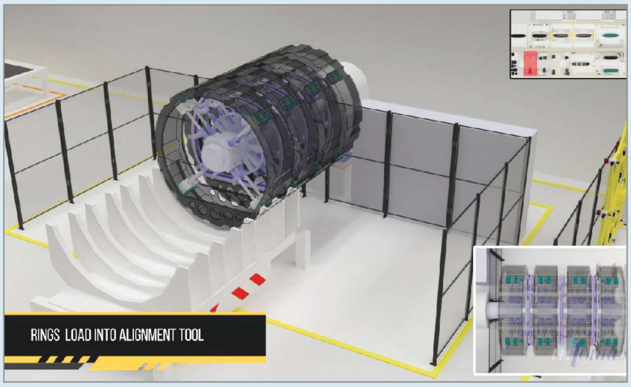
2 "Rings" or fuselage frames are produced first, via automated fiber placement (AFP) on metal mandrels. Two robots would work together, to reduce layup time, as the mandrel rotates on the positioning robot. Note that the rings have grooves, which will act as exterior stringers when overwound during final assembly.

3 After completion of the ring layup, the positioning robots move the rings to the bagging area, where the rings are prepped for resin infusion, and cure. Note that the flat plates that extend across the bottom of each ring will act as supports for the fuselage cabin's floor panels.

4 On a parallel production line, the flat floor panels are produced. A moving line brings flat table molds into position in front of stationary robots, which lay the lower skin, core panels and upper skin, in sequence.

5 Like the rings, floor panels are bagged and prepped for infusion and oven cure by technicians.

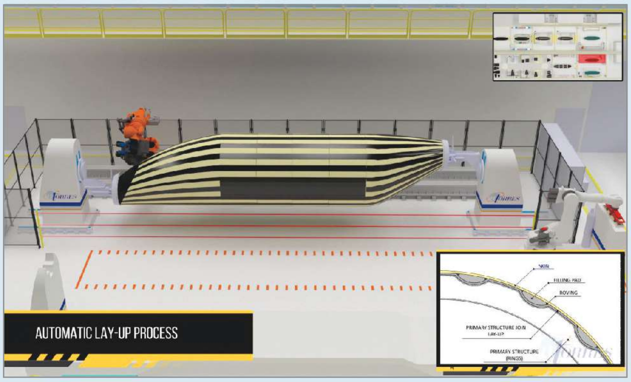
6 After oven cure is complete, parts are transported to the machining area, where a robot trims and creates openings in the rings' floor supports, and trims the floor panels. Shown here is a robot collapsing and removing a ring's mandrel. Following this step, the elemental parts undergo non-destructive inspection.



7 In a second building or manufacturing area, where final body joinery takes place, rings are brought to an alignment tool (note the robotic transfer jig that has transferred the group of four rings), where robots check for ring alignment and fit, and dispense.

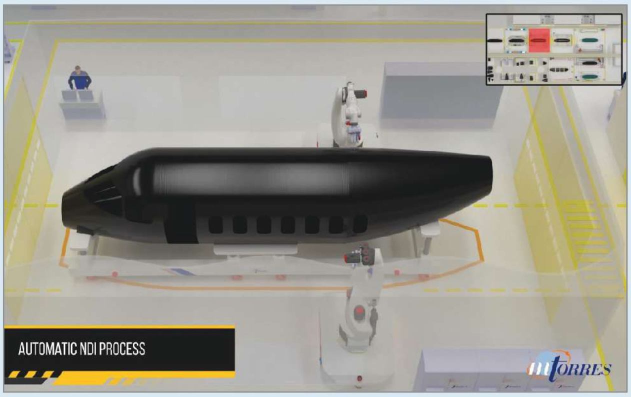
8 This photo shows the demonstrator fuselage rings being aligned and bonded, in this case, manually, but on a similar alignment tool as would be used in the factory concept.

9 Here, a larger alignment tool brings together all the fuselage segments, from nose cone to tail end, to check for fit, apply adhesive and bond the segments to create a complete fuselage structure.



10 After the complete fuselage is moved to the next station, it is installed in a layup machine with headstock and tailstock, and overwound with dry carbon fiber to form the fuselage skin. This image shows the filler material that has been robotically placed within the ring grooves; as the skin covers the grooves, it creates external stringers to stiffen the fuselage structure, says MTorres. The filler can be left intact as insulation or removed after skin cure.

11 This actual photo shows dry fiber placement over the rings, to create the demonstrator's skin. In actual practice, copper mesh for lightning strike protection would be added as well. Following standard caul placement, bagging, infusion and skin cure, a robotic machining station cuts out the door and window openings.



12 At the end of the final body join, automated nondestructive inspection occurs. Following this step, the fuselage is outfitted with its interior and any remaining systems, and is ready for shipment.

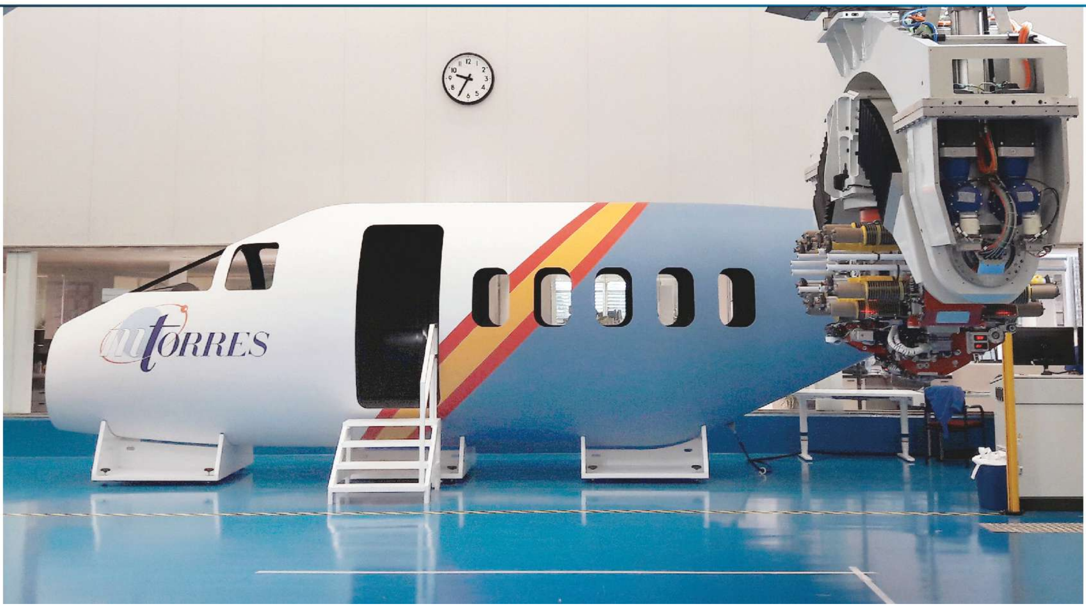


FIG. 2 The product and the process

The finished demonstrator inside the cleanroom manufacturing environment in which it was fiber-placed. Multiple customers have expressed interest in the automated factory concept as well as the fuselage's design principles.

but are produced in smaller, tapered shapes for the narrower tail and nose areas.

The completed, flat, cored panels are vacuum bagged and resin infused. At this point, small positioning robots automatically transfer the bagged and infused rings and floor panels to an oven for curing.

After cure, positioning robots ferry the cured parts to the next station, where the parts are unbagged and then placed in a workcell where a robotic arm with a cutting head performs machining steps. These include cutting holes in the flat plates on each ring (which will support the floor), to reduce weight and allow for wiring. The edges of the floor panels also are trimmed. As machining concludes, a robot extracts the mandrels from inside the cured rings and carries them back to the start of the ring layup line. Each part undergoes robotic nondestructive inspection (NDI) and then is carried to a final station where human inspectors look over each part and perform any remaining tasks prior to the next phase.

LEARN MORE

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

Read more online about FLEXMONT robotic vertical tail plane assembly in "The future of CFRP aerostructures assembly" | short.compositesworld.com/FLEX-VTP

Flexible "flying mandrel"

Completed elementals are assembled in a "final body join" process, within a second manufacturing hall. At the barrel assembly station, the completed rings are robotically loaded onto an alignment tool, from a transfer jig. Two robots take up positions on each side of the alignment tool and scan the rings to document their exact sizes, so that the best fit between them can be determined. Then, having determined the locations of gaps, the robots apply adhesive in greater or lesser amounts depending on the degree of misfit, and the alignment tool pulls the rings together to form a barrel, and ensure complete contact with the adhesive (Step 7, p. 33).

At the next station, the bonded barrel is placed on another jig by a positioning robot, where the two scanning robots scan the floor panel and the floor support plates within the barrel for best fit. While one robot uses an end-effector to pick up the floor panel, the second applies more adhesive to bond the floor panel to the support plates. As each fuselage segment is bonded and finished, human workers install wiring, ducting and other systems beneath the floor panels or inside the fuselage space.

This process is repeated for each fuselage segment, from nose to tail, to form a structural assembly of rings and floors — in essence, a full-sized mandrel for the next step of the process (Steps 8-9, p. 33). "No large metallic tooling is necessary. The carbon fiber elements, in any size or shape, act as mandrels or tools, and the remainder of the part is fiber-placed over those elements," explains De la Iglesia y Gotarredona. And the use of adhesively bonded segments easily enables the use of larger, smaller and/or a greater or lesser number of segments necessary to create a fuselage of the length needed for a particular aircraft.

Rings replace stringers

At the next station, automated positioners place the structure in a station with rotating headstock and tailstock fixtures, and an MTorres fiber placement head begins placing dry fiber over the assembled rings to form the fuselage skin. The first ply is placed down into the grooves created by the rings, noted above (Step 10, p. 33). . Then, a robot places pieces of "filler" material into the grooves. Filler material could be foam, which could remain in place as insulating material, or another type of material that would be removed after cure of the skin, perhaps a dissolvable material, explains Idareta.

Says De la Iglesia y Gotarredona, "The grooves essentially act as stringers on the *outside* of the fuselage, when overwound with a skin to form a hat structure. This is a huge departure from today's aircraft construction, which has longitudinal stringers and circular frames, typically made separately and installed by hand on the inside of the skin. The overwound grooved rings replace all of that." He adds that in existing composite aircraft, MTorres calculates that stringers account for 30% of the material but 70% of the cost.

When the overwinding is complete — a five-layer laminate (Step 11, p. 33), for a total thickness of less than 4 mm in the skin/ring structure, was used in the demonstrator (again, customizable for a specific aircraft) — cauls are placed, the entire fuselage is bagged, the skin is infused with resin and oven-cured. After cure, the fuselage is transferred to a machining cell, where a robotic head cuts window and door openings. Then it is taken to the final station before shipment (Step 12, p. 33), where workers manually install required electronics and avionics, and add seating.

Is this the future?

The Torreswing process is designed to eliminate virtually all metallic fasteners and rivets, a significant weight savings over today's aircraft, says the company. The adhesive used to bond the elemental rings, says Idareta, would be equivalent in weight to the shimming material used on conventionally built aircraft. And, with the high degree of robotic automation, cycle time and touch labor would be significantly reduced, resulting in process simplification and much lower manufacturing costs. For example, he adds, the number and size of part-specific tooling and the time needed for part production on that tooling would reduce manufacturing costs significantly. Other advantages include elimination of the autoclave in favor of oven cure, and use of dry fiber, reducing material cost.

Although it's a TRL 6 project, only one demonstrator has been built so far — the fuselage shown at JEC, using equipment similar to that depicted in the step photos. But there are plenty of opportunities for a first customer trial. "There are a lot of proposals for new aircraft today, and we see a big market, which we believe would justify this factory concept." Idareta acknowledges, of course, that certification of a bonded structure could be a challenge, given a regulatory environment that currently requires redundant fasteners for certification. "Our point of view," he says, "is how to enable the plane of the *future* using the factory of the *future*. We've designed for automation, not just for manufacturing." He also notes that a number of composites manufacturers in other industries are showing interest in the automated factory concept *behind* the innovative aircraft design, taking care to point out, "We're *not* aircraft designers, we're factory automation specialists." CW

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Drones: Composite UAVs take flight

First seen in defense applications, unpiloted aircraft development is surging in the commercial world, enabled by a host of new material, process and assembly technologies.

By Michael LeGault / Contributing Writer

» Change, better yet, rapid change. This best characterizes the current state of unmanned aerial vehicle (UAV) design and manufacturing. One big change is the terminology. UAVs are now *drones*, and drone technology, at one time, almost exclusively confined to military missions, are defying limiting definitions and finding use in hosts of cutting-edge industrial, commercial and consumer applications. No longer limited to control by humans on the ground, drones also are shaping the destiny of autonomous technology — what it will be and how it can be used.

On the radar: Drones for communication, automation

One of the great promises of composites use in drones is as an enabler for persistent, long-duration systems that provide wide-area Wifi Internet access. Ideally, such drones would be solar-powered and able to serve land areas of many square miles with uninterrupted Internet access for weeks at a time. There are at least two programs pursuing this technology, and results so far are promising, if mixed.

One is the work of social media giant Facebook (Menlo Park, CA, US), and the other, a product of the Massachusetts Institute of Technology (MIT, Cambridge, MA, US). Each has built and flown prototypes and aims to achieve

FIG. 1 The first of an autonomous WiFi fleet

Facebook's (Menlo Park, CA, US) Aquila, an all-carbon-fiber, solar-powered, four-propeller drone prototype shown here during its second flight test, is the drone at the center of an ambitious effort to design and build a fleet of UAVs capable of several months of continuous flight at altitudes of 60,000-90,000 ft (18,290-27,430m) to supply broadband signal to millions of people around the globe who are without access to the Internet. The plane has a wingspan in the range of 110 ft (±34m) and weighs about 1,000 lb (454 kg), much of the mass contributed by its batteries.

Source | Facebook

FIG. 2 Short-term, emergency communications drone

This team of engineering students at the Massachusetts Institute of Technology (MIT, Cambridge, MA, US) designed, built and fight-tested, at low altitude, this UAV prototype with 24-ft (7.32m) wingspan, made entirely from carbon fiber and Kevlar. A product of the US Air Force's Jungle Hawk Owl project, the UAV's performance goal is to fly continuously up to five days at an altitude of 15,000 ft (4,572m), to provide temporary communications in the event of a disaster. Source | MIT

unprecedented UAV flight durations with radically new designs, which, by necessity, hope to maximize the advantages of advanced composites.

In development since 2014, Facebook's *Aquila* (Fig. 1, p. 36), an all-carbon-fiber composite, solar-powered, four-propeller drone, has been test flown twice. In 2016, it was aloft for 96 minutes below 305m, and this past year, it flew for about 106 minutes, reaching an altitude of 914.4m. The *Aquila* is intended for big things: *Aquila's* stated target customer base is the several *billion* people around the world without reliable online access. Given the enormous geographical scale, the drone must be capable of very long, uninterrupted flight, and that, in turn, has profound consequences for *Aquila's* flight performance and design parameters. Facebook must build and launch pilotless aircraft capable of continuous flight for *months* and at very high altitudes — 60,000-90,000 ft (18,290-27,430m). At this height, the drone can provide WiFi coverage over about 60 square miles. When the technology is perfected, Facebook CEO Mark Zuckerberg has stated he intends to build a fleet of the drones.

Although this is potentially good news for the composites industry, Facebook has released little specific engineering detail about the *Aquila* or the carbon fiber materials and laminate used to construct it. *CW* has learned that the flight-tested version has a "wingspan wider than a Boeing 737," which puts it in the range of 110 ft (±34m). Foregoing the extra weight and drag of conventional landing gear, the *Aquila* also is equipped with a Kevlar "landing pad" bonded to the bottom of the motor pods, one reason it only weighs about 1,000 lb (454 kg), with roughly half of that mass accounted for by batteries. Zuckerberg, however, has made clear that the drone needs to be made even lighter.

When traveling upwind, the drone flies, by design, at a land speed of only 10-15 mph, which keeps it centered over the target area intended to receive signal. The communications system will use lasers to transfer data, which is about 10 times faster than land-based fiber optics. On the drone's second, most recently flown version, an unspecified coating material applied to the wings created a "smoother finish" and is credited for doubling its climb rate to 54.9m/min, compared to the climb rate of the first drone. That said, it remains to be seen if *Aquila's* ambitious flight duration goals can be met using only solar power. The project's main challenges in the next phase, according to posts on the *Aquila* Facebook site, are solar panel efficiency, battery storage and achieving acceptable cost paradigms for operation. Facebook says it intends to expand the test program to include drones with different "form factors, sizes and weights," and fly to higher altitudes in the next round of test flights.

Meanwhile, a team of MIT engineers has designed, built and tested a UAV with a 24 ft (7.32m) wingspan, fabricated entirely from composites reinforced with carbon fiber and Kevlar (Fig. 2, this page), The objective of the UAV development project, dubbed »

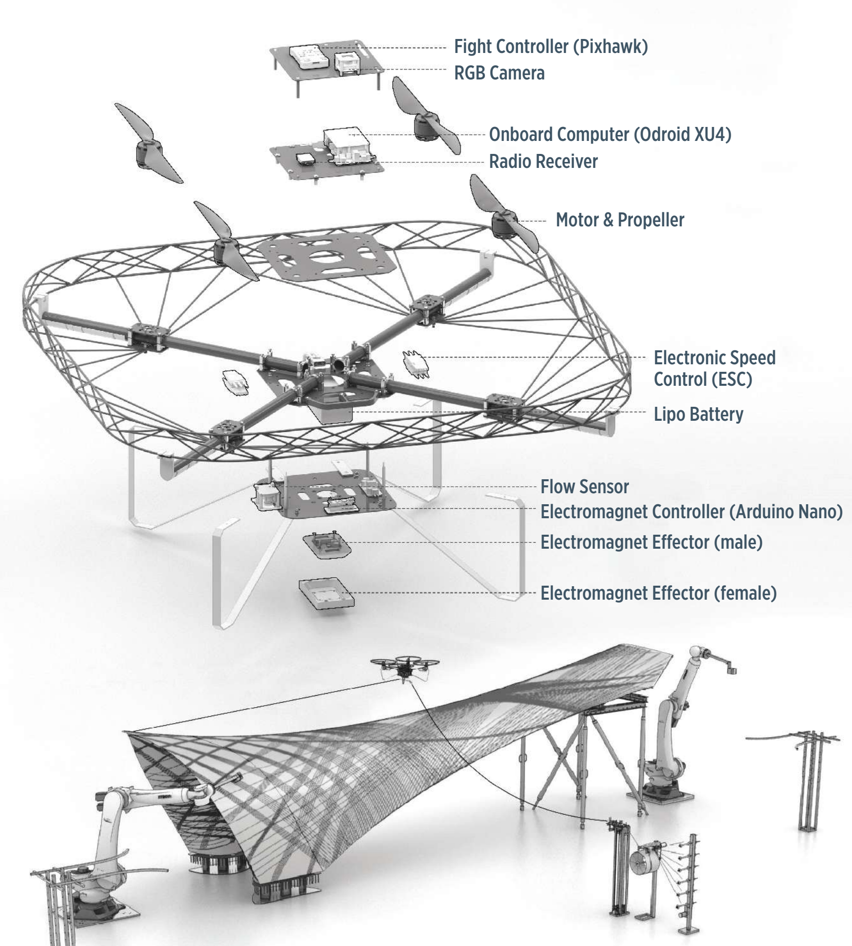

FIG. 3 Drone incorporated into robotic workcell

A "collaborative" fiber-winding process recently demonstrated by researchers at the University of Stuttgart consists of two, six-axis KUKA robots and a lightweight, custom-built drone or UAV "go-between." The robots precisely place wet-or pre-impregnated fiber on the winding frame, while the drone shuttles the fiber between each of the robotic arms. The project demonstrated the capability of the drone-aided fiber winding to fabricated long-parts normally exceeding the reach of a single, stationary robot. Source | University of Stuttgart

Jungle Hawk Owl and funded by the US Air Force (Gateways Branch, AFLCMC/HNAG, Hanscom Air Force Base, Bedford, MA. US), is a bit more modest than that for Facebook's *Aquila*. The goal is to build a drone capable of staying aloft for five or more days, in high and low geographical latitudes, in all seasons, at an altitude of approximately 4,572m. Such a drone would be designed to perform as a communications hub, providing temporary Internet/phone connections over a large area in the event of a wide-scale power or service outage.

The drone's design was modeled on a glider, with a typically thin aerodynamic profile. The first, full-scale version, test flown this past year at a maximum altitude of 122m, has a wing thickness of 42.4 mm tapering to 20.8 mm, and a total, empty weight of only 12.7 kg. After minor adjustments to the aircraft and its automotive rooftop launch system are complete, high-altitude flight tests are scheduled for this summer, with the drone carrying a full payload of communication equipment and fuel, weighing up to 45.4 kg.

John Hansman, professor of aeronautics and astronautics at MIT and one of the staff supervising the student research, a collaboration between MIT and the MIT Lincoln Laboratory (Lexington, MA, US), reports that the wings comprise a core sandwich molded in a two-step process. To achieve the necessary aerodynamic precision, the wing's upper surface skin was molded separately, via vacuum infusion, from one ply of unidirectional carbon fiber fabric oriented 90° to the length of the wingspan. To make the bottom wingskin, spar caps of varying thickness were molded from unidirectional fabric and placed in the mold. Styrofoam was then placed

SIDE STORY

Drones: MIT software casts doubt on solar-powered UAVs

Developed at the Massachusetts Institute of Technology (MIT, Cambridge, MA, US), the *Jungle Hawk Owl* unmanned aerial vehicle (UAV), funded by the US Air Force in an effort to develop a way to provide a drone-based alternative method of WiFi access, relies significantly on composites for its lightweight construction. One reason was the hope that the aircraft could be kept aloft for extended periods, exclusively by solar power.

Using a new modeling software tool called geometric programming optimization, however, researchers discovered that the goal of powering the drone with solar energy was infeasible. The program, called GPkit for short, was developed at MIT by Warren Hoburg, professor of aeronautics and astronautics and a member of the project team that is designing the *Jungle Hawk Owl* drone.

The GPkit program reportedly facilitates consideration of about 200 factors and physical models simultaneously, and then integrates them to create an optimal aircraft design. In the case of the solar-powered drone, the model determined it would work during the summer season in either hemisphere, but not in the winter. Further, it indicated that adding more batteries would make the drone too heavy. Alternatively, the same modeling predicted that a 5-hp gasoline engine would be sufficient to keep the drone in flight for more than five days at an altitude of 4,572m in up to 94th-percentile winds at any latitude.

Hansman says the GPkit tool provided a "state-of-the-art" design optimization technique. "In terms of its structural aerodynamics," he adds, "this plane is exquisitely proportioned."

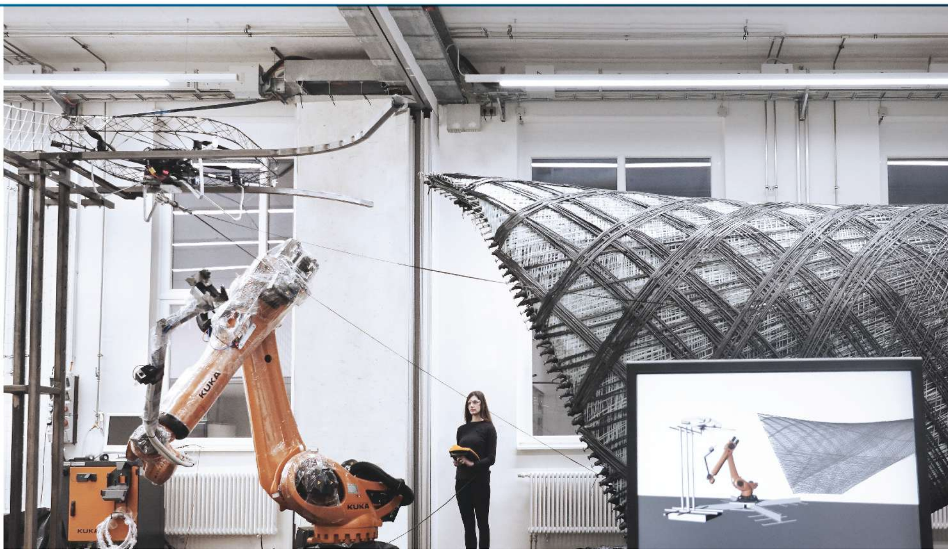

FIG. 4 Production drone in action

Researchers at the University of Stuttgart put theory into action, fabricating this long-span demonstrator "cantilever" structure by the novel fiber-winding process described in in Fig 3 (p. 38). The 12m long part, representative of long-span parts, such as roof sections or pedestrian bridges that could be built using the process, was wound from a combination of continuous glass roving and continuous carbon fiber tow, both pre-impregnated (epoxy) and dry fibers dipped in an epoxy resin bath.

Source | University of Stuttgart

around and between the spar caps, and the bottom skin was vacuum bagged in place against the construction. The top skin was then fitted to the bottom and wrapped in 12K tow. All fabrics were infused with West Systems 105, a low-viscosity epoxy supplied by Gougeon Bros. Inc. (Bay City, MI, US). All molds were CNC-machined from RenShape 440 polyurethane foam, provided by Freeman Manufacturing & Supply Co. (Avon, OH, US).

To make the fuselage, which houses its gasoline engine (see the Side Story on p. 38) and fuel tank, the team used a simple cylindrical concrete mold, applied two plies of unidirectional fabric, one at 90° and one at 45°, to the inner diameter of the tube, then used a toroidal vacuum bag positioned through and around the tube, to vacuum infuse the fabric, with the outside layer of the laminate positioned against the inner wall of the tube. To fabricate the nosecone, which contains the communications electronics, an external conic-shaped mold was machined in two halves from foam. A single layer of 0° Kevlar fabric was laid up on the mold halves (which had been bonded together) and vacuum infused. »

Drones: Fire-management technology delivery

The new IGNIS remotely controlled pyrotechnic system, designed by Drone Amplified (Lincoln, NE, US) specifically for transport on UAVs for the purpose of prescribed-fire management on public and private lands, was recognized on the US Department of Interior's 2017 list of top made-in-America innovations.

Launched last year, the patent-pending technology carries aloft a payload of ping pong ball-sized chemical spheres, which, upon command via radio from the ground, are injected with glycol, starting a chemical reaction that, after the spheres are released to the ground at the desired location, burst into flame to target an intentional fire start. When used for back-fire ignition to halt an out-of-control wildfire, the system minimizes the need to put human fire fighters in hazardous situations.

James Higgins, Drone Amplified's lead engineer and one of the founders of the company, says the IGNIS payload package can be provided already loaded on a UAV or can be integrated onto the UAV of the customer's choosing. That package includes parts made from CNC-milled carbon fiber composite plate, 3D-printed components and milled aluminum parts.

Higgins reports selling one of the first IGNIS drone systems to commercial UAV service provider 3FB Aerworx Pty. Ltd. (Ringwood, VIC, Australia), and also recently recorded a sale to the US Department of Interior. He says the company is in the process of securing new contracts with state and commercial agencies, with product deliveries expected this summer.

Airborne risk-reduction

Drone Amplified's (Lincoln, NE, US) IGNIS/drone payload package is used for prescribed fire management of public and private lands. Retrofitted on a drone, the system can be used to remotely start back fires during out-of-control wildfires, avoiding risk to human firefighters.

Source | Drone Amplified

Drones — new players in industry

Drones are having an impact in the industrial realm, going aerially where it is more difficult and expensive for workers and conventional machinery, including robots, to go.

One application with a potentially huge future is safety inspection of aging wind blades. UAVs equipped with cameras for military surveillance were one of the earliest uses of the technology. Today, drones fitted with special cameras, and operated autonomously by extremely sophisticated software, can inspect a giant wind turbine's rotor blades in as little as 15 minutes, (inspection by a human can take an entire day), and forward visual evidence of damage to a Web portal for onscreen viewing by inspectors in more comfortable surroundings. *CW* covered this growing drone-based business phenomenon in its May issue (see Learn More).

A group of researchers at the University of Stuttgart's (Stuttgart, Germany) Institute for Building Structures and Structural Design and Institute for Computational Design have demonstrated a novel and clever method of using drones in combination with industrial robots to fabricate a long-span composite structure via a fiber-winding process. Collaborative winding, as it is called, entails the use of two stationary industrial robots and a custom-built, lightweight drone or UAV "go-between" to fabricate long-span structures in the interstitial space between the robots (Fig. 3, p. 38). In simple terms, the fabrication layout establishes a favorable division of labor which capitalizes on the strengths of both machines — the robots are used to precisely place the resin-impregnated roving on the winding frame, while the drone shuttles the fiber from the spools to each of the robotic arms, thereby circumventing the limitation imposed on part size by the robot end-effector's reach envelope. Until now, the primary alternative to fabricating large parts exceeding the reach of the robot was to build the part by modularization, a process that is less than ideal, especially if the fabricated structure is load-bearing.

The project was the work of eight researchers at the University and is summarized in the paper "Multi-Machine Fabrication," published in the November 2017 edition of *Acadia*, a journal of interior architecture and spatial design. The workcell comprised two, 6-axis KUKA (Augsburg, Germany) KR 210 R3100 Ultra robots, equipped with steel extensions, a hydraulic gripper to grasp the winding effector from the UAV, and an infrared camera used to synchronize the robot's locations with the UAV. A custom tension mechanism, based on tension devices used in extrusion and rolling applications, provides control over fiber tension as it is passed from the fiber source to the UAV or robot.

James Solly, one of the project researchers, says the final design of the custom-built drone was derived from four earlier prototypes, in a design process that enabled the team to optimize the drone's weight and stabilize its flight behavior. Parts for the drone body were machined from standard carbon plate, while the craft's arms were fabricated from 20-mm carbon tubing. Other, smaller pieces, such as connectors and spacers, were 3D printed from polylactic acid (PLA). Drone dimensions are approximately 92 by 92 by 31 cm and the vehicle can carry a payload of about 2 kg.

To wind a single anchor point, the robot arm travels around the winding frame with the impregnated fiber elevated above the laminate. Upon reaching the anchor point, the robot winds the fiber around it, then returns the winding effector to the landing platform where the UAV

FIG. 5 All-day aerial survey drone

Stratus Aeronautics' (Burnaby, BC, Canada) Venture UAV is employed to perform various types of aerial surveys and is capable of long-range missions of up to 10 hr in duration. The unpiloted plane features an airframe molded from carbon fiber prepreg, wings comprising a semi-monocoque with foam cores, and a uncored, monocoque fuselage.

Source | Stratus Aeronautics

is waiting. After exchange is confirmed, the tension mechanism switches to low tension, and the drone carries the unspooling fiber to the next robotic platform. The researchers used the robotic-drone cell to fabricate a 12m long demonstrator cantilever as an example of the shape and size of parts that could not have been produced by traditional automated fiber-winding setup (Fig. 4, p. 39). The part comprised single-end continuous glass roving, SE1500-2400tex donated by Lange+Ritter GmbH (Gerlingen, Germany) and SIGRAFIL continuous carbon fiber tow, CT50-4.0/240-E100, donated by SGL Technologies GmbH (Wiesbaden, Germany). Fibers were pre-impregnated with EPIKOTE MGS LR 135 epoxy resin formulated with EPIKURE MGS LH 138 curing agent, supplied by Hexion (Columbus, OH, US). The part was fabricated using prepregged fibers and dry fibers impregnated in a fiber-dip resin bath. Solly reports the process demonstrated by the project is best suited to producing horizontal structures with long spans between vertical supports, such as ballroom roofs or pedestrian bridges in which the reduction in self-weight can be expected to yield significant reductions of materials used and cost. He reports that he and his colleagues will elaborate on the process and its applications with a paper being presented at the upcoming International Association for Shell and Spatial Structures (IASS 2018) conference, July 16-20, Boston, MA, US.

In another industrial-related project, a research team at the MIT Media Lab is investigating the use of drones to locate and identify warehouse inventory via radio frequency ID (RFID) tags. A need for improvements in inventory accounting practices, brought on by the increase in scale of modern warehouse and shipping operations, has been acknowledged for some time. Manual scanning is laborious, costly and prone to error. Walmart, for example, reported in 2013 losing more than US$3 billion in revenue due to mismatches between its inventory records and its actual stock.

The MIT team has successfully developed a prototype that enables small, lightweight drones with flexible plastic rotors — the only type approved for use in close vicinity to humans — to read RFID tags from tens of meters away while identifying the tags' locations with an average error of about 19 cm.

The *Bebop-2* drones used for the study are manufactured by Parrot Corp. (Paris, France). Designed specifically to exhibit low vibration for applications such as photography, the drone features a fuselage made from glass-filled Grilamid TR nylon, supplied by EMS-CHEMIE AG (Domat/Ems, Switzerland). Each drone weighs about 500g and can fly autonomously for about 25 minutes. Although they are approved for use around people, the drones are too small to carry an RFID reader with a range of more than a few centimeters. Instead — this is the key research breakthrough — the drones are used to relay signals emitted by a standard RFID reader to a RFID tag. When the signal reaches the tag, the tag then encodes its identifier on the signal before sending it back to the drone. The drone forwards the signal to the reader, which decodes the identifier, and thus the item and location of the item. The team » is currently working to improve the precision of the locating mechanism over longer distances, as well as ways to improve the speed and scalability of the process.

Innovation spurring new drone applications

Materials suppliers, contract 3D printing manufacturers, and printing equipment suppliers report growing business from drone manufacturers, and are developing new products and capabilities to service this business.

Clearwater Composites LLC (Duluth, MN, US) produces a line of carbon fiber tubing and plates it supplies to manufacturers of industrial equipment, robotics, aerospace, sporting goods and UAVs. Tubes, in a variety of shapes, are primarily made by roll-wrapping unidirectional carbon fiber epoxy prepreg on a mandrel, with a cure at 250°C. The tubes are made in standard-, high- and ultra-high modulus grades, the latter made from pitch fibers. The company manufactures plates in a range of thicknesses, in sheets up to 1.2m by 2.4m, from similar materials via compression molding or vacuum infusion. President Jeff Engbrecht says its UAV customers are typically North American-based companies that design and build UAVs for upper-end industrial and aerospace applications.

Clearwater, he reports, is supplying one of its customers, a UAV/drone designer and manufacturer, with a custom-tapered, thin-walled (0.03-inch/0.76-mm) tube, made from Toray Industries' (Tokyo, Japan) high-modulus M46J carbon fiber. The tube, for an unspecified new application, is round at one end, then tapers to an oval shape at the other end.

Stratus Aeronautics (Burnaby, BC, Canada) manufactures drones primarily used for conducting magnetic and aerial surveys in scientific research, mining, military and other applications. Designed and built in both fixed-wing and multi-rotor configurations, these survey drones provide significant cost advantages over piloted craft.

The company's fixed-wing *Venturer* UAV (Fig. 5, p. 41) is a small, lightweight aircraft, powered by a 100-cc, two-stroke gas engine and is capable of long-duration (>10 hr) missions — not a possibility with a piloted craft.

The plane features an airframe molded from carbon fiber prepreg, wings comprising a semi-monocoque with foam cores, and a monocoque fuselage without cores.

SIDE STORY

Drones: Unpiloted composite vehicles head out to sea

Drones to replace manned vessels for marine data gathering?

Saildrone (Alameda, CA, US) has built a fleet of about 20 semi-autonomous, sail drones used to gather oceanographic data. The unpiloted marine vessels feature a 4.6m-tall carbon fiber sail, as well as a mast and boom built from carbon fiber tubing. Two of the drones completed the company's longest mission to date, a 7,000-plus km trip to the equatorial Pacific to gather data related to the climate-disrupting *El Nino* weather pattern.

Source | Saildrone

Although the term *drone* for the most part has been synonymous with unmanned aerial vehicle (UAV) — that is, machines built to *fly* — the concept is being freshly applied to craft designed with the help of advanced composite materials to operate autonomously or semi-autonomously in marine and terrestrial environments as well.

A case in point are the *sailboat* drones designed and built by Saildrone (Alameda, CA, US), a marine robotics company founded in 2012. The company has built a fleet of about 20 of the semi-autonomous craft. They are intended as replacements for expensive (and manned) research ships and stationary buoy systems now deployed around the globe to gather data on everything from weather to fishery populations.

The sailboat drones are equipped with an array of instruments, including sonar and other sensors, for measuring water temperature, wave height, salinity and carbon dioxide levels. An onboard computer stores and transmits data and also steers the craft via a GPS downlink. Thirty watts of power are supplied by lithium-ion batteries, which are charged by solar panels installed in the 4.6m tall sail, manufactured in-house by Saildrone from carbon fiber composite skins, using an unspecified process. The boat's other composite components include a carbon fiber mast, boom and tabbed tail fin — the latter, a sort of unmanned, above-water rudder, responsible for keeping the ship trim to the wind at all times.

Saildrone fabricates parts from a variety of stock and custom tubing manufactured by a West Coast supplier. That supplier reportedly uses roll-wrapped prepreg and a toughened epoxy, supplied by Mitsubishi Chemical Carbon Fiber and Composites (Irvine, CA, US). Ordinarily, the tubes are oven-cured on a metal mandrel.

Recently, two of the 7m-long, 0.5-MT drones completed the longest voyage to date, returning to San Francisco Bay after an 8-month, 7,000-km round trip to the equatorial Pacific. The mission's directive, conducted in collaboration with the National Oceanic and Atmospheric Admin. (NOAA, Boulder, CO, US), was to take temperature and other measurements of the currents associated with the climate-disrupting system known in North America as *El Niño*. For the past 40 years, these measurements have been provided by a NOAA-maintained grid of buoys moored to the Pacific sea floor, called the Tropical Atmosphere Ocean (TAO) array. In recent years, however, the TAO array has degraded due to marine growth and destruction wreaked by fishing trawlers. It is expected that the mobile saildrones will be able to provide more readings, over a wider range, with greater accuracy than the aging buoy system.

Curtis Mullen, the company's chief technical officer, says design and testing is nearly complete for a new electric, multi-rotor UAV. At 3m in length and weighing about 15 kg, it is, except for the electronics, built entirely from carbon fiber composites. "The chassis is a self-aligning, monocoque structure made of CNC-routed carbon plate," Mullen reports. Tubular carbon of varying fiber orientation and moduli, depending on local loads, comprises the remainder of the structure. At *CW* July press time, the company planned to complete construction and flight testing in the June/July timeframe and introduce *Venturer* to the market later in 2018.

FIG. 6 **Additive manufacturing tooling alternative**

Swift Engineering printed the tooling for this drone propeller from Ultem 1010, a high-temperature PEI material, using Stratasys Inc. FDM equipment. The mold comprises two matched halves for a compression mold which took approximately 30 hours of build time. The propeller blades are molded from carbon-fiber reinforced epoxy. Source | Stratasys

Drones dovetail with 3D printing

Given the rapid development of drone technology, it should come as no surprise that drone builders have provided the impetus for additive manufacturing of composites. Drone designers are not only using large-format 3D printers to do the rapid prototyping for which the processes were first conceived, but also, as those processes evolve, to provide tooling and finished parts as well, to meet quick turnaround times required by drone OEMs.

Impossible Objects (Northbrook, IL), for one, recently partnered with Aurora Flight Sciences (Manassas, VA) to 3D print a 76-by-38-mm rear stabilizer mount from high-density polyethylene (HDPE) reinforced with 25.4-mm chopped carbon fibers, using its Composite-Based Additive Manufacturing (CBAM) technology. The part was installed on a new aircraft in development at the time, replacing a part made from unreinforced nylon that was breaking. Although additive manufacturing technology » has frequently been used to make prototype or test parts, Impossible Objects' CEO Larry Kaplan says the company is currently working on securing several commercial, higher-volume applications for parts in drones. Details of the applications cannot yet be detailed, but Kaplan reports that they will involve new, high-temperature-resistant, carbon fiber/nylon and carbon fiber/PEEK materials the company has developed. "We are the only composites additive manufacturer with a reinforced PEEK material," Kaplan claims, noting materials with high temperature resistance are increasingly in demand for parts and molds.

LEARN MORE

Read this article online | short.compositesworld.com/Drones2018

Read more online about how drones are changing the way wind farm operators inspect their massive rotor blades, especially in sometimes remote or offshore wind turbine installations | short.compositesworld.com/BladeServ

Printer supplier Stratasys Inc. (Eden Prairie, MN, US) is partnering with materials suppliers and aerospace/drone fabricators in the ongoing development and commercialization of its 3D printed tooling technologies for the molding of composite parts. Timothy Schniepp, senior director, composite solutions at Stratasys, says the company's fused deposition modeling (FDM) machines can produce most tools in two to three days or less, meaning a customer can be molding parts in less than a week. The company's high-temperature material, Ultem 1010, a polyetherimide (PEI) manufactured by SABIC (Pittsfield, MA, US), is a general purpose, unfilled material suitable for the manufacture of all lay-up tooling, including tools autoclaved to temperatures up to 300°F.

Swift Engineering Inc. (San Clemente, CA, US) used FDM and Ultem 1010 to manufacture matched halves of a compression mold for a UAV's carbon fiber-reinforced epoxy propeller blades. The 356-by-102-by-51-mm tools took 30 hours of build time and were manually abraded and sealed with a two-part epoxy, yielding a surface finish Ra (roughness average) of approximately 0.4µm.

Rock West Composites (West Jordan, UT, US) is collaborating with Stratasys to validate some of the tool designs by molding test parts. Adrian Corbett, director of business development at company, notes the drone industry is incorporating more 3D-printed parts into its products, and 3D-printed tools offer a clear advantage compared to machining tools from epoxy or other tooling materials. "This allows you to make a part as fast as you can print the tool," he says.

In short, a new drone-prolific era has emerged and is here. Fortunately, for many in the composites industry, change, in this case, is good. CW

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DURABLE UAV SPEEDS TO PRODUCTION

3D-printed prototypes shorten the path.

Assembly/disassembly tests of the 3D-printed parts helped with design for manufacturing, especially for the parts that connect the four arms to the UAV's body (shown here disassembled, top, and assembled, below).

› Unmanned aerial vehicle (UAV) manufacturer Hexadrone SAS (Saint-Just-Malmont, France) was looking to develop and mass produce a new, easy-to-use yet robust UAV, one that could function in harsh military, industrial, firefighting or agricultural environments. In answer, a new UAV called the *Tundra-M*, conceived by industrial designer Raphael Chèze, and designed for use in rugged environments, was developed over a period of two years, says Hexadrone's CEO Alexandre Labesse.

The *Tundra-M* has a central, square chassis or frame (complete with an emergency parachute) and four extended arms that support motors and propellers as well as smaller accessory rods or extensions; arms/extensions are quick-connect enabled so that customers can quickly swap out arms and accessories with different equipment and features. A landing foot structure on the back of the central frame supports landing loads.

Before the UAV could enter production, it had to be prototyped and tested. Hexadrone made the decision to use selective laser sintering (SLS) technology to produce functional prototypes, in collaboration with **CRP Technology** (Modena, Italy), to accelerate design iterations and expedite its proposed plans to manufacture its parts from lightweight carbon fiber-reinforced plastic (CFRP) via injection molding.

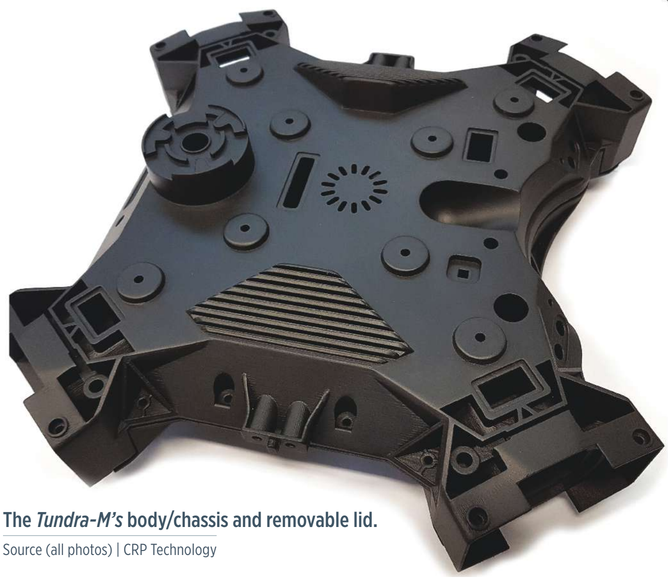
The UAV's four arms and propellers were 3D printed using CRP's Windform XT 2.0 carbon fiber-filled polyamide, a newer version of Windform XT with greater tensile strength and tensile modulus, and a 46% increase in elongation-at-break.

The *Tundra-M's* body/chassis components and removable lid were developed with CRP's Windform SP carbon fiber-reinforced polyamide. Also similar to XT 2.0, SP reportedly exhibits greater impact strength and elongation at break than XT, and demonstrates increased resistance to shock, vibration and deformation, has higher temperature resistance, and resists moisture uptake to help protect the batteries, cooling system and electronics.

During printing, CRP monitored thermal effects of the sintering process to maintain part precision as the layers were built up because slight "gains" in layer thickness can compromise finished part assembly. The 3D printed materials reportedly proved able to withstand the calculated flight stresses, which include compressive and tensile as well as vibrational forces.

Flight and landing tests confirmed the prototype's operability, while assembly/disassembly tests of the various parts helped with design for manufacturing. Says Labesse, "The Windform laser sintering technology allowed us to quickly prototype key components of our product, at a lower cost and much faster than plastic injection molding, and enabled us to have a flyable prototype with almost the same mechanical characteristics as injection molded plastic," says Labesse.

The *Tundra-M* just won a 2018 Red Dot Award from Red Dot GmbH (Essen, Germany) for outstanding product design. CW



The *Tundra-M's* body/chassis and removable lid.

Source (all photos) | CRP Technology

Composites Events

July 10-12, 2018 — Nottingham, UK
ICMAC 2018 – 11th Int'l Conference on Manufacturing of Advanced Composites
icmac2018.org

July 15-21, 2018 — Paris, France
ICCE-26, 26th Annual Int'l Conference on Composites/Nano Engineering
ice-nano.org

July 16-22, 2018 — Farnborough, UK
Farnborough International Air Show 2018
farnboroughinternational.org

July 31-Aug. 1, 2018 — Shanghai, China
Global Automotive Lightweight Materials Asia 2018
galm-asia.com

Aug. 21-23, 2018 — Detroit, MI, US
Global Automotive Lightweight Materials Summit
global-automotive-lightweight-materials-detroit.com

Sept. 5-7, 2018 — Novi, MI, US
SPE Automotive Composites Conference and Exhibition (ACCE)
speautomotive.com/acce-conference

Sept. 5-7, 2018 — Shanghai, China
China Composites Expo 2018
chinacompositesexpo.com

Sept. 10-12, 2018 — Toulouse, France
SpeedNews 19th Annual Aviation Industry Suppliers Conference in Toulouse
speednews.com/aviation-industry-suppliers-conference-in-toulouse

Sept. 10-15, 2018 — Chicago, IL, US
IMTS 2018
imts.com

Sept. 11-13, 2018 — Southampton, UK
SAMPE Conference 18 Southampton
sampe-europe.org/conferences/sampe-conference-18-southampton

Sept. 11-12, 2018 — Chicago, IL, US
AM2018: Additive Manufacturing Conference at IMTS
additiveconference.com

Sept. 13-15, 2018 — Xiamen, China
BIT's 7th Annual World Conference on Advanced Materials (WCAM-18)
bitcongress.com/wcam2018

Sept. 18, 2018 — Augsburg, Germany
Experience Composites
experience-composites.com

Oct. 1-3, 2018 — Atlanta, GA, US
2018 Polyurethanes Technical Conference
polyurethane.americanchemistry.com/2018-Polyurethanes-Technical-Conference.html

Oct. 2-4, 2018 — Tampa, FL, US
IBEX 2018
ibexshow.com/show-info

Oct. 3-4, 2018 — Loughborough University, UK
Composites in Sport
compositesinsport.com

Oct. 15-18, 2018 — Dallas, TX, US
CW CAMX 2018
thecamx.org

Oct. 30-31, 2018 — Bremen, Germany
ITHEC 2018 – 4th International Conference and Exhibition on Thermoplastic Composites
ithec.de

Oct. 31-Nov. 1, 2018 — Birmingham, UK
Advanced Engineering UK 2018
thenec.co.uk

Nov. 5-6, 2018 — Stuttgart, Germany
4th International Composites Congress (ICC)
composites-germany.org/index.php/en/dates/4th-icc

Nov. 6-8, 2018 — Stuttgart, Germany
Composites Europe
composites-europe.com

Nov. 14-15, 2018 — Vienna, Austria
German Wood-Plastic Composites Conference
10times.com/wood-plastic-composites

Nov. 14-16, 2018 — Seoul, Republic of Korea
JEC Asia
jeccomposites.com/events/jec-asia-2018

Nov. 21-22, 2018 — Marknesse, The Netherlands
International Symposium on Composites Manufacturing (ISCM 2018)
nlr.org

Dec. 4-6, 2018 — La Jolla, CA, US
CW Carbon Fiber 2018
carbonfiberevent.com

Feb 4-7, 2019 — Hilton Head Island, SC, US
2019 High Temple Workshop
hightemple.udri.udayton.edu

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

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

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

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

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

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

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New Products

» ADDITIVE MANUFACTURING EQUIPMENT & MATERIALS

3D printing factory floor solutions

Stratasys (Minneapolis, MN, US, and Rehovot, Israel) has unveiled a range of new solutions designed to accelerate the use of additive manufacturing in factory environments.

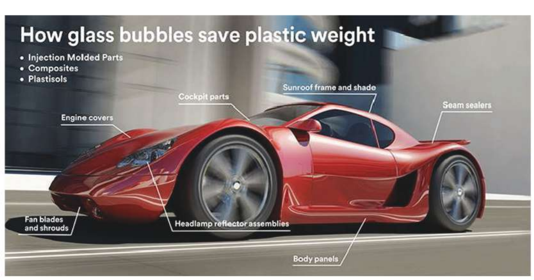
Announcements made at RAPID+TCT 2018 in April showcased 3D printers compatible with carbon fiber composite materials, including the new F900 Production 3D Printer, a third-generation version of the company's flagship Fortus 900mc fused deposition modeling (FDM) system. Features include an MTConnect-ready interface with production-ready accuracy and repeatability. The F900 is available in three solutions: the F900, the F900 AICS (Aircraft Interiors Certification Solution) and the F900 PRO. The latter two extend the platform into specialized products to meet the unique needs: The AICS is reportedly a first-of-its-kind solution that delivers the performance and traceability required for flight-worthy parts. The F900 PRO, described as a production-grade system, is said to produce parts with the highest FDM repeatability and performance, using ULTEM 9085 resin, and is designed to deliver AICS-equivalent repeatability to all target industries for final part reproduction. The company notes that owners of existing Fortus 900mc systems may upgrade to any of the three current F900 systems.

Also new: In addition to offering its carbon fiber-reinforced FDM resin, Carbon Fiber Nylon 12 (12CF), on its Fortus 900 and 450 systems, Stratasys' manufacturing services division, **Stratasys Direct Manufacturing**, now offers parts built with FDM Nylon 12CF, ideal for functional prototypes and production parts in high-requirement applications. Stratasys also now offers this material on a specialized Fortus 380 and has a family of 3D printers in a range of price points that can build with Nylon 12CF. At *CW* press time, Stratasys expected the first Fortus 380 CF to ship in by third quarter 2018. **stratasys.com | stratasysdirect.com**

» POLYMER RESIN ADDITIVES & MODIFIERS

Hollow microspheres for SMCs

3M (St. Paul, MN, US) introduced in May its hollow microsphere product, Glass Bubbles S32HS, for use in lightweight sheet molded compound (SMC) products. The microspheres, made from water-resistant and chemically-stable soda-lime borosilicate glass, are designed to help OEMs achieve up to a 40% weight reduction in composite parts, at a density below 1.0 g/cc, while still enabling a class A paintable finish. The company says the product not only reduces weight compared to conventional fillers but also functions to damp noise, vibration and harmonics and reduce thermal expansion, making SMCs an attractive option in automotive design.



The microspheres, according to 3M, average 25 microns in size, resist softening at temperatures below 600°C, and have a crush strength of 6,000 psi (90% survival by volume). **3m.com/us/auto_marine_aero/index.html | coremt.com**

» ADDITIVE MANUFACTURING EQUIPMENT & MATERIALS

New filaments for fused deposition modeling

SABIC (Pittsfield, MA, US) has three new filaments for fused deposition modeling: ULTEM AM1010F filament for general high-temperature applications, including tooling; and ULTEM AMHU1010F and LEXAN AMHC620F filaments for healthcare applications.

The two filaments are made with SABIC healthcare-grade resins, which are included in the SABIC's Healthcare Product Policy and offer traceability. The policy provides pre-assessment of resin bio-compatibility, according to ISO 10993 or USP Class VI standards, and FDA Drug or Device Master File listings. According to SABIC, new healthcare application development can become more efficient by using these filaments in prototypes, because the same base resin materials are available in injection molding grades for production.

The ULTEM AMHU1010F filament, an unpigmented polyetherimide (PEI) product, provides inherent resistance to high heat. Printed parts can be sterilized using gamma radiation or ethylene oxide (EtO) or via steam autoclave. It provides resistance to high heat (a T_g of 217°C) and high mechanical strength, and can be used in applications such as short-cycle injection molding tools, carbon fiber layup tools and automotive components. The filament is UL94 V-0 compliant at 1.5 mm and 5VA compliant at 3.0 mm.

The LEXAN AMHC620F polycarbonate (PC) filament, available in white, is also bio-compatible and can be sterilized with gamma or EtO methods. This filament meets UL94 HB rating at 1.5mm.

According to SABIC, both are suitable for a variety of medical devices, from conceptual modeling to functional prototyping and end-use parts that include surgical instruments, single-use devices and casts/splints. **sabic-ip.com**

» PROCESS CONTROL SYSTEMS & SOFTWARE

Automation/Industry 4.0 releases

JETCAM (Monaco) has announced new versions of its entire range of core applications, which now also includes new iOS/Android apps. The releases herald JETCAM's continuing move into total automation and Industry 4.0 support for the sheet metal and composite manufacturing sectors.

JETCAM Expert v20 includes JET-Cut, which enables complex grids of holes to be laser cut using artificial intelligence, and reportedly does so far more quickly than conventional methods — and without the user having to specify which areas should have the logic applied. It applies logic on any suitable geometry, allowing users to

import a CAD file, apply profiling information and nest components in seconds, automatically. JET-Optimizer delivers a highly optimized hole-cutting sequence, which is said to minimize machine movement and avoid unnecessary travel over already cut holes. Overall, the company says, JETCAM Expert benefits from hundreds of changes across all areas of the software, support for more than a dozen new machines and many enhancements to various existing postprocessors.

JETCAM Orders Controller (JOC), version 3, reportedly features dozens of enhancements over its predecessor, including what the company describes as a "powerful" new batch nest report, a completely redesigned nests screen and integration into JETCAM's Line Commander line management software.

Version 5 of JETCAM's award-winning composite manufacturing suite, CrossTrack, is now available, delivering what is described as enterprise-level tracking of material, complete automation of the nesting process, as well as order management and shop floor nest scheduling.

Using MS SQL Server, CrossTrack is said to provide real-time location information on raw material, assemblies and individual parts, as well as providing tight integration into JETCAM Expert. Tight integration and data exchange with existing systems such as MRP also is supplied. CrossTrack further benefits from the launch of mobile versions of its Material Transfer Station.

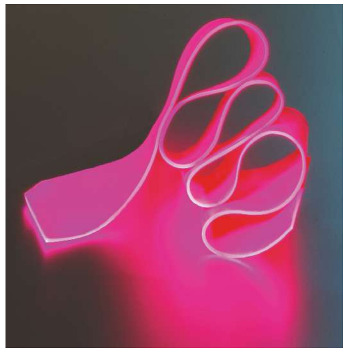
Available in both iOS and Android formats, the application reportedly enables users to quickly scan the barcode of materials or parts to facilitate location transfers or obtain information. The apps themselves are free to download and use via customers' existing Material Transfer Station licenses.

The above updates are available free to existing customers with a current maintenance contract.

jetcam.com

» THERMOPLASTIC RESINS & ADHESIVE SYSTEMS

Light-cure adhesive for engineered plastics



A new light-curing adhesive, Vitralit UV 4802, has been developed by **Panacol** (Steinbach, Germany) for the purpose of bonding high-temperature-resistant thermoplastics, such as polyetheretherketone (PEEK), with other, noncompatible materials.

Vitralit UV 4802 is based on acrylate resin, which reportedly demonstrates excellent adhesion to many thermoplastics, including PEEK, polyethylene naphthalate (PEN) and thermoplastic polyurethane (TPU), which are typically difficult to bond using conventional adhesives. It also is said to adhere very well to ceramics and glass. Vitralit UV 4802 is highly resistant to heat: tests have shown that it remains soft and flexible even after exposure to temperatures of 150°C for seven days. Due to its high flexibility, the adhesive is reportedly well suited for bonding thin and bendable materials.

The adhesive is pink in color and cures within seconds under either a UV or visible light source. Both gas discharge lamps and LEDs are suitable for curing. When cured, the adhesive fluoresces, which enables inspection of the bond line under black light.

Vitralit UV 4802 is being launched in the UK by **Techsil** (Bidford-on-Avon, UK), Panacol's authorized distributor. panacol.com | techsil.co.uk

» ADDITIVE MANUFACTURING EQUIPMENT & MATERIALS

3D printing filaments based on PEKK and PVDF

Arkema Inc. (King of Prussia, PA, US) announced that new Kynar PVDF and Kepstan PEKK-based filaments are now available in 1.75-mm and 2.85-mm diameters from 3DXTech (Byron Center, MI, US) and are marketed under the Firewire trademark.

Kynar PVDF, used for decades in demanding industrial applications, reportedly exhibits resistance to a wide range of aggressive chemicals. PVDF exhibits high thermal stability up to 150°C and extreme durability in direct sunlight exposure.

Kepstan PEKK is said to be an extreme performance thermoplastic with a highly stable chemical backbone. Its semi-crystalline structure offers a combination of mechanical and thermal strength together with chemical and fire resistance. The Kepstan PEKK filaments, says the company, offer both ease of printability and the highest performance of any thermoplastic material currently available.

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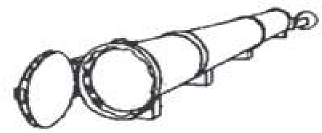

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■ **Composites offer creative seepage solution**

This composite lining, designed to channel large volumes of concrete-wall water seepage down to canals that transport the water out of this tunnel and away from its railway, also makes a striking visual impression in one of northern Spain's Pajares Tunnels. Source | ACCIONA

Composites perform water rescue in high-speed transport tunnel

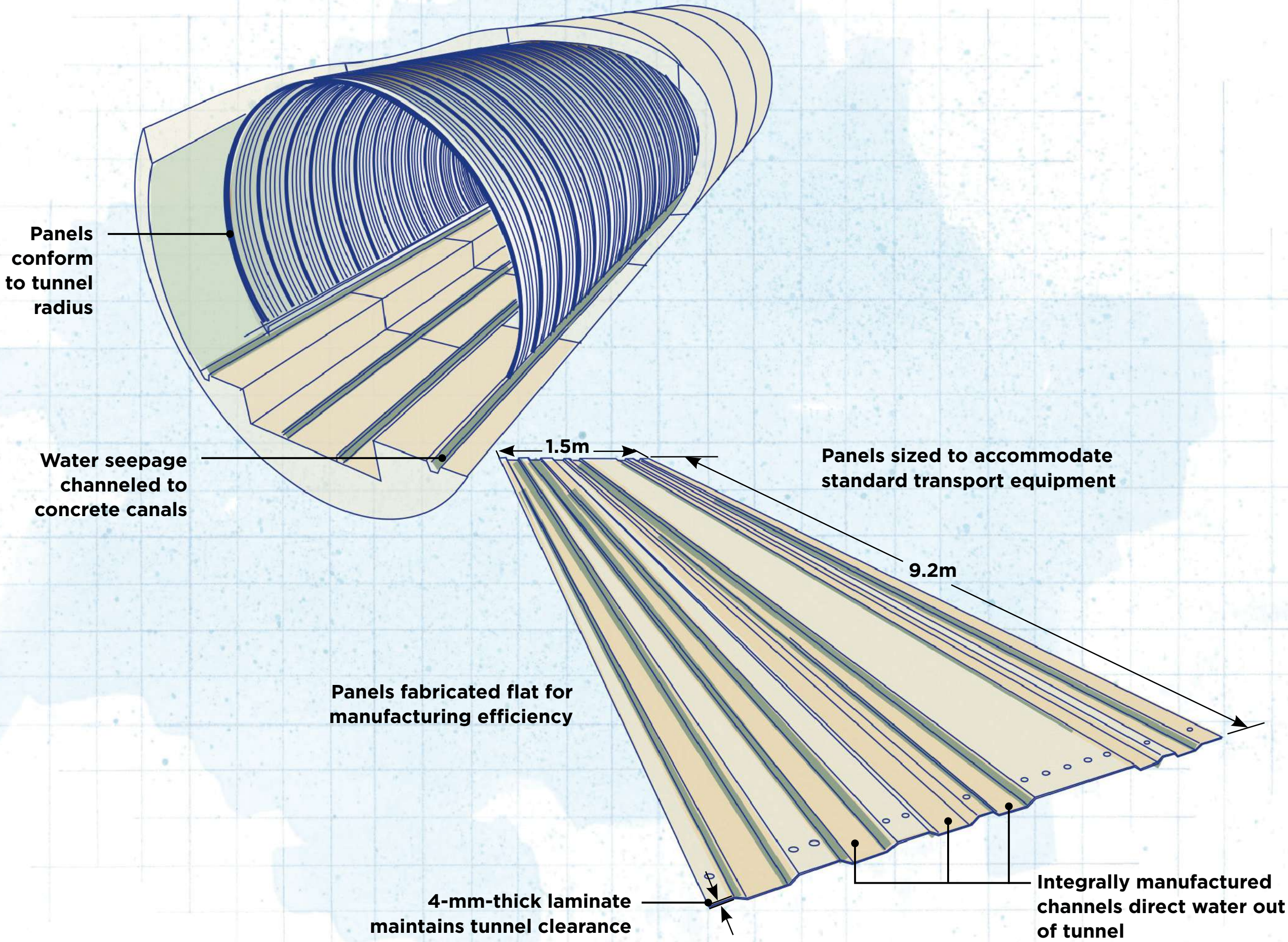
Channeling out the great quantities of water that flow into Spain's Pajares railway tunnels in the Cantabria Mountain range required an award-winning composites innovation.

By Karen Mason / Contributing Writer

» When it comes to water intrusion into transit tunnels, there's seepage, and then there are the Pajares Tunnels in Spain. Part of a future high-speed rail line intended to link centrally located Madrid to the Principality of Asturias, a region on the country's northern shoreline known for its rugged coast and mountains, the 24.6-km twin tunnels will enable high-speed rail service through the Cantabria Mountains. Until now, the only rail passage through the mountain range was a winding, sometimes steep route, used primarily for freight, that limited train speeds to 70 km/hr. The new route will provide passenger travel at speeds topping 300 km/hr. The twin tunnels are among the longest in the world, but they have proven to be among the most challenging to engineer. One reason? The Cantabrian region is known for its lush vegetation, enabled by a very wet climate. Positioned on the Bay of Biscay, with wet Atlantic winds trapped by its mountain range, it reportedly can tally up to 1,200 mm of annual precipitation!

Initial tunnel construction was completed in 2009, but unprecedented water infiltration threatened to thwart rail line installation. Water was seeping in from the surrounding soils at a rate a full order of magnitude greater than is seen in most tunnels — up to 2,200 liters/sec, enough to fill an Olympic-sized swimming pool every 20 minutes. The culprits were cracks in the tunnels' concrete walls. Conventional approaches to waterproofing — injecting polymeric paste into the cracks, installing a polymeric membrane — and other attempts to seal tunnel walls or retrofit tunnels with an existing abatement solution proved ineffective.

A new solution was needed, and Madrid, Spain-based ACCIONA Infraestructuras S.A. – Technology & Innovation Div. was tapped



DESIGN RESULTS | **ACCIONA Composite Panels for Pajares Transit Tunnels**

- Composite laminate 4 mm thick meets physical and mechanical design requirements without compromising tunnel clearances.
- Panel design allowed use of standard transportation and installation equipment, optimizing cost and time efficiencies.
- Design for manufacture enabled production of 15,000 panels, each 9.2m by 1.5m, at a rate of 34 minutes per panel.

Illustration / **Karl Reque**

for the job. “We realized we could not stop the water from coming out, so we looked for a way to channel the water,” recalls ACCIONA’s then composites manufacturing head Anurag Bansal, who now serves as the division’s global business development manager. ACCIONA’s innovative solution, consisting of a now-patented composite lining and anchorage system, merited a 2017 JEC Innovation Award in the construction category.

Design challenges

One key consideration that led to the choice of composites over other material options was the need to maintain sufficient tunnel diameter. The raw tunnel cut could have been larger, potentially allowing for a noncomposite water-channeling system, but Bansal emphasizes, “Every additional millimeter that has to be excavated is expensive.” Of course, additional excavation at this point in the project was infeasible, because construction of the tunnel walls was already substantially complete. The water channeling system’s thickness, therefore, could not compromise tunnel clearances. That ruled out conventional options. To meet structural requirements, cement panels, for example, would have had to be 10 cm thick, unacceptably diminishing the tunnel’s size. But the thickness of the laminate in the composite design is a mere 4 mm; and the panel profile, which creates water pathways in the form of integrally manufactured longitudinal ribs/channels, decreases tunnel diameter by an acceptable amount.

Another key consideration was that the water-channeling system’s panels would have to provide adequate radial strength once they were fastened in place against the curved tunnel walls. »

Production speed and repeatability

This pultrusion line, with a specially designed infusion system that ensured complete fiber wetout, completed each of the more than *15,000* 9.2 by 1.5m composite panels in 34 minutes. Source | ACCIONA

Design for practicality and manufacturability

The basic panel's design minimized potentially troublesome horizontal seams (there is only one, at the curvature's peak) and enabled both flat-panel manufacture and delivery via standard trucking equipment. Source | ACCIONA

High-speed trains create significant air pressure as they enter a tunnel. But even more significantly, "when they exit, they create a vacuum that, along with other forces, will try to pull the panels out of their fixtures," Bansal explains. A specially designed nut-and-bolt anchorage system developed by CELO-APOLO Construction Systems (Castellar del Vallès, Spain) helps keep the panels in place, while the panels themselves are designed to handle the kinds of loads created both by the speeding trains and by the ongoing water seepage.

Bansal's team also had to find a way to address the seemingly conflicting needs of panel manufacture versus panel installation. On the one hand, flat panels are much easier, faster and more cost-efficient to manufacture than curved panels. On the other hand, the panels need to conform and be secured effectively to the curved tunnel structure. Addressing both sets of needs, the answer was to manufacture flat panels with a considerable proportion of the reinforcement in the longitudinal direction, so that they could be flexed into their final shape as they were installed. Because of the panels' flexibility, their final shape met design requirements and did not compromise laminate integrity, Bansal reports. The flexibility also enabled relatively easy adaptation to irregular tunnel features.

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To create the mix of physical and mechanical properties needed in the panels, the ACCIONA team incorporated three types of glass fiber reinforcement: unidirectional and bidirectional continuous rovings as well as continuous filament mat. The unidirectional product was developed, manufactured and supplied by Owens Corning (Toledo, OH, US). ACCIONA also collaborated with resin manufacturer Scott Bader Co. Ltd. (Northamptonshire, UK) to formulate a workable resin system. This was especially difficult because the resin formulation had to meet stringent subterranean flammability standards, yet also maintain the pre-cure fluid characteristics necessary for manufacturability.

Mass production

With more than two decades of experience in the fabrication of composite components, Bansal nevertheless faced new manufacturing challenges with this project— starting with its sheer magnitude and very tight production schedule. To line more than 200,000m² of tunnel wall — a stretch of about 10 km — ACCIONA produced more than *15,000* panels, each 9.2m by 1.5m. "We chose pultrusion from the beginning because we needed an automated process," Bansal explains. Its relatively low labor requirements and high manufacturing consistency also made pultrusion the fabrication method of choice. ACCIONA employed a pultrusion machine built by LYT Composite Equipment Manufacturer (Nanjing, China).

But working with the specially designed resin system added a layer of complexity to the engineering of the pultrusion process. ACCIONA started with Scott Bader Crestapol 1212 pultrusion resin, a rapid-cure methacrylate-based thermosetting resin. Additives needed to meet performance requirements — in particular, a high filler level of 170 phr (per hundred resin) alumina trihydrate (ATH) to meet the flammability standard — changed the resin system's composition significantly enough to demand a change in

Formable panels fill the bill

The flexibility of the cured material system allowed ACCIONA to conform and install the flat panels to the curvature of the tunnel wall while maintaining structural integrity. Source | ACCIONA

processing. A standard pultrusion bath was unworkable because some components of the ACCIONA mixture would settle to the bath's bottom. Resin injection also was problematic because of the filled resin's very high viscosity.

Bansal's team worked with several industry partners on modifications to the resin system, the resin injection system and the injection points that ensured good delivery and wetout of all the glass filaments with the filled Crestapol 1212 resin. Additives provided by BYK-Chemie GmbH (Wesel, Germany) helped ensure uniform wetting and dispersion of inorganic fillers in the resin mixture.

LUM Industry (Boisseuil, France) developed and manufactured the pultrusion mold. Final cycle time for the carefully engineered pultrusion process was 34 minutes per panel.

Additional benefits

The composite lining system covers the 18m arc of the tunnels with a pair of panels. The 9.2m panels overlap by 20 cm at the tunnel apex, which is sufficient to keep water from leaking through the seam — a "path of least resistance" away from the seams is generated by gravity and the water channels that the panels create. Likewise, water won't leak through the long edge seams. Bansal explains, "The lateral overlap along the edges creates a kind of interlocking, and the mechanical forces [from flexing and anchoring the panels] prevent the panels from moving during installation and usage, thereby keeping the interlocking intact." When water travels down through the channels, it empties into concrete canals on either side of the tunnel floor and travels out of the tunnel.

Standard transportation equipment can accommodate products up to 10m in length and 1.5m wide, so the paired approach allowed ACCIONA to employ a cost-effective means of transportation to the site. The standard trucking option is also limited to a mass distribution of approximately 8 kg/m^2, a limit with which the lightweight composite panels easily complied. Further, the composite panels could be installed using standard installation machinery already on site. Each of these factors helped speed installation. Importantly, the panels also are positioned in such a way that the tunnel structure's ring segments can still be inspected as required.

Other characteristics of composite materials enhanced the project's cost efficiency and diminished its environmental impact compared to other material systems, Bansal says. "Steel panels would have had to be galvanized," he notes. "Otherwise, corrosion and rust would contaminate the water. A steel structure would also require electrical grounding." In contrast, the composite panels offer easy maintenance and high corrosion-resistance. Production and installation of the composite panels generated significantly lower CO_2 emissions than might otherwise have been produced with alternative approaches.

Because of the efficiency with which ACCIONA worked to waterproof the twin tunnels, one of the pair was opened to broad-gauge trains in 2016. The other tunnel opened later that same year. It is hoped that completion of the high-speed rails and the inaugural high-speed ride to Asturias will take place sometime soon after 2020.

Multiple advancements

Asked about the innovations generated by this project, Bansal mentioned the application (first-of-its-kind tunnel lining system), the panel and material design, and the process modifications needed to pultrude the panels in a timely manner. He believes, though, that the most innovative aspect of this project was "designing a solution to a real-world problem. We had to prepare the team to make the panels and, in a very limited time, start up production and continue for two years to make consistent, quality panels." His pride in the result is apparent — and well deserved. CW

ABOUT THE AUTHOR

CW contributing writer Karen Mason has been researching and writing about the composites industry for more than 25 years. **kmason@compositesworld.com**

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*"Mafic has really enjoyed the connective and creative environment within the IACMI community. We have established **productive partnerships and customers that have helped build our foundation for future growth including our new US facility, currently under construction in North Carolina. The facility is set to create over 100 new jobs making products that are currently featured in several IACMI projects."***

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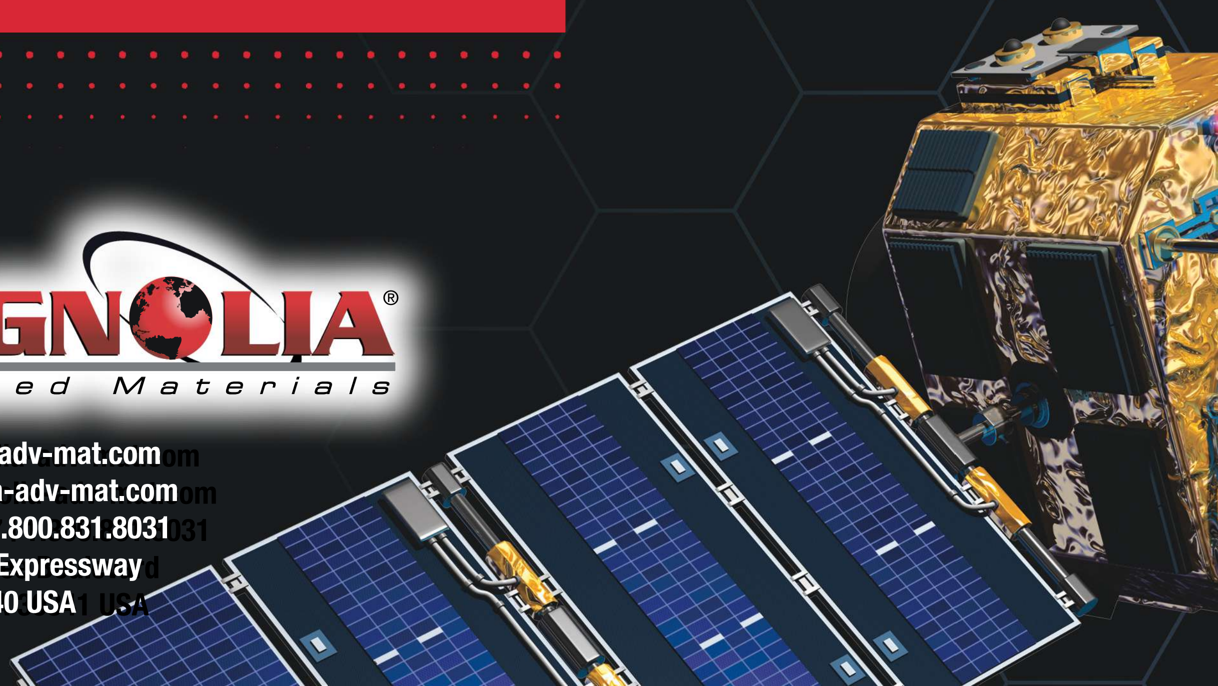

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