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Diamond Aircraft Austria: PUSHING THE COMPOSITES ENVELOPE

JANUARY 2018

A property of Gardner Business Media

VOL 4 № 1

JANUARY 2018 / Vol: 4 №: 1

COLUMNS

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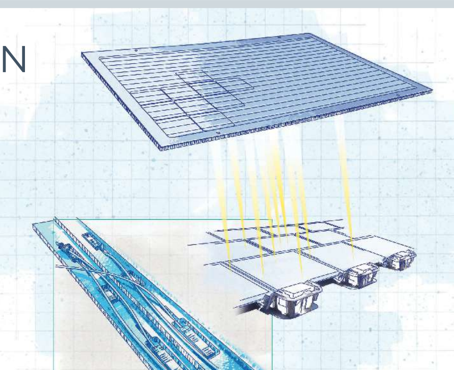
» ON THE COVER

The twin-engine, seven-seat *DA62* on *CW's* cover this month is the most recent entry in the general aviation market from Diamond Aircraft (Wiener Neustadt, Austria), which has from its inception applied advanced composites to the primary structures of its aircraft. The company's aircraft designs flow from a push-the-limits design culture. Get an inside look at this airframer's operation on p. 28.

Source / Diamond Aircraft Austria

FOCUS ON DESIGN



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As I key in these words on my computer, CAMX 2017 has been history for less than five hours. I am in seat 28C on a plane flying home from Orlando, hoping that the person in front of me does not recline his seat and, thus, make an already difficult typing job an impossible one. It might be too soon for me to put the show and conference into perspective, but I will give it a shot.

CAMX 2017 was postponed, the event's quality was not.

First, if you are wondering if it is possible to have a major composites trade show canceled (at the last moment) in September due to a hurricane blowing through Florida, and then turn around and host that same trade show a mere three months later, and have it be a success, I can assure you it is. Possible. But not without a lot of hard work. Show organizers at ACMA and SAMPE took the September edition of CAMX 2017 almost to the finish line only to have it washed away by Hurricane Irma. Then these folks had the unenviable task of doing it all over again in December. And they pulled it off remarkably well.

The consensus at the show? Although there was some exhibitor and attendee attrition between September and December, the people who did show up were serious about the show and composites. In other words, quality seems to have won over quantity. So, hats off to ACMA, SAMPE and CAMX officials for not only making it work, but making it work *well*.

One question I get often at any trade show is, "So, what Earth-shattering technologies have you discovered?" The answer, inevitably, is, "Not much." This is not to say that the composites industry is not innovating or evolving, but it is rare that a trade show is the site of those "a-ha" revelations.

That said, CAMX offered much to see and contemplate, including two robust and competitive parts contests (The CAMX Awards and the Awards for Composites Excellence), some new additive manufacturing solutions (from Vartega and Cincinnati Machine), a creative metal/composite solution for truck structures (Structural Composites), automated work-cells built around filament winding (Mikrosam and Autonational), a variety of resin systems for high-speed/high-volume manufacturing (Huntsman and TenCate), some interesting nano-materials (General Nano and N12) and a host of recycling technologies and recycled materials (Carbon Conversions, Vartega, ELG Carbon Fibre, Adherent Technologies and Addesso).

Perhaps most revelatory was not what was exhibited or introduced, but what was said. I fielded several questions from materials and equipment suppliers, as well as fabricators, about how automotive composites might evolve, and how poised they are or are not to "take off." Of course, I don't really *know*, but I was certainly willing to hazard an educated guess, which might be the topic of another editorial. Regardless, that such questions are still floating around says to me that there remains much uncertainty about how seriously automotive OEMs are taking composites.

Also "heard" was a lot of talk about next-generation aircraft programs (i.e., Airbus A320 and Boeing 737 replacements), and the composite materials and processes likely to find a place therein. The upshot here should not be surprising: Aircraft OEMs are looking for faster production rates (60+ shipsets/month), more automation (less touch labor), better process/quality control and reliable non-autoclave cure solutions. Thermoplastics, in particular, seem uniquely well positioned to meet many of these requirements. The material/process window for such programs seems to be 2020-2025.

I am happy to report that the gentleman in 27C did not recline, and we will have a more detailed CAMX 2017 report in the February issue of *CW*, as well as at CompositesWorld.com.

JEFF SLOAN — Editor-In-Chief

Composites for aging and disabled populations

» I've spent most of my engineering career trying to find new ways to make transportation more accessible for seniors and people with disabilities. I managed the General Motors' Mobility Center from the late 1990s to late 2004. I then worked at Disney for a few years, helping make rides, attractions and transportation more accessible. Next, I moved to the Boston area and developed the System-Wide Accessibility Department for the Massachusetts Bay Transportation Authority (MBTA), a multi-modal public transportation provider. And for the past six years, I've had a similar role at Amtrak, trying to make America's national passenger-rail system, including trains, stations/platforms, etc., accessible to customers with disabilities.

Over the years, I've worked with many materials and processes. What I've learned is just how undervalued composites are as tools to help seniors and people with disabilities get out of their homes — attend school or church, go to work, run errands, visit family and friends — and become better integrated into our society. That's not an inconsequential goal when you consider that up to 75% of people with severe disabilities in this country are either unemployed or underemployed, and an increasingly large percentage of our citizens are entering their "golden years" when visual and hearing acuity and the motor skills necessary for mobility begin to deteriorate. The quality of life for seniors and people with disabilities can be greatly improved by increasing their *visitability* (ability to visit the outside world).

> I've learned how undervalued composites are as tools to help seniors and people with disabilities ....

I've spent the past couple of years leading a program to develop a lighter, safer, more feature-rich means for this group to get on and off trains. At Amtrak, we call these Accessible Boarding Technologies (or ABTs). ABTs help bridge the gap between a railcar and a platform. Shorter ABTs, called *bridgeplates*, are used when train and platform are at similar vertical heights. Longer *ramps* are used when the vertical heights of the train and platform differ. Bridgeplates and ramps help customers who use wheeled mobility devices, as well as seniors and those who must push strollers or pull wheeled luggage get on/off trains quickly and safely.

Current bridgeplates are often made from diamond-plate or other aluminum structures. Longer ramps can be channel aluminum sections, and hinged in the middle due to the mass of each section. Both units can be heavy and, therefore, take a toll on crews that lift, carry and then deploy them. Weights range from 35 lb/16 kg for a short bridgeplate up to 70 lb/32 kg for a ramp without handrails. To limit their weight, they were shorter in length and narrower in width, and they were often slippery when wet. Redesigning bridgeplates and ramps in carbon fiber composites has significantly reduced their overall weight, despite increases in length and width and the addition of integrated folding handrails to the ramps. We simply couldn't have done this in metals. Only composites provide the stiffer, stronger, more durable designs that permit weight reduction and the parts integration that enables manageable production costs. As we begin to deploy carbon fiber composite ABTs across our network, our hope is that they will make passenger rail more accessible to more people.

Given all the smart and creative people in this industry, how else could we use composites to help seniors and people with disabilities gain more autonomy? What about lightweight, modular telescoping composite ramps that increase *visitability* by enabling access across stairways, at the homes of family and friends who don't have an accessible entrance?

And how about the wheeled mobility devices themselves — technology that, in some cases, hasn't been revisited since the 1960s? Right now, an occupied power wheelchair can weigh 1,000 lb/454 kg or more, making transitions from house to van, bus or train, to office building or store and back again very difficult. Couldn't we apply what we've learned designing electric vehicles to make power-based wheeled mobility devices lighter and more durable, with extended-life battery packs? And what if the devices could be folded or disassembled without tools? Could they be stowed in smaller vehicles that didn't require a hoist and/or lift?

Molders who turn out bicycles and sports car accessories could help us convert heavy aluminum and steel wheelchair parts and wheels into lighter composites.

The same goes for canes, crutches and rollators (rolling walkers). The latter can weigh 25-35 lb/11-16 kg. If they were lighter and could be stowed more compactly and redeployed easily, many users could exercise greater independence when traveling.

Anyone game to take on these challenges? CW

ABOUT THE AUTHOR

Gary Talbot is the program director – ADA for the National Railroad Passenger Corp./Amtrak (Washington, DC, US). Previously, Talbot was the assistant general manager for System-Wide Accessibility (SWA) with the Massachusetts Bay Transportation Authority. Before that, he served as a senior project engineer for Walt Disney World Ride and Show Engineering (San Dimas, CA, US). Talbot also served on the US Access Board, the agency responsible for developing Americans with Disabilities Act (ADA) guidelines. Talbot began his career at General Motors (Detroit, MI, US) and eventually managed GM's Mobility Center. He holds a BS in mechanical engineering from the University of Michigan and is active in a variety of trade and civic organizations. Visit **www.gtalbot.com**.

Driving down costs: Technologies to follow in 2018

» A saying attributed to a senior executive at a German automaker goes, "In the end, the only technical parameter that matters is cost." I won't name the automaker or individual, but based on my experience, I agree. That's why, although the initial cost is higher, commercial aircraft manufacturers use advanced composites to reduce much larger in-service operating and maintenance costs. And why automakers talk about "making the business case," through parts consolidation, lower investment cost, and/or lower end-user cost due to better fuel efficiency.

Composites are found in chemical plants, on oil rigs and, in marine structures because their corrosion resistance economically justifies their use. But it is not always easy to make the argument. As we've learned over and over, building bridges from composites is hard to justify on lifecycle analysis alone. Budget-sensitive government buyers are reluctant to pay the premium, even when structures would last two- to three-times longer than those of concrete and steel.

> Cost drives most decisions about composites use, but most innovation now focuses *beyond* material cost.

Cost, in some fashion, drives most decisions about the use of composites. As a result, much of the innovative effort in the composites industry today is focused in some way, whether explicitly stated or not, on reducing the initial cost, in-use cost or cost of recycling and reusing composite materials. Here are a handful of technical areas that I am watching in 2018 — areas that go beyond raw material cost reduction:

Modeling and simulation – In a world where the possible combinations of fibers, resins, fiber and resin contents, processing techniques and fiber orientations can number in the billions, advances in the analysis of process-induced microstructure will enable the prediction of virtual allowables, suitable for many industrial applications, including more accurate crash behavior. The linking of simulation tools throughout the manufacturing process is improving confidence in understanding end-to-end cause and effect. Validation of simulation over multiple scales, from laboratory to full parts, enables reductions in mass, hence costs.

Automated layup and consolidation of smaller parts – The aerospace industry has long focused on large tape and fiber placement machines for wingskins and fuselages. But each aircraft also has multitudes of clips, brackets, frames, stringers and other smaller components. Innovative companies, such as Orbital ATK (Clearfield, UT, US), have developed automated equipment for forming these components at much lower costs, and this technology is being quickly adopted. Simultaneously, many companies in Europe and the US are introducing quick laminating machines with relatively low material waste for small parts, aiming at both aerospace and the much larger automotive markets. Combined with ever-shortening forming/molding/curing times, reducing layup cycle time and material waste will drive down costs.

Hybrid molding – Selective reinforcement, using continuous fiber inserts in discontinuous structures, has been done for at least 15 years. Historically, small patches have been applied locally (e.g., atop a beam or near an attachment point) making up a small fraction of a part's overall mass. But I am seeing examples where the continuous portion forms the majority of the surface area of a very light, strong hybrid structure, while discontinuous material forms bosses, ribs and the part periphery, minimizing secondary trimming and, thus, reducing costs. Further, no longer limited to thermoplastic injection overmolding, this hybrid technology is being adapted for thermoplastic and thermoset compression molding.

Recycling – A rough estimate puts the portion of the total carbon fiber that winds up as landfill waste in the range of 30%. In the past several years, many technologies and associated companies have sprung up to deal with this growing quantity of manufacturing waste in advanced composites, dry and impregnated, cured and uncured. There are solutions emerging for molded scrap and end-of-life components. A growing supply of high-quality, recycled carbon fiber will reduce the cost of parts that can leverage discontinuous material forms, such as mats and molding compounds.

The Industrial Internet of Things (IIoT) – This is the technology that knits together the items above and leverages them further. Embedded process sensors tie into accurate simulation models to verify part quality, predict process "drift" and make adjustments on the fly. Vision equipment verifies ply count and orientation in layup, and validates fiber angles in preforms. Infrared cameras capture infusion and exotherm data on large vacuum-assisted RTM structures to verify proper flow and cure. Electronic prepreg tags determine whether there is sufficient outlife to use (or chop and reuse) material, and classify its pedigree for third-party recyclers.

Progress on each of these fronts in 2018 will continue to drive down costs and raise the value proposition of composites across multiple markets. CW

ABOUT THE AUTHOR

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

What's the most important type of mechanical test for composites?

» When the opportunity arises, I like to ask those familiar with composites testing this question: What type of mechanical test do they consider to be the most important for composite materials? After listening to responses, I follow up by asking people what they think is the primary purpose for performing the test and what are its intended applications. I'll share here what I've learned from asking these questions. But before I do, I'd suggest those who read this spend a minute thinking about what their responses would be to these questions.

Perhaps it comes as no surprise that there is no single type of mechanical test that's the consensus choice as most important for composites, especially given the variety of purposes for testing and intended applications. There are, however, a few test methods that were more often mentioned. These can be grouped into three general categories and best discussed in terms of the primary purposes for performing the test.

One test method mentioned frequently as most important is the short beam shear test, described in ASTM D 2344[1] (Fig. 1). One of the simplest to perform, it uses the smallest test specimen of any mechanical test method for composites. The test consists of a three-point bend test performed using a short loading span relative to the specimen thickness. This results in interlaminar shear failure within the specimen's interior. The measured short beam strength is highly sensitive to problems with porosity, fiber-to-matrix adhesion and the layer-to-layer strength within the composite laminate. Therefore, although the measured short beam strength may be considered only an estimate of the interlaminar shear strength, this test method is widely considered an excellent choice for comparative testing purposes. Accordingly, stated purposes for performing this test include material comparison and selection, material and fabrication process development and quality control.

Not as commonly mentioned as most important, the ±45° tensile shear test, ASTM D 3518[2], may be used for these purposes as well. The advantage of this test is that it produces a shear stress vs. shear strain curve throughout the loading and, thus, provides a measurement of shear modulus in addition to shear strength. The nonlinear shear stress vs. shear strain curve is analogous to a "fingerprint" that corresponds to a tested material, allowing for a more thorough comparative assessment between materials or processing conditions. However, the disadvantage is the required use of bonded strain gages for shear strain measurement and, therefore, significantly greater effort and cost. As a result, the ±45° tensile shear test remains a distant second choice as most favorite for the above stated purposes.

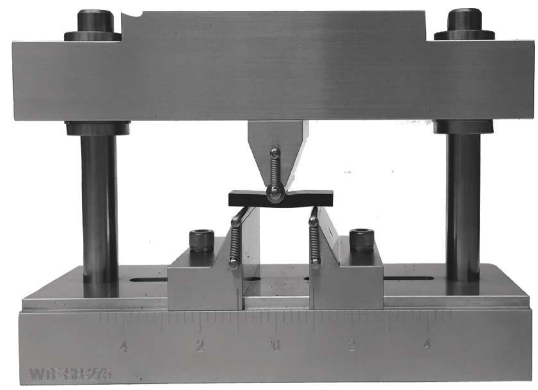
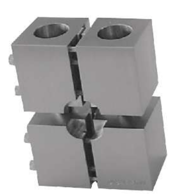


FIG. 1 Short beam shear test, ASTM D 2344.

Source (all images) | Dan Adams

FIG. 2 Combined-loaded ASTM D 6641 test (left) end-loaded Boeing-modified D 695 test (center) and face-loaded ASTM D 3410 test (right).



Another common purpose for performing mechanical testing of composites is to determine material properties for use in design and analysis. While many types of material characterization tests are performed with composites, compression strength testing in the fiber direction is often considered most important. The reason? For virtually all carbon fiber-reinforced polymer matrix composites, the compression strength is significantly lower than the tensile strength and, therefore, is the limiting design value. Interestingly, those who identify compression testing as most important sometimes will also identify the most important test environment in which to perform the test. For polymer matrix composites, the most severe environmental condition is often the highest service temperature, coupled with a moisture saturation condition. This "hot/wet" combination is typically specified as the most important environmental condition in which to perform the fiber-direction compression test.

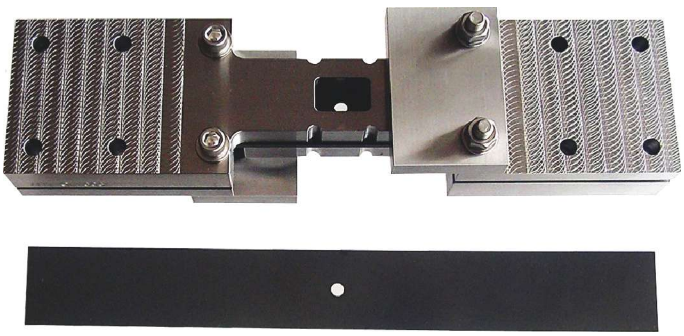


FIG. 3a Open-hole compression test, ASTM D 6484.

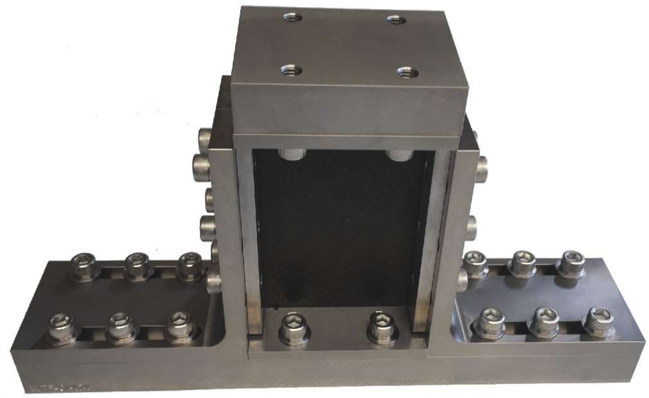


FIG. 3b Compression-after-impact test, ASTM D 7137.

In my July 2015 column, I discussed the variety of test methods available for determining the compression strength of composites. The primary way in which they differ is the method of load introduction into the specimen. The three most commonly performed tests (Fig. 2) are the combined-loaded ASTM D 6641[3] test, the end-loaded Boeing-modified D 695[4] test and the face-loaded ASTM D 3410[5] test.

The final category of test methods that have received a considerable number of most important votes are those used to develop structural design allowables. For this purpose, the open-hole compression test, ASTM D 6484[6], and the compression-after-impact test, ASTM D 7137[7], have been named most important, particularly for aerospace applications.

The open-hole compression test (Fig. 3a) uses a 36-mm-wide specimen with a central 6-mm-diameter hole, producing a specimen width-to-hole diameter (w/D) ratio of 6:1. To prevent buckling during compression loading, a support fixture is bolted to the 300-mm-long specimen. The ASTM D 7137 compression-after-impact test uses a 100-mm-wide by 150-mm-long specimen that is loaded in edgewise compression while it is supported to prevent out-of-plane bending along the vertical edges (Fig. 3b). Prior to compression testing, the specimen is subjected to a drop-weight impact to produce damage in the specimen's central region. Note that when structural design allowables are generated using either test method, the composite laminate used in the test specimen is representative of the laminate that will be used in the intended application. For compression-after-impact testing, the impactor shape and impact energy used to produce the damage are also selected to represent impact threats for the application of interest.

In addition to producing critical structural design allowables for a variety of applications, these two test methods share other important features. First, both are performed under compression loading because the resulting strengths typically are lower than those under tension loading. Second, both tests produce design allowables that typically are more critical than those resulting from the strength-based material properties discussed in the previous category. As a result, both the open-hole-compression and compression-after-impact tests also are commonly used in the material selection process for an intended application. Because a consistent laminate must be used when testing to compare candidate materials, the use of a quasi-isotropic laminate is suggested. CW

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[1] ASTM D 2344/D 2344M-16, "Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates," ASTM International (W. Conshohocken, PA, US), 2016 (first issued in 1965).

[2] ASTM D 3518/D 3518M-13, "Standard Test Method for In-Plane Shear Response of Polymer Matrix Composite Materials by Tensile Test of a ±45° Laminate," ASTM International (W. Conshohocken, PA, US), 2013 (first issued in 1994).

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[6] ASTM D 6484/D 6484M-14, "Open-Hole Compressive Strength of Polymer Matrix Composite Laminates," ASTM International (W. Conshohocken, PA, US), 2014 (first issued in 1999).

[7] ASTM D 7137/D 7137M-17, "Compressive Residual Strength Properties of Damaged Polymer Matrix Composite Plates," ASTM International (W. Conshohocken, PA.), 2017 (originally published 2005).

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Dr. Daniel O. Adams is a professor of mechanical engineering and has been the director for 21 years of the Composite Mechanics Laboratory at the University of Utah and vice president of Wyoming Test Fixtures Inc. (Salt Lake City, UT, US). He holds a BS in mechanical engineering and an MS and Ph.D in engineering mechanics. Adams has a combined 38 years of academic/industry experience in the composite materials field. He has published more than 120 technical papers, is vice-chair of ASTM Committee D30 on Composite Materials and co-chair of the Testing Committee for the *Composite Materials Handbook (CMH-17)*. He regularly provides testing seminars and consulting services to the composites industry.

The Composites Fabricating Index returns to near calendar-year average

November 2017 – 54.3

» Registering 54.3 in November 2017, the Gardner Business Index (GBI): Composites Fabricating moved lower after establishing an impressive, all-time high of 59.8 in October. The decline in the Index reading indicates only that the composites industry grew more slowly in November than in October. But for the calendar year-to-date period, an average composite reading of 55.0 means 2017 is almost certain to beat the 2014 monthly average high of 54.1. For the year-to-date period, the Index is up 5.3%. The Gardner Intelligence review of the underlying data for November indicates that Employment, Production, New Orders and Supplier Deliveries were the subindices that lifted the Index up, while Backlogs and Exports held it down.

No component of the Composites Fabricating Index contracted during the month, although exports posted no change after a multi-year, record-high reading in October. All components of the Index indicated slowing growth, with Backlogs exhibiting the most dramatic decline: The Backlogs reading changed by approximately 9 points, signaling a transition from very fast growth in October to nearly no growth in November. CW

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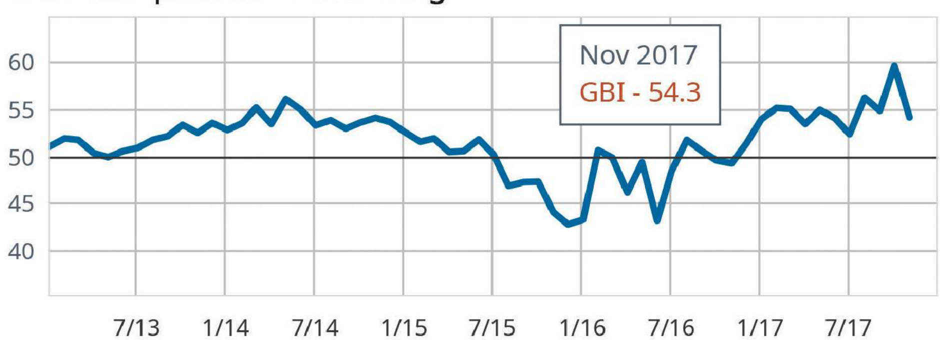
Michael Guckes is the chief economist for Gardner Intelligence, a division of Gardner Business Media (Cincinnati, OH US). He has performed economic analysis, modeling and forecasting work for nearly 20 years in a wide range of industries. Guckes received his BA in political science and economics from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

GBI: Composites Fabricating



Composites Fabricating Index shows slower but still strong growth

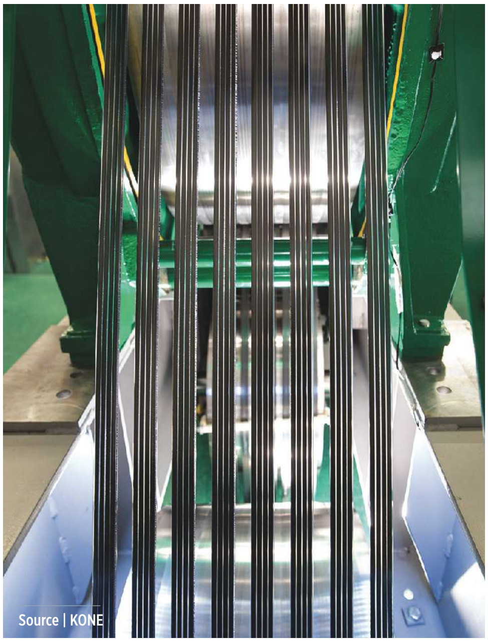
The Composites Fabricating Index reading for November fell from the prior month. However, the November reading was comparable to readings from the first-half of the year and the year-to-date average reading.

GBI: Composites Fabrication - New Orders & Backlog
(3-month moving averages)

New Orders fall, taking Backlogs with them

The New Orders number fell more sharply than that for the Production subindex in November, which may have contributed, in part, to the exceptional change in the Backlogs index, which moved nearly 9 points in one month to end just above 50.0.

An excerpt from the *CW* Talks interview with Steve Gonzalez about elevator manufacturer KONE's CFRP elevator rope, and selections from *CW* coverage of the fast growing, broadly expanding trend toward full automation of composite part production.



Q&A: Steve Gonzalez, director of major projects unit, Americas, KONE

Editor's note: As skyscrapers get taller, the task of physically moving people via elevators over long distances has become more difficult, particularly given the sheer mass of steel cabling required. Elevator manufacturer KONE, about 10 years ago, started looking at ways to replace steel cables with carbon fiber composites, and a couple of years ago introduced UltraRope, a pultruded, flat, flexible, lightweight alternative (see photo) that is making next-generation elevator technology possible. Gonzalez was CW's *guest recently on* CW Talks: The Composites Podcast. *Excerpts of that conversation follow. To listen to the entire conversation, search for* CW Talks *on iTunes or Google Play, or visit* www.compositesworld.com/podcast.

***CW*: The Kingdom Tower in Jeddah, Saudi Arabia, when it's complete, will be 1 km tall. What are the challenges posed as the world's buildings get taller?**

SG: We are working with architects and general contractors and building owners to really understand how they plan for the building to be used, initially, and then what types of changes might be seen from a usage perspective in the future so that we can design a building that functions now, and also functions after the building's usage changes. It may be a mixed-use building now, but it may turn into a full residential building later. Or it may turn into an office building later.

***CW*: How is elevator technology evolving as buildings get bigger?**

SG: Elevator technology has not changed very much over the last several years, and includes use of steel ropes, motors and counterweights to move the car up and down in a building. But the ropes themselves, when you get to ultra-tall buildings, become so heavy that in order to suspend the ropes, you need more ropes. Therefore, in order to allow for longer trips, which ends up being important when these buildings get really tall, you need to do something to address the weight associated with the ropes themselves.

***CW:* Walk us through what UltraRope is and how it was developed.**

SG: The rope ends up being an important place to take weight from, especially when the buildings get really tall .... In a really tall building you could have 20 or more miles of this rope .... That means that if you can cut that weight down, not only do you save energy because you're not moving all that mass — and the rope itself if the vast majority of the moving mass in the elevator system — but you can buy yourself the opportunity to put weight elsewhere, which means you can have different materials in the car and change the way the cars are insulated .... We've got a very robust R&D group and we've got folks who are infinitely curious, and it just so happens that some of these guys are really interested in these alternative materials .... The challenge really is the flexibility. Carbon fiber when we think about it is this lightweight but rigid material, but of course when we're talking about doing is taking this carbon fiber rope and wrapping it around a pulley .... We spent lots of time making sure the carbon fiber would last a long time, be flexible enough to wrap around the [pulleys] and then figured out how to coat the carbon fiber so that we had the necessary friction to make the system work.

***CW:* What kind of benefits have you seen UltraRope convey to the market?**

SG: The weight loss is good, but it's what that allows for that is the big impact. Because the weight is so much less, the cars can travel much further in a single run .... Energy savings is significant because the rope is the largest component of moving mass in a traditional elevator system, and when you cut that moving mass 75-80%, obviously you can cut down on the amount of energy required to move it .... Another significant thing is that UltraRope doesn't stretch. Steel rope stretches, which means that after you've had the building open for a while, you have to shorten the rope .... Because UltraRope doesn't stretch, you don't have to take the elevator out of service once the building is opened and commissioned .... The UltraRope life is also significantly longer than a standard steel rope. And because of that, you reduce the downtime associated with service .... We don't really want the elevator to be something you notice. We want the elevator to be something you don't notice. Because if you think about the elevator ride you remember, it's the elevator you had to wait forever for, or the one that was not smooth.

CW: How have your customers responded to UltraRope?

SG: They're excited because they are able to design buildings in ways they haven't been able to do before. When you think about just the savings in square footage if you can have a single hoistway or elevator shaft that runs the entire length of the building, rather than having multiple shafts staggered as you move up the building, that ends up saving square footage. That's leasable space .... They're excited about the energy savings. They are excited about the increased uptime and long-term reliability. It's a great innovation that has immediate impacts on all phases of a building's life.

BIZ BRIEF

Teijin Ltd. (Tokyo, Japan) announced on Nov. 30 that it will establish a new carbon fiber production facility in Greenwood, SC, US. Also, Teijin is integrating its Toho Tenax unit via the establishment of a new company, Teijin Carbon Fibers Inc. (TCF), a wholly owned subsidiary. TCF is expected to be incorporated this month and begin operating its new carbon fiber production facility by the end of fiscal 2020.

AEROSPACE

Automated manufacturing solutions growing

Airborne International's (The Hague, The Netherlands) Marcus Kremers, the company's chief technology officer, talked recently with *CW* about its growing smart automation initiatives for its customers. A composite parts producer with about 120 employees, Airborne is focused primarily on space, aeronautics, automotive and maritime industries. The latter — where the emphasis is on tidal turbine blades, ship propellers and other subsea composites — comes under the purview of Airborne Maritime (AEL, based in the UK). A separate company, Airborne Oil and Gas (operating in IJmuiden, The Netherlands; Houston, TX, US; and Kuala Lumpur, Malaysia), manufactures thermoplastic composite spoolable pipes for the petroleum industry. Parent company Airborne International is transforming itself into an automated solutions provider, thanks to more than 20 years of experience with advanced composite manufacturing.

For the past several years, says Kremers, Airborne has been developing faster, smarter and automated strategies: "We're in the business of providing our customers high-end composite solutions, whether that means manufacturing the parts in our facility, or developing industrialization packages so that they can produce the parts themselves.

Source | Airborne International

Customers come to us with an idea," he explains. "We help them realize that idea using our knowledge of composites and machine technology. Airborne's focus is on high-end composite components, at high production rates, at radically low conversion costs."

Its three-phase approach is called "Prove and Move." In Phase 1, clients partner with Airborne to develop an efficient manufacturing method, then Airborne takes over part production. Phase 2 involves analysis of the part's manufacturing process to identify quality-critical steps and develop a plan for automated and digital manufacturing, with input from equipment and software partners KUKA (Augsburg, Germany) and Siemens Nederland NV (The Hague, The Netherlands), respectively. During Phase 3, production is shifted to a new, qualified automated line, located either at Airborne's facility, at the customer's facility, or at a subcontractor's manufacturing site. Says Kremers, "We have set up a Field Lab called Digital Factory for Composites, part of the Dutch Smart Manufacturing Initiative, to implement Industry 4.0 for composites with our partners Siemens, KUKA, TU Delft [Delft, The Netherlands] and, more recently, materials supplier SABIC [Sittard, The Netherlands]."

A representative example of Airborne's approach is a fully automated process for picking, sorting and placing composite plies, introduced at the AIRTEC 2017 trade show. The solution reportedly can be integrated with any automated flatbed or conveyor-type cutting machine to reduce cost and labor time required to convert composite rolls into sorted kits. Built around a KUKA robot and a camera system integrated with the end-effector, the robot takes up cut pieces as directed by the kitting system programming, and automatically sorts them into kits: "It's one integrated cell. No human labor is needed to create the kit. The camera records the operation, and the code on each piece, and the program does the work. It provides full traceability for each kit."

Kremers adds that the system is sophisticated: "For example, if you are working on four different shipsets of parts, each of which uses some of Material A, it is possible to nest and cut all four shipsets with Material A as one batch, which saves tremendously on material waste. The robotic system never loses track of which piece goes in which kit." He notes that the automated kitting system is advancing the adoption of advanced and dynamic nesting software strategies, which nesting software providers, such as Plataine (Waltham, MA, US), are promoting.

Many more automated applications are in process, he says, although specifics can't be announced yet: "We are working on an end-to-end automated process flow for thermoplastic tailored blanks for aerospace, and have a low-cost, robotic multi-functional ATL cell for thermoset prepreg that also features pick-and-place for local patches and ultrasonic cutting, for example."

AEROSPACE

Automated preforming and RTM cell cuts helicopter seat cost and weight

Source | Israel Aerospace Industries and Techni-Modul Engineering

Israel Aerospace Industries (IAI, Tel Aviv, Israel) has produced crashworthy seat structures for aircraft since 1978. Providing design, certification and manufacturing, it has earned a reputation for lightweight seating using composites and also has developed efficient production via RTM. Now it is augmenting both with intelligent automation.

"The idea was to implement 'one-shot' technology, manufacturing a part in a single, automated process," explains IAI development program manager Hary Rosenfeld. IAI already had acquired expertise in resin transfer molding (RTM) during development of the 2.8m-long, one-piece composite rudder it now produces for the Gulfstream *G250* business jet (see endnote). "We know how to design parts for RTM," says Rosenfeld, "but now we wanted to automate the preforming as well."

For a test case, IAI selected an in-process composite helicopter cockpit. Designed using autoclave-cured prepreg, the original enabled comparison of part weight and cost vs. the consolidated design using automated preforming and RTM.

Design allowables were defined for the two laminates used: a satin weave glass fiber fabric and a satin weave carbon fiber fabric from Hexcel (Stamford, CT, US), impregnated with Prism EP2400 epoxy resin from Solvay Composite Materials (Alpharetta, GA, US), which meets aircraft/rotorcraft flame, smoke and toxicity (FST) requirements. "The epoxy resin is cured at 180°C to meet strength requirements," Rosenfeld notes, adding, "There are resins that can cure at lower temperatures, such as 130°C, but these have a longer cycle time."

A key partner in IAI's development was composites automation specialist Techni-Modul Engineering (TME, Coudes, France). IAI had been working with RTM equipment supplier Isojet (Corbas, France), which then recommended TME for making the RTM tools. Isojet and TME are part of Composite Alliance Corp. (CAC, Dallas, TX, US), which provides composites manufacturing solutions that range from single tooling and equipment to automated workcells and complete turnkey systems (see endnote). After completing the RTM tooling, IAI decided to keep working with TME. "They helped us to define the design and requirements for the production line and suggested automation possibilities," adds Rosenfeld.

In the solution developed by IAI and TME, an automated cutting table and single robot are synchronized via a central control unit. Rosenfeld explains: "The robot picks up plies in a predefined sequence per the design: Two glass fabric plies (face-up and face-down) and two carbon fabric plies (face-up and face-down), which achieve a symmetric laminate." The synchronized system changes the rolls of fabric automatically, as needed, to keep the production line running. Cuts are nested to maximize material usage and minimize waste. The fabric also is coated with thermoplastic powder to aid preform consolidation. The robot then places the cut plies onto a heated mold to achieve a 3D shape.

"We have developed specialized end-effectors that operate like hands," explains Marc-Ruddy Thimon, director of sales for CAC. "This allows 2D materials to be folded and formed into complex-shaped areas, like corners." A reusable membrane and vacuum helps to consolidate the thermoplastic-coated fabrics into a high-quality preform.

The single workcell robot, with end-effector — now changed to trimming head — is then used to trim the preform to achieve a net-shape part. The trimmed preform is manually transferred to the bottom mold in the RTM press. "We apply vacuum and begin resin injection, using the Isojet injection machine," says Rosenfeld. "Both temperature and pressure are increased in the mold, reaching 180°C and a pressure of 6 bar, during a 2-hour molding cycle." Then the mold is cooled to 50°C, opened and the finished part is removed. The overall cycle time, including injection and mold cleaning, is about 7 hours.

The resulting seat reduces cost by 30% vs. its prepreg predecessor while maintaining critical strength and crash performance *and* shaving weight by 7%. The latter, says Rosenfeld, is due to very accurate plies. "We optimized the part design for RTM, so there is not as much overlap in ply location and less material wasted. You also don't have to factor in manual layup errors, so this reduces extra material as well."

Part of what makes the robot so accurate is TME's "intelligent automation." "We integrate a camera into the robotic arm," says Thimon, "so that vision inspection is completed during preforming operations. When you unroll material, it will check fiber orientation. It will also inspect during pick-and-place layup for fine positioning of the ply onto the tool/preform and for other defects in this part of the process, such as missing plies and incorrect fiber orientation." IAI has worked with CAC to validate the inspection results. "It compares the visual images taken by the camera with the computer design file and shows any deviation," says Rosenfeld. "CAC has developed a very good algorithm for this, and we have verified how well it works."

Source | Israel Aerospace Industries and Techni-Modul Engineering

Although cycle time has already been reduced to one completed RTM seat per 8.5-hr shift, Rosenfeld believes robotic inspection can eventually further reduce manual inspection times for even faster production. The automated RTM process also produces net-shaped parts with a high-quality finish on both sides, so the only post-molding operation is drilling a few holes. "We will also keep looking at newer resins that cure more quickly, like in automotive," notes Rosenfeld.

"We have a very strong design group at IAI," he says. "Now we have a stronger manufacturing technology, and can extend this to other types of seats as well as aerodynamic surfaces and aeroassemblies, such as flaps, doors and rudders."

Read more online | short.compositesworld.com/1PieceRudd and short.compositesworld.com/SmartPandP

AUTOMOTIVE

SGL: One stop for solutions from thermoplastic compounds to CFRP parts


Source | SGL Group

Pre-eminent as autocomposites pioneers, SGL Group (Wiesbaden, Germany) and partner BMW AG (Munich, Germany) have industrialized production of carbon fiber-reinforced parts, controlling the supply chain from manufacture of fiber to production of textiles and parts. BMW has done so, thus far, through its joint venture with BENTELER Automotive (Paderborn, Germany). But BMW recently announced production of its own carbon and glass fiber-reinforced organosheets and long fiber thermoplastic (LFT) materials for overmolding and has acquired BENTELER's share of the BENTELER-SGL joint venture, bringing its part manufacturing capacity and expertise into the broader SGL supply chain.

"The complete takeover of BENTELER-SGL enables us to expand our serial production capabilities for components made from fiber-reinforced composites. In future, we will be able to offer our customers one-stop-shop solutions along all steps of the value chain, from carbon fibers to materials and components," explains Jürgen Köhler, CEO of SGL Group. He adds that this serial production expertise will now be made available in other industries.

The company's newly launched thermoplastic materials toolbox will include long fiber thermoplastics (LFTs), unidirectional (UD) tapes, polyamide-based organosheets and new developments regarding carbon fiber sized for polypropylene composites, plus thermoplastic profiles and carbon/glass hybrids for automotive and other high-volume applications. It is offering both polyamide- and polypropylene-based materials, and sees a strong market trend toward combining glass fiber with carbon fiber, using the former to reduce cost and increase impact resistance while the latter

BIZ BRIEF

Victrex Plc (Thornton Cleveleys, UK) reports that its new US$13 million (£10 million) Polymer Innovation Center is now fully operational and will house Victrex's R&D efforts focused on its trademarked VICTREX polyetheretherketone (PEEK) polymer and other differentiated grades within its polyaryletherketone (PAEK) family of high-performance thermoplastics. Co-located at the company's UK headquarters, the Center will extend Victrex's capabilities in innovation, assist customers in the development of technological advances using VICTREX PAEK solutions, and function as an enabler for rapid prototyping of new parts with novel PAEK materials. The company sees 10-20% of its medium-term sales coming from PAEK sales and expects the Center's R&D capability to support its work to formulate customer-specific solutions. Target markets will include the automotive, aerospace, electronics and energy industries, and the Center will be the stage for design and development of materials and selected semi-finished/finished implantable products for the medical industry.

Source (both) | BENTELER-SGL

BENTELER-SGL prototyped this CFRP spare wheel well, using one-shot RTM and foam core to reduce noise, vibration and harshness (NVH) vs. the previous SMC design. BENTELER-SGL's wet-pressing cell features fully automated dual lines and integrated parts inspection.

provides for local reinforcement where needed, resulting in load-path-optimized parts.

It will complete the process chain with development in its 1500m^2 Lightweight Application Center (Meitingen, Germany), helping customers through simulation, process evaluation and material characterization to find optimized product and manufacturing options. There, customers will be able to work with SGL's thermoplastic products in pilot manufacturing lines, and have the capability to combine continuous semi-finished materials with injection molding processes as well as tape placement, thermoforming and automated handling. This capability will be augmented by BENTELER-SGL's 2,000m^2 Technical Center (Ried im Innkreis, Austria) where it develops, prototypes and completes qualification and ramp-up of custom parts manufacturing production lines before moving these to its 10,000m^2 high-volume production facility in nearby Ort im Innkreis.

Read more in the *CW Blog* | short.compositesworld.com/Overmold

Read more about BENTELER SGL online in an exclusive *CW* Plant Tour | short.compositesworld.com/BentelerSG

CW MONTH IN REVIEW

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

Spirit AeroSystems plans major expansion
The company will add 1,000 new jobs, with the majority in the hourly ranks, including skilled sheet metal mechanics, composite technicians and CNC machine operators.
12/11/17 | short.compositesworld.com/SpiritAExp

Composites enable handicap-accessible train platforms
MBTA found a corrosion-resistant replacement for previous concrete structures in Composite Advantage LLC's fiber-reinforced polymer (FRP) deck panels.
12/11/17 | short.compositesworld.com/TrainPlat

Hexcel acquires Oxford Performance Materials
Hexcel announced Dec. 8 that it has entered into a definitive agreement to acquire Oxford's aerospace and defense (A&D) business.
12/11/17 | short.compositesworld.com/Hex-Oxford

Boom Supersonic receives investment from JAL
Japan Airlines and US-based Boom Supersonic announced on Dec. 5 a strategic partnership to bring commercial supersonic air travel to passengers.
12/11/17 | short.compositesworld.com/BoomJapan

Kordsa acquires two US companies
The Istanbul, Turkey-based firm announced Dec. 6 that it has entered into a definitive purchase agreement to acquire Fabric Development Inc. and Textile Products Inc.
12/11/17 | short.compositesworld.com/Kordsaand2

Michelman announces partnerships with EFT and Mafic
Partnerships with Engineered Fibers Technology LLC and Mafic will increase the performance and surface characteristics of fibers and composites.
12/11/17 | short.compositesworld.com/MMEFTMafic

Weber Manufacturing expands, buys huge machine
Weber's new 5-axis machining center from DMG Mori (Bielefeld, Germany) is the first of its kind in Ontario and only the third such machine in North America.
12/11/17 | short.compositesworld.com/Weber5axis

Zoltek fiber in new electric car
The St. Louis, MO, US-based producer of industrial-grade carbon fiber, has its PX35 carbon fiber featured on the new *Uniti* electric car, produced in Sweden.
12/11/17 | short.compositesworld.com/ZoltekUni

Faction Skis feature TeXtreme spread-tow fabrics
Each Prime 4.0 ski from Faction Skis weighs only 1740g and is optimized for high-performance, technical skiing.
12/11/17 | short.compositesworld.com/FactionTeX

Fill to expand Austrian production facility
Preforming machinery specialist Fill GmbH will expand its production facility, adding 5,000m^2 for machine and systems assembly.
12/11/17 | short.compositesworld.com/FillExpand

AEROSPACE

CW's Automated Inspection Series preview: Real-time automated ply inspection (RTAPI) system

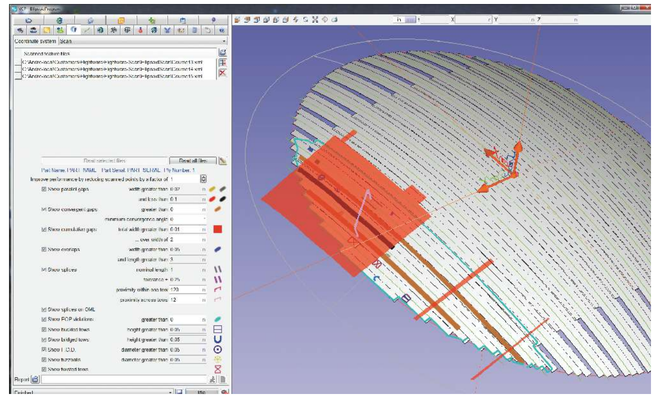
Despite the availability of fast, efficient automated fiber placement (AFP) and automated tape laying (ATL) machinery and AFP/ATL-compatible composite materials, commercial aircraft production has often not been very fast and efficient because mandated inspection of parts is still a production bottleneck. Careful visual inspection and verification is needed after each ply, by trained human inspectors, to meet quality assurance requirements. For a large composite part, such as a fuselage barrel requiring hundreds of plies, the negative impact of inspection (and any rework) on automated process efficiency is significant, according to information presented at recent industry gatherings. For example, in a paper presented several years ago by Robert Harper of Fives Cincinnati (Hebron, KY, US) and Allen Halbritter of The Boeing Co. (Chicago, IL, US), based on a generic fuselage barrel and using an optimized AFP process, inspection and rework still made up more than *60%* of the total part production time. David Maass of Flightware (Guilford, CT US) puts it in more stark terms: "We've got to get rid of an 18th Century methodology being used for a 21st Century part."

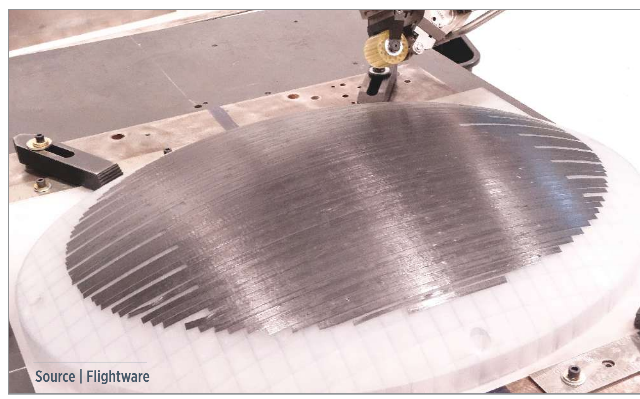
Fortunately, that situation is changing, for two reasons. First, increasing percentages of newer aircraft are made from composites and, second, resulting pressure for higher production rates is driving development of new technologies for *automated, in-process* inspection — taking inspection *out* of the hands of humans and performing inspection *as the part is being fabricated*. Groups around the world are working on the necessary technology development and taking great strides toward the goal of making inspection as fast as the production process.

CW is in the process of gathering information about these new automated inspection processes, and plans to publish a series of articles in print (in *CompositesWorld* magazine) to bring these technologies to light.

"It's been said that automated inspection is 'low-hanging fruit' and the easiest way to really reduce aerospace AFP part production time," says Maass. His Real Time Automated Ply Inspection (RTAPI) system is one example. It consists of a laser profilometer, available commercially, off the shelf. This very powerful but very low-cost sensor, contains a laser line generator and a camera. The sensor collects measurements of height and width points (about 1,000 points for every tow course) and delivers point cloud data to a software program and user interface that Maass has developed, which converts the data into layup features of interest, such as tow edges, tape ends (adds and drops), gaps, overlaps, etc.

Maass' system mounts the profilometer directly on the layup head, from where it measures the heights of the fiber tows following the compaction roller, generating "millions of data points for each course in a very dense point cloud,"





Source | Flightware

states Maass, adding that the data-processing step of the RTAPI technology is patented. In early work, the system was capable of detecting all features of a single course in fewer than 10 seconds, but in recent work that time is being reduced to near real-time operation.

The software compares the as-made layup against the automated machine's part design program to identify gaps, overlaps, dislocated plies, late adds, perform foreign object detection (FOD) and more, explains Maass. Flightware worked with CGTech (Irvine, CA, US) to adapt the latter's VCP AFP programming software to read and display layup flaws automatically detected by the RTAPI system. Flaw types are shown using symbology and color codes, so the operator knows where to look and what to look for. The system was designed to accept and allow operator-selected QA criteria.

The API (Automated Ply Inspection) technology was developed in 2014 under a NASA-funded program. Then the US Department of Defense's Defense Logistics Agency funded work to enable "real-time" operation (hence the acronym, RTAPI). The current program includes funding to demonstrate the system on actual, complex aerospace parts. Watch a YouTube video produced by Maass, which shows how the software works to identify problem tows | **https://www.youtube.com/watch?v=_2KuzbHe4eU&feature=youtu.be**

AUTOMOTIVE

China-based Geely acquires Terrafugia and its "roadable aircraft"

Zhejiang Geely Holding Group (Hangzhou, China) announced in mid-November that it has entered into a purchase agreement with Terrafugia Inc. (Boston, MA, US), best known for its *Terrafugia* flying car. The acquisition includes Terrafugia's engineering and production of flying cars, future technologies, and operations and assets in their entirety.

Terrafugia was founded in 2006 by five award-winning graduates of the Massachusetts Institute of Technology (MIT, Cambridge, MA, US). Since its inception, the company has delivered a number of working prototypes of what it calls its "roadable aircraft" and still aims to deliver its first commercial model in 2019. The company intends to field the world's first flying car with vertical-take-off-and-landing (VTOL) capability by 2023.

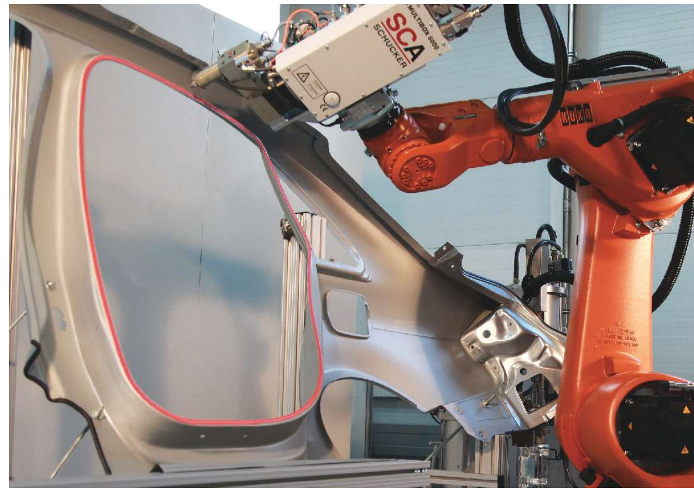
Under the terms of the agreement, Terrafugia will remain domiciled and headquartered in the US, and will continue to focus on its existing mission of developing flying cars. Terrafugia also will benefit from the Geely Holding's significant expertise and track record of innovation within the global auto industry. The deal has received approval from all relevant regulators including the Committee on Foreign Investment in the United States (CIFIUS). Chris Jaran, former managing director for Bell Helicopter China has been announced as a board member and CEO, effective immediately. Terrafugia founder Carl Dietrich will serve on the board of directors, and transition to the newly created role of chief technology officer (CTO). In anticipation of the transaction, Terrafugia's US engineering team has tripled, with Geely Holding's support.

Read more about Terrafugia's flying car technology | short.compositesworld.com/Roadable

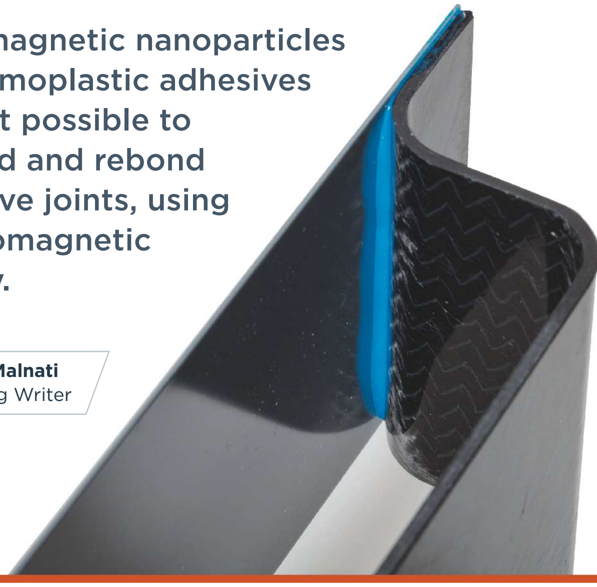
BIZ BRIEF

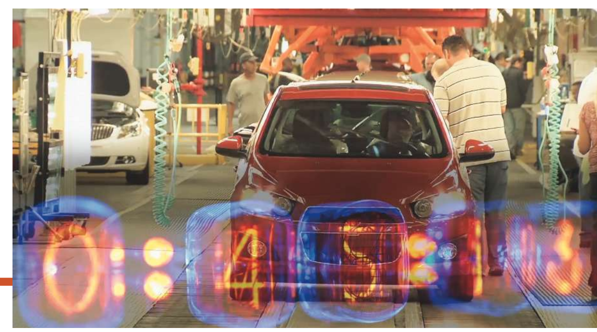
Mikrosam AD (Prilep, Macedonia) reported in November that it is entering into partnership with **Composite Automation LLC** (Collingswood, NJ, US) to bring its solutions to the North American market. Mikrosam says that with the growth in advanced composite parts production, the need for sophisticated automated fiber placement and automated tape laying (AFP/ATL) systems in the North American market has never been greater. To meet that need, Mikrosam also has invested more than US$2.3 million in an advanced composites R&D and customer solution center, where customers can perform prototyping, testing, product design, and receive help with technology development.

Reversible multi-material adhesive bonds



Ferromagnetic nanoparticles in thermoplastic adhesives make it possible to debond and rebond adhesive joints, using electromagnetic energy.





By Peggy Malnati
Contributing Writer

» As the auto industry moves toward use of multi-material vehicle structures, the ability to structurally join dissimilar materials and keep them together during the vehicle's useful life, yet also *separate* them for repair, rejoin them and then separate them again at end-of-life for recycling has become increasingly important. This is especially important for primary vehicle structures. These are far more safety critical than interior or exterior panels and, therefore, it's vital to prevent unwanted separation during vehicle operation. They are also costlier to replace, which makes them highly desirable targets for repair rather than the junkyard if damaged.

Problems with conventional joining methods

The conventional structural joining technologies — welding, mechanical fastening (with its associated hardware) and adhesive bonding — each fall short of ideal in this new multi-material reality.

Effectively executed, welding produces strong joints but permanently links components, making it difficult to separate and repair subcomponents, and then rejoin them to the assembly. Also, welding is limited to certain metals and to thermoplastics, and is impractical for thermosets and for multi-material systems.

Mechanical fastening is a well-known industry standard for joining, and, in most cases, it is reversible. A damaged component can be disconnected from a larger assembly, and then a repaired or a replacement part can be reattached to the assembly. Although this approach works well with metal-to-metal assemblies, it is less desirable for assemblies that feature composite (and/or plastic) components because fasteners require drilling, or molding in, holes. Fasteners not only disrupt surface aesthetics, but also concentrate stresses, so provide opportunities for cracks or interlaminar separation to begin. Furthermore, coefficient of linear-thermal expansion (CLTE) differences

Bonding dissimilar materials without loss of production speed

As the auto industry moves toward use of multi-material vehicle structures, the capability to structurally join components of unlike composition (photo, far left), keep them together during vehicle use life despite differences in coefficients of linear-thermal expansion (CLTE), then separate them for repair or recycling becomes an important consideration. Just as important, automakers want joining processes (near left, top) to take less than 1 minute, to keep up with assembly line speeds (near left, bottom).

Sources | General Motors Co. (top) / American Chemistry Council (bottom)

between dissimilar materials can further increase stresses. Lastly, mechanical fasteners are heavy and, significantly, can corrode.

Properly executed, adhesive bonds (generally with thermoset polymers) are lightweight, protect surface aesthetics, and are stronger than surrounding material. The adhesive bond is preferred for joining composites because, unlike mechanical fasteners, it spreads joint stresses evenly over the entire surface-to-surface contact area. Bonding also is preferable for multi-material assemblies because the adhesive's flexibility can better accommodate those differences in CLTE. Adhesive bonds, however, are typically permanent, making removal of components for repair or replacement impractical.

That could change. A multi-year research program involving the American Chemistry Council's Plastics Division (ACC-PD, Washington, DC, US) and Michigan State University (MSU, East Lansing, MI, US), has yielded surprisingly effective results in its quest to develop *reversible* adhesive joints that can be debonded and rebonded multiple times. This capability could facilitate composites use in mixed-material vehicle structures because it gives adhesively bonded joints the durability *and* the reversibility of mechanically fastened joints at reduced weight.

Fortuitous timing

This project came about when separate research efforts at MSU and ACC-PD intersected. Three years ago, MSU — through its Composite Vehicle Research Center (CVRC) headed by Dr. Lawrence Drzal, university distinguished professor and a renowned expert on composites, nanocomposites, and surface chemistry — submitted a proposal in response to a US Department of »

Seeking fastener-like bond reversibility

Adhesive bonds spread stresses over the entire surface-to-surface contact area, can better accommodate differences in CLTE, and provide better surface aesthetics than mechanical fasteners. But unlike most fasteners, adhesive joints are permanent, preventing debonding for subcomponent repair and reassembly, or end-of-life recycling. Debondable/rebondable structural adhesive bonds could facilitate composites use in mixed-material vehicle structures and give those joints the reversibility of mechanical fasteners at reduced weight. Source | American Chemistry Council and Michigan State University

Testing electromagnetic nanoparticle performance

Researchers from the American Chemistry Council's Plastics Div. and Michigan State University take a measurement as a electromagnetic coil excites ferromagnetic nanoparticles in an adhesive used to bond a small assembly. The team has demonstrated that an adhesive joint can be rapidly unbonded in the presence of an electromagnetic field, then rebonded again with another round of electromagnetic energy. At 4% particle loading, the joint has good impact and strength, but takes 10 minutes to heat and unbond or rebond. At 12-16% loadings, there is a small drop in mechanicals but the joint heats to unbond/rebond temperature in <20 seconds. Source | Michigan State University and the American Chemistry Council

■ Testing shows extensive effectiveness in multi-material combinations

The reversible adhesive bonding research has enabled successful attempts to join a wide variety of metals, plastics and composites to create multi-material assemblies. When resin/particle surface compatibility and substrate surface prep are rightly done, the team has achieved joint shear strengths in the 12-13 MPa (1,741-1,886 psi) range, which it says is better than epoxy structural adhesives.

Source | Michigan State University and the American Chemistry Council

Energy (DoE) program aimed at exploring lightweighting and multi-material joinery.

At the time, researchers were working with graphene nanoparticles in thermoplastic polymers. They already knew that applying microwave energy excited the nanoparticles, and that doing so heated and melted only the polymer in which nanoparticles were embedded. This led researchers to think the phenomenon could be harnessed to create reversible adhesive joints. The project received a grant and research began.

ACC-PD's parallel roadmapping projects, done with industry and federal government partners, had identified "technology gaps" that were slowing the adoption of lightweight plastics and composites in vehicle applications. One such gap was the need for better joining technologies for multi-material structures. "Seeing the problem, our member companies decided to take the initiative and try to develop a solution," recalls Mike Day, an ACC-PD technical consultant and career-retiree from DuPont (Wilmington, DE, US). While conducting a technology review for possible solutions to the bonding problem, ACC-PD discovered MSU's work and contacted the university a month into the DoE research program.

Research detour

Not long after collaboration began, the joint MSU/ACC-PD research team ran into a problem. Researchers checked how big commercial microwave-generation units were. "The biggest variable-frequency microwave ovens anyone seemed to be making were the size of home microwave ovens," recalls Dr. Mahmoodul Haq, MSU assistant professor – Department of Civil & Environmental Engineering. "Those were too small to be practical for field use — particularly for some of the structural applications we were envisioning." Until in-field microwave applicators were developed, it was back to the drawing board to find another nanoparticle that could be excited by energy transmitted by a device not so size-constrained.

"Fortunately, there are lots of nanoparticles out there," he adds. "For example, we knew ferromagnetic particles could be excited with electromagnetic energy, and that to generate that energy, all we needed were small coils without all the surrounding structure you need to safely operate microwave systems." Making that shift put "rockets under the project," Haq recalls.

What's been tried

Fast forward three years and a lot has been accomplished. The team has used iron oxide (Fe_2O_3 and Fe_3O_4) nanoparticles at loadings of 4-20% in a variety of thermoplastic adhesives. "We characterized the particles in and out of the adhesive, so we could understand their synergy and be able to predict when impact and strength would drop, and what concentration was best so mechanicals stayed good but the bond was quickly reversible," explains Haq. "For example, at 4% loading, the joint has good impact and strength, but takes 10 minutes to heat. However, at 12-16% loadings, we have a small drop in mechanicals but we can heat the joint in less than 20 seconds. Those bonds still carry loads, prevent fractures, resist fatigue and eliminate corrosion."

They started with polyamide (PA) 6 and 6/6, then tried acrylonitrile butadiene styrene (ABS), polycarbonate (PC), high-impact polystyrene (HIPS) and several olefin-based hot-melt adhesives. Thanks to Drzal's surface-chemistry expertise and the team's hard work, Haq says they now know how to adjust the surface chemistry of not only the polymers but also the nanoparticles and, therefore, can make the technology work in just about *any* thermoplastic adhesive system, although he acknowledges that some polymers require more adjustment than others.

> Any specific commercial applications will still require fine-tuning, regardless of which polymer is used.

"This is a fairly tailorable technology, so it doesn't matter if we're using amorphous or crystalline, polar or non-polar resins," he adds. "It's just a matter of establishing application needs, then adjusting the chemistry so functional groups on particles match up with those on the polymer."

"It's been part of our technology approach from the beginning to think of this as an enabling technology," adds Day. "We took a fairly broad view of thermoplastics as an adhesive element and tried lots of resins so we weren't limited to one polymer family." He notes that specific commercial applications will still require fine-tuning, regardless of which package is used. "This is pre-competitive work, so we knew we couldn't figure everything out, but had to focus on proving the concept," Day explains.

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When resin/particle surface compatibility and substrate surface prep have been rightly done, the team has achieved joint shear strengths in the range of 12-13 MPa (1,741-1,886 psi), which it says is *better* than epoxy structural adhesives.

Interestingly, bond strength reportedly *increases* after several cycles of bonding/debonding vs. that achieved via convection heating alone. While the initial target was to create a reversible joint that could survive six cycles of bonding/debonding — a goal the team thought a reasonable lifetime expectation — they were pleasantly surprised to find joints surviving 20 and even *100* cycles. Also, electromagnetic bonding is faster than with convection ovens, it does not heat surrounding substrates and is amenable to automation.

From the theoretical to the practical

When the technology moves from the lab to commercial application, however, manufacturers will need to be aware of certain limits. One is that regardless of the plastic used in the multi-material mix, it must be a grade without internal mold release, to avoid potential release interference with the bond. Another is that, despite the seemingly limitless theoretical ability to debond/rebond, in practical terms, bondline *thickness* will limit the number of cycles a joint can survive. The joint is thin to start with and becomes thinner with each rebonding cycle as resin is squeezed out when substrates are forced together.

A third concern is whether composites with ferromagnetic particles in the matrix could increase the risk of galvanic corrosion when joined to metal. "We've been thinking a lot about this issue," notes Haq, who says his team has had joints with 18% particle-loading levels sitting in salt-corrosion chambers for more than two months without seeing any corrosion. He feels confident that adhesive and substrates can be tailored for each application in ways that avoid such galvanic reactions.

So far, substrate geometry has not presented limitations. The technology has been successfully applied to lap shear joints, out-of-plane T-joints and torsional joints. While exceptionally large electromagnetic coils probably present a practical size limitation, another MSU professor, Dr. Lalita Udpa, is working on coils to go around very tight geometries.

To avoid that late-project falter when it is often discovered that a technology is feasible but not affordable, ACC-PD worked with analysts at the Center for Automotive Research (CAR, Ann Arbor, MI, US) to evaluate the economics of reversible bonding in current automotive assembly operations. "You can do technical research all you like," explains Day, "but in the end, economic reality can really complicate things if you don't address it." Based on benchmarking different joining technologies and comparing those with the new process, the team believes its reversible bonding technology will be cost-effective. Because a trained workforce will be needed to apply a commercially viable technology, MSU undergraduate and graduate students are deeply involved in the research.

What's next? The team is looking at coating nanoparticles to increase toughness, reduce corrosion risks, and improve dispersion. They also are wrapping up simulation work and looking for partners interested in field trials. CW

ABOUT THE AUTHOR

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Plant tour: Diamond Aircraft Austria, Wiener Neustadt, Austria

Composites use among general aviation manufacturers is far from unusual, but none apply them quite like this airframer does.

By Jeff Sloan / Editor-in-Chief

» Given all the attention paid to composites use in the Boeing 787, Airbus A350 XWB and other large, high-profile aircraft, it is easy sometimes to forget that those who build general aviation (GA) aircraft not only embraced composites long before the major airframers, but also continue to do so in ways unheard of in the big planes. Innovation in layup methods, manufacturing processes, out-of-autoclave cure, adhesive bonding and nondestructive testing abound in the GA environment, all developed with the goal of making these craft as efficient, safe and affordable as possible.

Arguably, no GA aircraft manufacturer is more committed to composites use than Diamond Aircraft. For decades, it has pushed the composites envelope to manufacture a line of single- and twin-engine aircraft for a variety of uses, ranging from pilot training to commuting to surveillance. Along the way, the company has developed a creative suite of materials, processes, assembly methods and aircraft architectures that enable it to easily mix and match manufacturing solutions for a variety of aircraft types.

David-Alexander Bausek (Fig. 1, p. 29), the company's head of production, says this push-the-limits culture flows down from CEO Christian Dries, whose intentionally high-risk/high-reward environment is designed to drive innovation. "There is a risk that we will fail, but it is very innovative," Bausek says. "And in most cases, we succeed."

Composite from the beginning

The twin-engine, seven-seat *DA62* is the most recent entry to the market from general aviation specialist Diamond Aircraft (Wiener Neustadt, Austria), which has from its inception applied composites to the primary structures of its aircraft. Diamond Aircraft also produces the single-engine *DA40*, the twin-engine *DA42* and the *DART 450* single-engine trainer. Coming later this year is the single-engine *DA50*. Source | Diamond Aircraft

The heart of Austria

CW's visit required travel to Austria, about an hour south of Vienna, to the small town of Wiener Neustadt (population 44,000), where Diamond Aircraft spans a multi-building campus adjacent to the single-runway Flugplatz Wiener Neustadt Ost (Wiener Neustadt East Airfield). Founded in 1981 as Hoffmann Flugzeugbau, the fledgling airframer first manufactured the *HK36* motorglider. Dries acquired the company in 1991 and, in 1992, bought Diamond Aircraft in London, ON, Canada, then combined the two companies under the name Diamond Aircraft Industries in 1996. Today, the Diamond Canada facility, which focuses on engineering and manufacturing, is 60% owned by Christian Dries. In addition, Diamond Aircraft operates two manufacturing facilities in China via joint ventures, one in Pinau and one in Wuhu.

Diamond Aircraft's first product was the *DV20*, a two-seat, single-engine plane, delivered in 1995. A year later, the company rolled out its single-engine *DA40* and twin-engine *DA42* — planes that eventually put the company on the general aviation map. Today, most of Diamond Aircraft's manufacturing — as many as 150 aircraft per year, depending on portfolio mix — is split evenly between single-engine and twin-engine aircraft, comprising three models: The single-engine, four-seat DA40; the twin-engine, four-seat DA42; and the twin-engine, seven-seat *DA62*. Diamond Aircraft also makes the *DART 450*, a civil single-engine, two-seat aerobatic trainer. And, coming this year is its new single-engine, *five*-seat *DA50-V.*

Composites use, as might be expected, has evolved as aircraft have evolved. The early *DA40* composites structures are all glass fiber. The later *DA42* structures are a combination of glass and carbon fiber, and the more recent *DA62* is all carbon fiber. Composites, as a fraction of each plane's finished weight, are about 30%.

Primacy of platform architecture

Before the tour commences, *CW's* guide, Bausek, explains the material and manufacturing philosophy that shapes Diamond Aircraft's composites fabrication operations. Its overriding principle is that of common platform architecture. For example, the wings of all Diamond Aircraft products are fully interchangeable. Beyond that, the company has a stable of fuselage designs and horizontal flight-surface designs that can be mixed and matched, depending on aircraft type, aircraft size, passenger limit, number of engines and the aircraft's intended use.

"For instance, the *DA40* and the *DA42* have the same fuselage, just a different nose section and a different midsection. This gives us the ability to produce more parts out of the same tool," Bausek points out. He notes that it also limits the mold inventory "and keeps our manufacturing pricing more attractive in terms of cost for the end-user. Also, we have a common part policy. That means we try as much as possible over all aircraft to use common parts."

In addition, Diamond Aircraft, on the *DA40* and *DA42* (but not the twin-engine *DA62*), uses adhesive bonding only to join composite structures. This is done to minimize the need for drilling that might weaken composite structures, and to save the weight associated with metallic fasteners. This means Diamond Aircraft has become highly adept at bondline verification. »

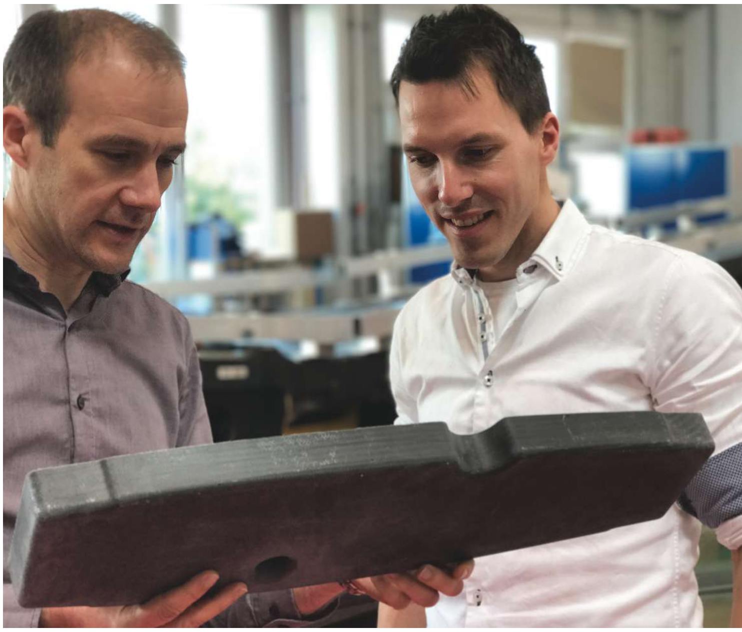

FIG. 1 Long-term supplier relationship

Olaf Krause, technical account manager, Hexion, and David-Alexander Bausek, the head of production at Diamond Aircraft, discuss a carbon fiber composite wing structure. Hexion has a long history as a supplier of epoxy and onsite technical support to Diamond Aircraft's composites manufacturing operations.

Source | Diamond Aircraft

SIDE STORY

Diamond Aircraft: Color and aircraft composites

Paint color has been the topic of much research at Diamond Aircraft (Weiner Neustadt, Austria). When its *DA62* was in development, the company wanted to differentiate the craft in the market by offering a variety of color options. The dark color range, however, was a challenge. On a hot day, the sun can heat a plane's structure while it sits out on the tarmac to more than 70°C, which exceeds the specified limits of many epoxies, including the legacy Hexion epoxy used on the *DA40* and *DA42*. The effect is a possible weakening of the structure that could result in failure during takeoff. It's important to note that such failure would require that the plane experience a 3.6G event while at that elevated temperature, Further, when the plane is in the air, it cools rapidly, so the risk of such a failure is remote. That said, the possibility of such an outcome, although highly unlikely, still must be dealt with from a design and manufacturing perspective.

There are two ways to overcome the potential loss of composite structural strength, says David-Alexander Bausek, the company's head of production: Increase the composite laminate thickness by adding plies, or change to a higher temperature resin matrix. However, he notes, increasing thickness adds weight, and "the lighter the aircraft, the better the performance." Changing the resin matrix has its own risks because it requires a change in manufacturing processes to accommodate a different cure profile. Diamond Aircraft chose the latter, which led to the application of Hexion's RIM epoxy system on the *DA62*, and enabled the company to offer the plane with the desired range of light and dark colors.

FIG. 2 Wet-preg the material format of choice

Wet-preg plies for Diamond Aircraft composite structures are impregnated either by hand or by machine but all are currently cut to precise size by hand prior to layup. The company's wet-preg material has proven difficult to cut using automated ply-cutting systems, although investigation continues into ways and means to do so, particularly in a series production environment.

Source | *CW* / Photo | Jeff Sloan

Bausek says, "It is not easy to certify a fully bonded aircraft, but we have never had an aircraft structure failure caused by bondline failure."

Diamond Aircraft also emphasizes simplicity of design, equipment and technology to give the pilot a comfortable and manageable flying experience, combined with easy customization of features and aircraft color. This extends to maintenance as well. All Diamond Aircraft wings, for example, are bolt-on structures, which eases repair and replacement and reduces cost of ownership.

Finally, the company's operations are very much characterized by its manufacturing systems, which revolve around "wet-preg," which is the process of applying mixed resin to dry fiber immediately prior to layup. This is called lamination at Diamond Aircraft and it is done for all larger parts automatically, the latter of which is accomplished with in-house developed fiber impregnation machines. Bausek says Diamond Aircraft primarily employs five material/manufacturing combinations, depending on the location and physical and mechanical requirements of the structure:

- Hand lamination without vacuum bag.
- Hand lamination/automated lamination with vacuum bag.
- Automated lamination with vacuum bag in a pressure chamber.
- Automated lamination with vacuum bag and medium heated pressure chamber (autoclave).
- Resin Infusion.

The process limits greatly the shelf life of the wet-preg, Bausek admits, which means that plies must be laid up as soon as they are impregnated, but the quality of the finished structure meets the company's needs well.

Cutting, kitting

Bausek begins the plant tour in the company's cutting and kitting area, which features a film-covered floor and film-covered cutting tables. Currently, wet-preg comes into this room following

SIDE STORY

The man behind Diamond Aircraft

Christian Dries, CEO of Diamond Aircraft (Wiener Neustadt, Austria), knows all about crashworthiness. More than 35 years ago, as he worked to earn his pilot's license, one of the tests he had to pass was to pull a plane out of an intentional spin. He was flying an all-metal aircraft, and during the test, he says, a wing almost detached from the plane. Indeed, after he regained control of the plane and landed, he discovered that only *five rivets* still held the wing in place.

"From that day onward," he says, "I was very reluctant about airplane structure. And the more I learned about airplanes, the less confidence I had in airplanes."

So, when he founded Diamond Aircraft and started manufacturing them, safety became the company's guiding principle, and composites, says Dries, "were best for that." Thus was launched Diamond Aircraft's push toward the development of composite materials and structures that best provide safety and economy.

As a testament to the advantage conveyed by composites, Dries points to his company's *DART 450* two-seat trainer, which went from concept to first flight in a mere 367 days. "This is only possible because of composites," he argues.

Today, Dries claims, Diamond Aircraft is, from a composites perspective, years ahead of its competitors and "10-20 years ahead of the regulatory authorities." This makes aircraft testing and certification a challenge. "Composites are the ideal material for airplanes," Dries insists, "but with regulatory authorities, we must work to evolve standards."

Over the next five years, Dries expects the Wiener Neustadt facility will evolve to focus exclusively on research, development and low-rate production, with serial production done at other Diamond Aircraft plants. Today those are located in Canada and China, but Dries plans to add two or three other facilities in the coming three years.

In the meantime, personnel will continue to innovate — with composites and other technologies, including autonomous piloting, and improved radar and camera technologies. And what's on the drawing board? A helicopter, Dries says.

Outside of aerospace but still within composites, Dries' other company, DAS Energy (also in Wiener Neustadt), is working on new photovoltaic solar panel technology that uses a flexible glass fiber composite membrane. "We are looking for opportunities to solve other problems," he says.

impregnation by hand or automated means and must be hand cut. Bausek says the company is researching automated cutting solutions for its in-house manufactured wet-preg, but the technology readiness level is not high enough yet for serial production.

Smaller parts and structures, including nacelles (Fig. 2, p. 30), are laid up in the cutting area immediately after they are cut. Ply schedules associated with each mold specify which material to place where and specify periodic quality-control steps to check accuracy.

Bausek notes that Diamond's common platform concept is operative here. Therefore, one mold can be used to make parts for several different aircraft, but that means the materials, fiber orientation and/or thickness vary by aircraft type. Making sure that a layup meets the requirements of the intended part is critical. "We must make sure the right material is used for the right aircraft," he sums up.

Carbon fiber is supplied to Diamond Aircraft by Toho Tenax Europe GmbH (Wuppertal, Germany) and Mitsubishi Chemical Carbon Fiber & Composites (Irvine, CA, US). Format is either UD, 2x2 twill or plain weave. A carbon fiber/aluminum weave or a carbon fiber/copper weave is used for the lightning strike protection layer. The epoxy resin for all of Diamond Aircraft's parts and structures is supplied by Hexion (Columbus, OH, US), including a "legacy" epoxy still used on the *DA40* and *DA42*, and a newer epoxy for the *DA62*.

Bausek says Diamond Aircraft has enjoyed a long relationship with Hexion, which has been a partner to the company since 1997. Indeed, Hexion technical personnel are frequently at Diamond's facilities and provide support for all aspects of composites manufacturing.

Large parts

Bausek leads the way into an adjacent room where parts too large for the cutting/kitting room are laid up. Here, a wide variety of molds and other equipment are in several stages of production.

Of particular interest is the lower shell of a *DA42* mid-section, which features a spar bridge that connects the wings to the plane's primary structure. Part of this structure includes the landing gear rib, fabricated from a glass fiber composite, which will better show cracks if it is damaged.

At the next mold, a technician is working on an engine reinforcement structure and has applied adhesive paste to the mating surfaces in advance of bonding. »

FIG. 3 C-spar: The most complex aerocomposite

Infusion of the *DART 450* C-spar is one of Diamond's most technical, if unusual, composites fabrication operations. Production head David-Alexander Bausek calls it the company's most complex, labor-intensive layup and says managing resin flow during injection is the key. For that, he uses a Membrane Tube Infusion (MTI) resin flow promoter, from DD | Compound (Ibbenbüren, Germany).

Source | *CW* / Photo | Jeff Sloan

FIG. 4 Interchangeable bonded wing structures

A fully assembled *DART 450* wing spar structure, featuring two C-spars (Fig. 3, above), in a bonding fixture. All Diamond Aircraft wings are interchangeable. Source | *CW* / Photo | Jeff Sloan

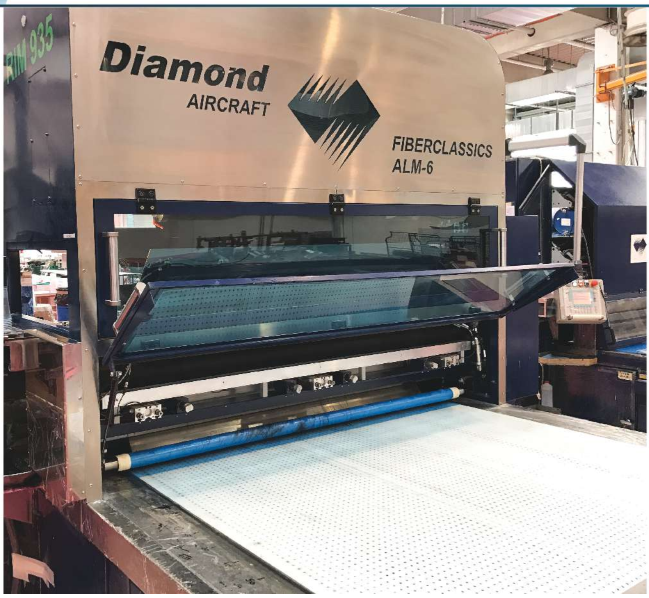

FIG. 5 Automated wet-pregging

One of the unique aspects of Diamond Aircraft's composites fabrication operations is the use of this in-house developed Automated Laminating Machine (ALM), which produces wet-preg plies for layup. Although the use of wet-preg limits fabric out time, it reportedly enables production of high-quality, low-porosity structures. Source | *CW* / Photo | Jeff Sloan

FIG. 6 Seven axes of post-mold forming freedom

CNC machining at Diamond Aircraft is performed with an HG Grimme SysTech GmbH (Wiedergeltingen, Germany) rotary cutter. It offers 5 axes of freedom at the spindle, with another 2 axes available through manipulation of the part itself.

Source | *CW* / Photo | Jeff Sloan

The longest mold in the room is for the main wing C-spar for a *DART 450* (Fig. 3, p. 31). It is one of the few resin-infused parts at Diamond Aircraft. Bagged and under preparation for infusion, its process employs a Membrane Tube Infusion (MTI) resin flow promoter (manufactured by DD | Compound, Ibbenbüren, Germany). Bausek says this C-spar represents the company's most complex and labor-intensive layup. "The know-how here is the injection point," Bausek says, "to manage resin flow."

FIG. 7 Pre-fit, postcure, paint and final assembly

In pre-assembly, composite structures — wings, fuselages, nose sections, tails, horizontal structures, are first fitted together and then postcured. Next steps? Painting and final assembly. Source | *CW* / Photo | Jeff Sloan

Moving on, Bausek points out a full *DART 450* wing spar structure (two C-spars) in a bonding fixture (Fig. 4, p. 31). The spar is part of a "wet" wing, meaning that aircraft fuel will be stored inside the wing structure, in addition to other onboard fuel tanks.

Following this, *CW* watches as one of Diamond's in-house-built Automated Laminating Machines (ALM, Fig. 5, top left) applies Hexion liquid epoxy to 60-inch-/1.52m-wide carbon fiber laminates, which are then cut and immediately applied by a team of technicians that is working on — and in — a large *DA62* half-fuselage mold. When the technicians are done with layup, the mold will be bagged for pre-cure in a heating room at temperatures around 45°C. Bausek says it takes about 6 hours to lay up one half of a *DA62* fuselage.

As noted, the manufacturing process Diamond Aircraft employs depends on the part's structural requirements. With vacuum bagging of the laminate material, says Bausek, parts porosity is about 2.4%. More void-free molding processes are used for spars, spar caps and radomes. "Everywhere that we need very low porosity and high quality," Bausek explains, infusion or medium-heated pressure chambers are used, which provides 0.2% porosity or less.

After cure, structures are adhesively bonded together. The only bonding paste Diamond Aircraft uses is a modified form of Hexion's legacy epoxy resin. Bausek says this is applied primarily by hand and only occasionally via automated methods. The company, he says, would like to move toward more automated paste application, but that would require a material that has more consistent viscosity characteristics, which is something Hexion is working on. All mating surfaces of all structures, Bausek says, must be easily accessible for external interrogation and assessment, which is performed with a BondMaster ultrasonic bond

FIG. 8 Complex final assembly

A *DA62* undergoes final assembly, integrating windows, seats, avionics, wing guts, ailerons, flaps, push/pull rods, fuel tanks, engines, propellers (wood core with glass fiber skin), landing gear and de-icing systems. Source | *CW* / Photo | Jeff Sloan

FIG. 9 Savoring the sights from a *DA40*

The *CW* tour of Diamond Aircraft concludes with a 45-minute aerial tour of the towns, Alpine countryside and Alps surrounding Wiener Neustadt. Source | *CW* / Photo | Jeff Sloan

tester, manufactured by Olympus (Waltham, MA, US). Diamond Aircraft also uses traditional tap testing, which the company says works very well. It also considers tap testing not unlike ultrasonic testing: "Same principle, different frequency," quips Bausek.

The next stop is CNC machining, which is performed with an HG Grimme SysTech GmbH (Wiedergeltingen, Germany) rotary cutter (Fig. 6, p. 32). Offering 5 axes of freedom at the spindle, with another two available via part manipulation, the system cuts holes for fuel ports, instruments and other devices. At this point, also, the interiors of the wings are fitted with rubber liners for fuel contact.

Pre-assembly, paint, assembly

Bausek moves on to pre-assembly (Fig. 7, p. 32), where wings, doors, tails and fuselages come together for final fitting, after which they are sent to post-cure at 120°C for 6 hours. Next comes painting, which is done in one of three paint booths. This includes epoxy primer/filler, grinding, electrostatic discharge coat and then final color coat.

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After painting, all composite structures move on to final assembly (Fig. 8, above), where the plane's noncomposite components — windows, seats, avionics, wing guts, ailerons, flaps, push/pull rods, fuel tanks, engines, propellers (wood core with glass fiber skin), landing gear and de-icing systems — are integrated to realize the final aircraft. Bespoke features ordered by customers are usually added here as well. *DA40s* and *DA42s* are assembled on one side of the assembly area, with *DA62s* assembled on the other. Each craft, when it is fully assembled, goes through five hours of production flight testing before customer delivery.

A finished *DA40* weighs 900 kg, is 8m long, 2m high and has a wingspan of 11.6m. The *DA42* weighs 1,410 kg, is 8.6m long, 2.5m high and has a wingspan of 13.55m. The *DA62* weighs 1,590 kg, is 9.2m long, 2.8m high and has a wingspan of 14.5m. The single-engine, five-seat *DA50*, when it enters the market this year, will weigh around 1,200 kg, be 9m long, 2.9m high and have a wingspan of 13.4m.

Increasingly, manufacture and assembly of Diamond Aircraft planes will migrate out of Austria and toward the company's other facilities. Indeed, *DA62* production was moved to Diamond Canada in October 2017. As this pattern continues, the Wiener Neustadt facility will focus more on research and development and low-rate production, and less on full-rate production.

Says Bausek: "Diamond Aircraft Industries, with its innovative spirit, has progressively innovated sustainable, environmentally friendly, reliable, high-performance general aviation products, and will continue to help make general aviation the automobile of future."

The final stop of *CW*'s Diamond Aircraft tour was a walk out of the final assembly line and onto the tarmac, where a *DA40* and a test pilot waited to give us a demonstration flight (Fig. 9, above). The captivating 45-minute flight took us up to, and around, the snow-capped peaks of the Alps surrounding Wiener Neustadt. And then safely back to Earth. CW

ABOUT THE AUTHOR

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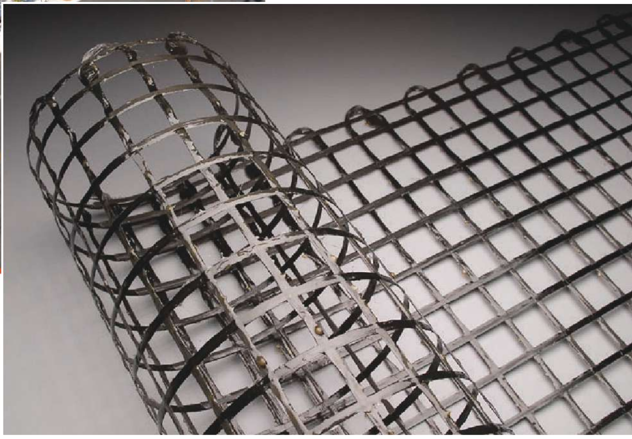


Lighter, thinner, stronger walls = faster construction

Construction of the GSU Piedmont Central student housing project in downtown Atlanta was completed in one year — from foundation pour to student move-in — using the CarbonCast wall system, reinforced with carbon fiber composite C-GRID shear trusses (photo below).

Source (left) | AltusGroup / Metromont

Source (below) | Chomarat

Higher performance in precast concrete with CFRP

C-GRID trusses in CarbonCast wall system cut construction time, cost, complexity and carbon footprint in energy-efficient urban student housing.

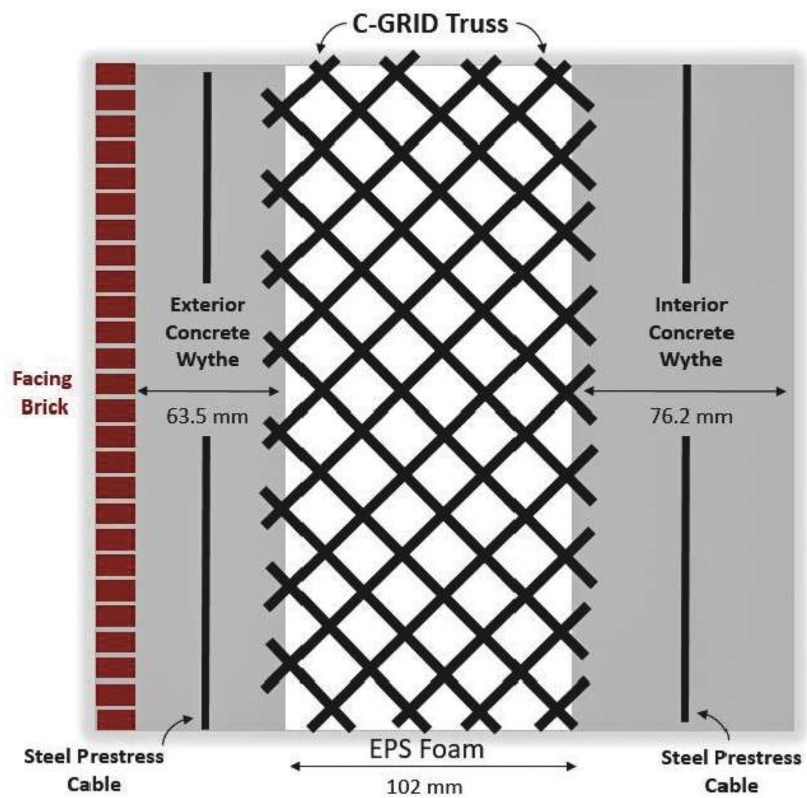
By Ginger Gardiner / Senior Editor

» Precast concrete is a construction product made by curing concrete in a reusable mold or form. Produced in a controlled factory environment, precast concrete can be closely monitored during cure, resulting in a higher quality product than can be provided when concrete is poured and cured in job-specific forms at construction sites. This offsite production also enables wider design possibilities, including use of lightweight, high-strength concrete mixes, foam-core insulation in precast panels and reinforcement with steel or synthetic materials. These options allow for longer spans, a reduced number of supports and thinner panels, which contribute to reductions in weight and cost.

A precast plant can reuse its concrete forms hundreds to thousands of times, which also helps to reduce cost. Onsite complexity is reduced as well, as is the construction schedule because manufacturing of the precast elements can begin while the building foundation is prepared. Manufactured off-site, precast elements can be stored, then transported to the construction site and installed as needed. Precast concrete is commonly used today in bridges, parking structures, office buildings, arenas, manufacturing and storage facilities, high-rise apartments and other residential structures, as well as commercial and public municipal buildings.

In 2004, Altus Group (Greenville, SC, US) introduced CarbonCast technology into North America, enabling even further weight and cost benefits, thanks to the use of carbon fiber reinforcement. An alliance of precast concrete manufacturers that brings innovative technologies to the construction market, Altus Group worked with Chomarat North America (Williamston, SC, US) to use its carbon fiber/epoxy C-GRID as a shear truss in precast concrete panels, creating a precast wall system that is lighter, thinner and stronger than most cast-in-place concrete, solid precast concrete and conventional steel-reinforced precast concrete wall systems. Because carbon fiber is much stronger than steel, panel size can be increased, meaning fewer pieces are produced and transported, so installation is faster and the overall carbon footprint during construction is smaller vs. conventional precast.

With more than 1,400 CarbonCast projects completed to date, totaling 40 million ft^2 (3.7 million m^2), Altus Group members see continued growth for C-GRID panels and structures as a solution to increasing demands for efficiency and performance in construction. *CW* explores why and how through a recent project with serious cost and schedule challenges: the Georgia State University (GSU) Piedmont Central student housing in downtown Atlanta.



C-GRID, the key to CarbonCast economy

The CarbonCast insulated wall system sandwiches EPS foam between two concrete wall sections, or wythes, held together using C-GRID shear trusses. Made from carbon fiber and epoxy resin by Chomarat North America (Williamston, SC, US), C-GRID can enable reductions in precast concrete panel weight of 40-50%. In the GSU Piedmont Central student housing project, CarbonCast wall panels featured a 2.5-inch/63.5-mm-thick exterior concrete wythe with molded-in facing brick, a 4-inch/102-mm-thick EPS foam core and a 3-inch/76.2-mm-thick interior concrete wythe finished with paint. Source | *CW*

Preparing the winning bid

"The student housing market is very large and increasing its use of precast concrete," says John Carson, managing director for Altus Group. He explains that this type of project typically begins with an owner (e.g., college or university), an architect that has design responsibility for the project and/or a general contractor. The latter will help to define construction of the building envelope as part of the design process. Quite often, the owner/architect/contractor team will proceed through a design-assist model of development, where the precast manufacturer also is included, to help optimize the number of precast elements, which affects cost. The precaster also plays a large role in scheduling and determining how the finished elements are erected.

The GSU Piedmont Central project was one of seven campuses receiving housing through a public/private partnership (P3) between The University System of Georgia and the private developer Corvias Group (East Greenwich, RI, US). After a competitive bid process, the Piedmont Central project was awarded to the team of Choate Construction (Atlanta, GA, US), architecture firm Cooper Carry & Associates Inc. (Atlanta, GA) and precast manufacturer Metromont (Greenville, SC, US).

"GSU is interesting because it is an urban campus," explains Tim Fish, architect and principal at Cooper Carry. "It actually had very little housing, but now has the largest student body in the state. This project was part of that growth." The urban setting meant space was at a premium. "The building would occupy 1 acre on the 1.4-acre site, so there was no room for staging materials," notes George Spence, business development manager at Metromont. The team decided early on to transfer labor to the Metromont plant. "In that way," he adds, "only one contractor would be on site to erect the walls and no space would be required for storage and staging. Trucks would simply pull up to the site and the precast panels would be installed directly."

Another issue was cost. "The university was determined to maintain its affordability for students," says Fish. This meant the new dorm building had to be economical and stay on budget. And then there was the schedule. "We had one year from pouring of the foundation to student move-in," says Spence. »

1 EPS foam boards were placed on top of the first concrete pour of the exterior wythe. Source | AltusGroup

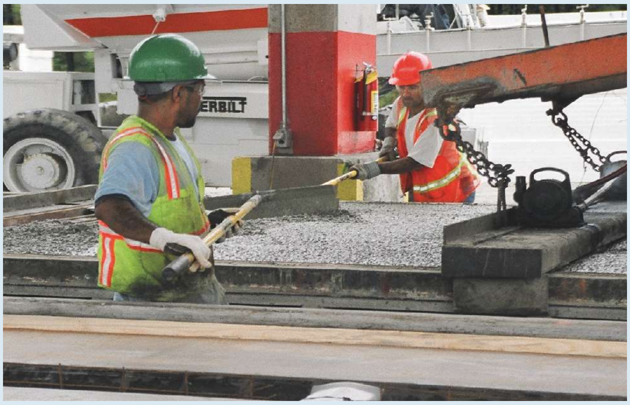
2 C-GRID strips were placed in between the foam boards and pushed down into the wet concrete of the exterior wythe. Source | Metromont

3 Prestressed steel cables and other steel reinforcement were placed on top of the EPS foam prior to the final concrete pour. The yellow objects are inserts for crane lifting points, each anchored with a square of C-GRID. Source | Metromont

Cooper Cary began working with GSU and other team members on the building design. "We began with trying to make the building blocks of the project, the residential units, as efficient as possible," Fish recalls. This was important for the 253,843-ft^2 (23,583m^2) project comprising 1,152 beds in 320 suite- and semi-suite-style dorm rooms.

"Beyond that, we tried to create space for varying levels of social engagement on every floor, and we also had to create the 400-seat dining hall on the entry level, but without a lot of structural gyrations in order to meet the cost target." Actually, the building skin was the structure, so materials were very important. "The structure had to be buildable, but also provide the desired aesthetic. We wanted to make it fit in with downtown Atlanta, but also have an identity within GSU." He explains that the university sees each building as a way to reinforce its brand, which is a mix of modern and traditional. "A lot of demands were unfolding simultaneously," says Fish, "and precast has a unique ability to provide a solution."

The GSU Piedmont Central project was designed as an entirely precast building — all of its elements would be precast concrete. "This speeds construction by at least 15-25%," says Carson. The CarbonCast-based design features loadbearing wall panels with a brick and sandblasted concrete exterior finish. Thermally efficient, the insulated wall panels have an R-value that exceeds the energy code with painted back sides that provide the interior finish. All wall system requirements were met in one precast panel, versus several passes around the building (and use of subcontractors) to perform individual framing, insulation, interior-finish, air/moisture barrier, waterproofing and exterior finish. "This CarbonCast construction is everything you want in a wall system:



4 Concrete was poured and troweled for the interior wythe. Source | Metromont

5 Completed wall panels were loaded onto trucks and delivered to the construction site, where they were lifted by a crane and set into place. Source | Metromont

6 After steel angles and plates embedded in each of the precast panels were welded to those in adjacent walls and floors, the building structure in that locale was complete. Source | Aerial Innovations of Georgia / Metromont

7 As the previous step was completed, building trades could proceed immediately with installation of systems and interior finishes, progressively finishing the building. Source | Aerial Innovations of Georgia / Metromont

airproof, waterproof, moistureproof," notes Spence, "and it eliminates \$7/ft^2 [\$75/m^2] worth of studs, framing and insulation."

Light weight, high insulation

C-GRID was developed to replace the welded metal wire mesh in concrete structures and prefabricated panels. It is made from 24K and 50K carbon fiber tows, which are assembled perpendicular to each other into a grid, using a continuous rotary-forming process that chemically binds them with a tough, heat-cured epoxy resin. In the CarbonCast wall system, C-GRID is a key component of the overall composite panel design.

CarbonCast insulated wall panels use foam insulation sandwiched between two concrete wall sections called *wythes* (Fig. 1, p. 35). Spence explains that C-GRID "acts as a truss, holding the front and back faces of the wall panel together, which is very efficient structurally." For example, a 9-inch (229-mm) thick CarbonCast insulated wall panel, with 3-4 inches (76-102 mm) of foam, and held together with C-GRID trusses behaves as if it were a 9-inch thick solid concrete panel. "But the C-GRID can make the panels 40-50% lighter," he adds. "It's cheaper to supply C-GRID panels to the job site vs. heavier, solid panels, and we can get two to three more C-GRID panels per truckload."

Thermal performance also is a benefit. Carson touts the higher insulation values of C-GRID panels, which reduce a building's energy use and carbon footprint. "Another big advantage of C-GRID is no thermal bridging," says Spence. Thermal bridging occurs when a building's insulation is breached because heat or cold is conducted to its exterior via metal-to-metal contact between fasteners and other components. "C-GRID prevents this because it is not metal and, therefore, does not interrupt the foam » insulation performance or conduct temperature in or out of the panel." He adds that continuous insulation is a requirement in most building codes today. There also are no voids or cavities to support mold growth, and the C-GRID panels provide inherent corrosion resistance and fire resistance without additional layers or concrete additives.

Fast-paced production

With the design and construction approach determined, Metromont worked with Cooper Cary and the Engineer of Record (EOR) to optimize panel sizes, aiming for the fewest number of panels that would satisfy building code requirements. During this final phase of design, each piece in the building was engineered to carry its required load and its connections were detailed, both to the structural frame and to other precast elements. "Once the construction drawings were approved, we were released to start production," says Spence. "This was roughly two months before they would be ready for us on the job site."

> C-GRID panels provide the architect and builder inherent corrosion and fire resistance.

When production began at the Metromont precast plant, each wall panel was made using basically the same steps. "The panels were 12 ft [3.7m] tall because they span from floor-to-floor in the building and, for this project, range from 24 to 44 ft [7.3-13.4m] in length," Spence explains. The exterior face of each panel was poured first. "It used a 2.5-inch [63.5-mm] thick architectural mix concrete poured on top of 0.625-inch [15.875-mm] thick facing bricks used for exteriors, which had already been set face down in a mold," he continues. Next, 4-inch /102-mm thick expanded polystyrene (EPS) foam boards were placed on top (Step 1, p. 36). Strips of C-GRID were then placed vertically next to and in between the EPS foam boards at regular intervals, plunged 0.75 inch/19 mm down into the wet concrete (Step 2, p. 36). Their tops would extend into the final pour of concrete. "These connect the exterior wythe to the interior wythe, which will be poured next," notes Spence.

Before the final concrete pour, prestressed cables and some conventional steel reinforcements (see black and brown strands, respectively, in Step 3, p. 36) were placed on top of the EPS foam. (These also were used in the previously poured exterior wythe and were part of the approved design for these loadbearing walls.)

Plastic covers (the yellow "cups" visible in Step 3) for lifting inserts that enable crane installation of the panels were also placed, each anchored with a square of C-GRID. Finally, the 3-inch /76.2-mm thick interior concrete wythe was troweled on (Step 4, p. 37). The Metromont production crew could make one panel in about an hour. The panels then cure until the concrete reaches a stripping strength — strength at which formwork can be removed — of 4,000 psi, which takes roughly 10 hours. The panel forming bed is then set up to cast again the next day.

Spence explains that where the C-GRID trusses are placed is defined by the EOR, based on the wall system structural requirements and other considerations for each project. "Generally, the C-GRID shear webs are placed 2 ft [0.6m] apart," he notes. Non-loadbearing walls require fewer C-GRID connections, so they can be spaced further apart. For the GSU project, however, every panel was loadbearing.

As panels were completed, they were loaded onto trucks for just-in-time delivery to the job site. "We staged production to make sure that erection of the walls and floors proceeded per the plan," says Spence. At the building site, panels were lifted with a crane and set into place (Step 5, p. 37). "There were metal plates or angles embedded in the vertical wall panels and horizontal floor panels," Spence explains. "These were welded together to form the wall-to-floor connections. The resulting box structures comprise the building. When the welding was finished, structurally, the building was complete." He notes that a final layer of concrete was poured on top of the installed floor panels to cover the welded connection details.

The precast structure — including 1,803 pieces and 200,670 ft^2 (18,643m^2) of C-GRID panels — was erected in five months by a six-man crew. "After about one month into this process, Choate began bringing in other trades," says Spence. This allowed the contractor to jumpstart installation of electrical, plumbing and interior finishing systems (Steps 6 & 7, p. 37) in order to complete the dormitory for the start of the 2016 school year.

+ LEARN MORE

Read this article online | short.compositesworld.com/C-GRID-GSU

See more in an Altus Group C-GRID video | short.compositesworld.com/C-GRIDvid

Read online *CW's* report titled, "Pultrusion provides composite thermal break" | short.compositesworld.com/ThermBrk

Continued drive for efficiency

The GSU Piedmont Central dorm is just one example of the CarbonCast system's success based on C-GRID. "We've converted all of our vertical wall panels to this system," says Spence.

"We just finished building apartments in Tampa, Florida, using these panels," he adds, "because C-GRID walls can withstand 200-mph hurricane winds. That is a tough building code

»

requirement to meet," he points out, noting, "You can do it with solid concrete, but it's heavy and expensive."

The CarbonCast system also is a plus in the booming digital world. "We build a tremendous number of data centers, and C-GRID is used in the precast walls to meet the mandatory 180- to 200-mph wind load requirements," Spence adds. The Carbon-Cast panels also meet data center *conditioned space* (heating/cooling/dehumidification) requirements. "I don't quote a job with conditioned space, where I don't specify C-GRID. The panels are cheaper and the energy costs are lower," he explains, emphasizing, "The customer wins twice."

But why must the fiber-reinforced plastic (FRP) composite be reinforced with carbon fiber? Wouldn't glass fiber be more cost-effective? "There are other FRP forms that CarbonCast competes against, most being glass fiber-reinforced vinyl ester resin," Carson replies. "But CarbonCast offers higher performance, enough that you can use significantly less concrete. There is also an advantage in how the CarbonCast system uses the C-GRID vs. how other FRP elements are used in competing wall systems."

This last point is part of the unique relationship between Chomarat as the C-GRID manufacturer, Altus Group, the CarbonCast technology licensor, and the precast manufacturer members of Altus Group as CarbonCast licensees. "All of our members which use CarbonCast use the same design engineering protocol and manufacturing guidelines," Carson explains. He adds that Chomarat's manufacturing process for C-GRID is unique. It supplies the reinforcement trusses straight to each precaster. "It's ready to use as delivered, and is one of the lowest-cost forms of carbon FRP [CFRP] used for building/construction applications."

"Composites, in general, offer a lot of flexibility in projects," says Cooper Carry's Fish, citing a current project where FRP is being considered to reinforce a building that must be supported during partial demolition because it is lightweight yet stronger than steel. All of the GSU Piedmont Central partners agree that the demand for speed, efficiency and performance in building and construction will continue to increase. According to industry reports, this will drive continued growth in precast concrete's share of the overall construction market, and continued opportunities for C-GRID and CarbonCast. CW

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Composites Events

Jan. 23-24, 2018 — Long Beach, CA, US
1st Int'l Conference on Composites in Sports
jeccomposites.com/events/composites-for-performance-in-sports-2018

Jan. 29-Feb. 1, 2018 — Palm Springs, CA, US
38th High Temple Workshops
hightemple.udri.udayton.edu

Jan. 31-Feb. 1, 2018 — Las Vegas, NV, US
Global Composites 2018
globalcompositesconference.com

Feb. 14-15, 2018 — Dubai, UAE
CompIC Middle East 2018 Conference
mecompositesin.construction

Feb. 20-21, 2018 — Indianapolis, IN, US
SPE 2018 Thermoset Topical Conference – TOPCON
4spe.org/Events/event.aspx?EventID=82791

Feb. 21-22, 2018 — Detroit, MI, US
5th Lightweight Vehicle Manufacturing Summit
www.global-lightweight-vehicle-manufacturing.com

March 1-2, 2018 — Vienna, Austria
14th World Pultrusion Conference
pultruders.org/pdf_news/1_WPC_Save%20the%20date.pdf

March 6-8, 2018 — Paris-Nord Villepinte, France
JEC World 2018
jeccomposites.com

March 6-8, 2018 — Osaka, Japan
4th Annual World Congress of Smart Materials
bitcongress.com

March 26-29, 2018 — Long Beach, CA, US
AeroDef 2018
aerodefevent.com

April 10-12, 2018 — Knoxville, TN, US
Composites Recycling Conference
s1.goeshow.com/acma/RecyclingConf/ereg346937.cfm?clear

May 7-10, 2018 — Chicago, IL, US
WINDPOWER 2018 Conference and Exhibition
windpowerexpo.org

May 16-18, 2018 — Shanghai, China
SAMPE China 2018
sampechina.org

May 21-24, 2018 — Long Beach, CA, US
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nasampe.org/events/EventDetails.aspx?id=699309&group=

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June 21-23, 2018 — New York City, NY, US
Composites Pavilion – American Institute of Architects Convention 2018
conferenceonarchitecture.com

June 27-28, 2018 — Chicago, IL, US
The Future of Composites in Transportation
jeccomposites.com/knowledge/international-composites-agenda/future-composites-transportation-jec

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

Oct. 2-4, 2018 — Tampa, FL, US
IBEX 2018
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CW Oct. 15-18, 2018 — Dallas, TX, US
CAMX 2018
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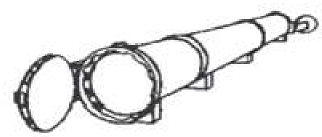

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SHOWCASE

Simplifying the solar panel with composites

Replacing glass and aluminum with a polymer/cored polymer composite laminate raises panel durability at reduced weight.

By Sara Black / Senior Editor

» Solar power's history is notable for peaks and valleys. As early as 1839, certain materials were found to be conductive when exposed to sunlight. Albert Einstein weighed in, in 1905, about photoelectric effects, and the first US patent for a "solar cell" was granted in 1913. Bell Labs (now Nokia Bell Labs, Murray Hill, NJ, US) unveiled working solar cells in the early 1950s that ultimately powered US space missions.

Since then, the technology has matured and solar cell energy efficiency increased, despite a string of spectacular bankruptcies of solar startups due to a combination of overcapacity, price pressure, changing tax subsidies and credits, bad timing and/or bad luck. The past two years have seen a surge in industry growth and, importantly, solar installations. A March 7, 2017 story in *The Guardian* by Adam Vaughan says solar power grew 50% in 2016, reaching a global capacity of 305 GW. In the US, the Solar Energy Industries Assn.'s (Washington, DC, US) *Solar Market Insight Report 2016 Year In Review* reported that 2016 US solar energy installations nearly doubled compared to 2015. Further, total installed US solar capacity is expected to nearly triple over the next 5 years. By 2022, more than 18 GW of solar PV capacity will be installed annually.

"In the last decade, solar has become the cheapest source of energy," explains Mark Goldman, CEO of Armageddon Energy (Menlo Park, CA, US). He says the cost per watt — the total solar system cost divided by the watts or power produced — has dropped from US$7 to ~US$3. "It's true that industry has suffered," he comments on the fates of previous players, but notes that interest in solar is still strong. "Volume continues to grow spectacularly." Given the demand, Goldman's company recently introduced a new, composites-intensive version of its rooftop solar panel system that is significantly lighter in weight and considerably more robust than typical solar panels.

■ **Lighter more durable solar collectors via composites**

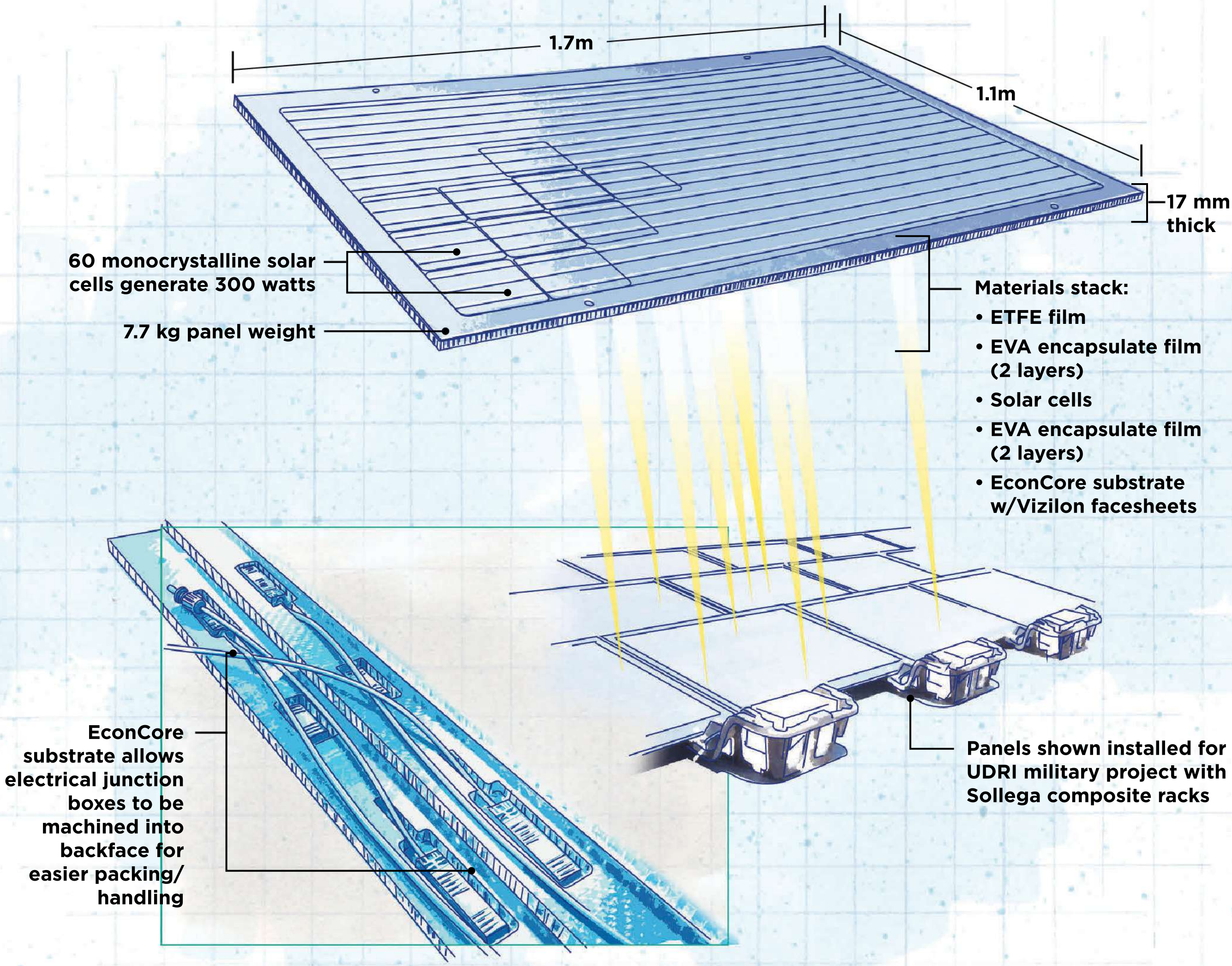
Solar energy innovator Armageddon Energy (Menlo Park, CA, US) worked with the US Air Force and the University of Dayton Research Institute (UDRI, Dayton, OH, US) on this pilot project to show the value of rugged, composites-intensive solar panels for military operations in off-grid areas. The portable panel racks shown are also composite, made by Sollega (San Francisco, CA, US).

Source (all photos) | Armageddon Energy

Plug-and-play solar

"Solar panels had traditionally been produced with float glass, which provides rigidity, serves as a good moisture barrier and has good light transmission properties," explains Goldman. Such glass, usually coated to reduce reflectivity and repel dirt, is more expensive than window glass and, in some cases, is tempered (toughened), adding more cost. Although these glass grades are less prone to breakage, they add weight, a challenge in roof-top installations, and can become cloudy over time, reducing energy efficiency. And, they must be rectangular.

Goldman continues, "Our initial strategy was to offer consumers an easy-to-install system with nicer aesthetics and a smaller overall system size, to focus less on zeroing out all of a customer's electricity usage and more on offsetting expensive peak usage, with an average system providing 2-3 kW instead of a typical 5-6 kW." That goal was realized by replacing glass with a thin, clear polymer film of ethylene tetrafluoroethylene (ETFE), trademarked Tefzel, from DuPont Performance Materials (Wilmington, DE, US), resulting in Armageddon's version 1.0 panel design, SolarClover, the industry's first film-covered solar panel to meet the solar industry UL1703 standard (Standard for Flat-Plate Photovoltaic Modules and Panels).



DESIGN RESULTS **Armageddon Energy's v2.0 Ultralight Solar Panel**

- ETFE, a fluorinated polymer film, replaces standard glass front sheet in solar cell units, significantly reducing unit weight and providing additional crack and breakage resistance.
- Weight is further reduced by replacing aluminum solar unit back support with a polyamide honeycomb core panel between fiber-reinforced polyamide facesheets.
- Very lightweight, robust panels have integrated connectors, machined into the composite core backing, for fast and easy deployment in remote, off-grid areas.

Illustration / **Karl Reque**

"We wanted to move beyond glass, and with ETFE films, our first version was light enough for a child to lift with one hand, and unique in design," says Goldman. "The pre-wired, rapid-assembly racks were designed for installation by a roofer or electrician, with no special solar training." One notable rooftop installation of SolarClover is the City Hall in San Jose, CA, US.

Finding alternative materials

Since that initial design, the company has continued to innovate, and has come up with a new and robust rectangular panel design. Says Goldman, "The impetus was to double-down on the things that make us different." Those include low weight, durability, safety and the ability to produce custom panel formats cheaply. We're a technology company, so we can't afford to stand still." He adds that Armageddon decided to eliminate aluminum to reduce the risk of electrical shock, reduce cost and produce a more composites-intensive design that was safer, stronger and even lighter than its first panel. The new design grew from the company's decision to move away for the moment from residential applications and to pursue a niche providing power for »

Version 1.0 solar installation

This rooftop installation shows Armageddon's first generation, hexagonal SolarClover design, which uses aluminum frames.

commercial and military microgrids, where ease of installation and robust design are essential. He stresses that key hurdles for the panel design were to choose materials that were no more expensive than standard glass and aluminum materials, and to be able to manufacture on standard equipment, at scale: "This is a very cost-competitive market. We knew our materials, methods and associated costs, and we know where our advantages lie, but it's still a long road."

To realize this improved design, the company turned to its long-time partner DuPont with its requirements. Dupont introduced Armageddon to EconCore (Leuven, Belgium), a honeycomb core manufacturer that uses a high-volume, continuous process to form honeycomb panels inline from a roll of thermoplastic sheet, via a series of thermoforming, slitting and folding steps (see Learn More).

The group determined that EconCore's ThermHex thermoplastic honeycomb panel, made of DuPont Zytel polyamide resin film, with panel faceskins made with DuPont Vizilon thermoplastic composite (TPC) polyamide sheet reinforced with continuous glass fibers in a twill weave, would create a strong and rigid panel able to replace aluminum in the structural backpanel, used for version 1.0, says Janet Sawgle, program manager at DuPont. Indeed, the EconCore ThermHex with Vizilon skins enables a cored panel product of minimal weight and high strength and stiffness, with sufficient heat tolerance to hold up to the high temperatures (up to 150°C during manufacturing as well as long-term stresses faced on roofs in the hot sun). Adds Sawgle, "We have field and lab testing underway to further demonstrate the performance of these panels."

"The honeycomb panels are easy to work with," says Goldman. "We can machine the features we want and shape them without the dust generation you'd get from fiberglass. They meet our 30-year weathering requirements and our application needs — fast installation and resilience in harsh, outdoor environments."

With the new support or "substrate" developed, Goldman describes how the rest of the 1.7m by 1.1m by 17-mm-thick, 300W, 7.7-kg panel comes together, a process he calls "packaging," typical of all solar cell manufacturing: "We laminate high-efficiency monocrystalline solar cells onto our composite substrate, using encapsulants to protect the cells, typically ethylene vinyl acetate or EVA, and the ETFE frontsheet to protect the front of the panel and provide the performance advantages we want."

Prior to being placed in the stack, the cells have been wired and connected in series. The clear ETFE is 2-5 mils thick, depending on the application, This stack is laminated in a heated press, under vacuum, for 10-20 minutes. The heat and pressure causes the EVA to crosslink and cure, thus encapsulating the solar cells, with care

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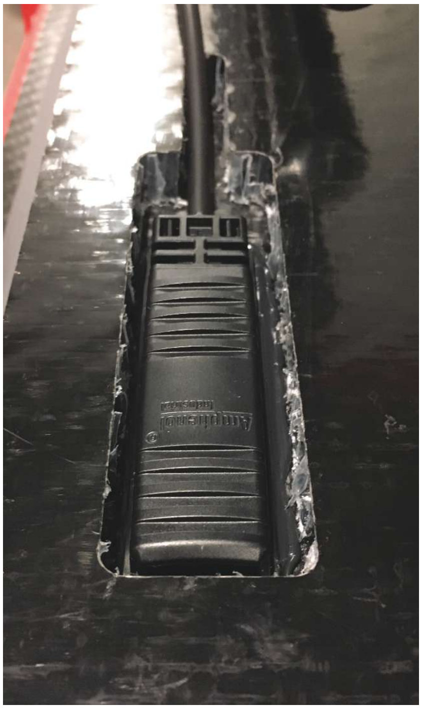
Electrical energy costs from solar and other forms of power generation are compared at Solar Cell Central, Four Peaks Technology Inc. (Scottsdale, AZ, US) | solarcellcentral.com/cost_page.html

See more about EconCore's continuous process for manufacturing ThermHex honeycomb core | www.compositesworld.com/products/camx-2015-preview-econcore

Watch a YouTube video that describes how typical solar panels are made | www.youtube.com/watch?v=qYeynLy6pj8

A background resource on solar cells and panels | www.letsgosolar.com/faq/how-are-solar-panels-made



■ **Composite enables compact design**

The use of a EconCore/Vizilon composite sandwich panel for the solar panel's back support easily allows machining of a pocket to hold the junction box for a more compact installation.

■ **Glass- and aluminum-free geometry**

Armageddon's rugged version 2.0 solar panel, featuring a clear polymer face and composite back support, is shown just after lamination. This configuration has reduced finished solar panel weight by 70-80% compared to panels made with glass front sheets and aluminum frames.

taken to avoid damaging the fragile cells during manufacturing. "The EconCore/Vizilon panel holds up well in the laminator, and it is even possible to thermoform it into simple curved shapes, if needed, for a specific customer. If more strength or lighter weight is required, we can specify a more heavily reinforced grade of Vizilon or a grade with carbon fiber instead of glass," adds Goldman. He points out that the rugged version 2.0 panel can be made with a profile as thin as 11 mm. For the military project described below, a 17-mm thickness was chosen to allow for machining of pockets in the EconCore/Vizilon back panels to accommodate recessed electrical junction boxes (see photo, above).

A microgrid niche

Armageddon has worked with the US Air Force and the University of Dayton Research Institute (Dayton, OH, US) on a pilot project to show the value of rugged solar panels for military operations in off-grid areas. More than 50 of its version 2.0 composite panels were constructed for that project. "For one of the pilot systems, when UDRI used standard (glass) panels, it took the installation team two days to set up the system," Goldman claims. "With our panels, it took 40 minutes, and the panels were less than half the weight." Armageddon partnered with Sollega (San Francisco, CA, US), a maker of simple, off-the-shelf composite panel racking systems, to mount the panels. The speed and simplicity of the installation allowed quick panel activation.

"With lighter panels, rooftops can hold more panels, for greater power output," Goldman points out. And, installations can be accomplished at ground level more easily and quickly, as was the case for the UDRI project. Armageddon is currently working with customers to produce bespoke designs for each installation. Goldman notes that the company has a long-term plan to develop an all-composite rack for residential rooftop installations, and to pursue partnerships with Sollega and similar companies.

Concludes Goldman, "Solar, despite its ups and downs, is now unstoppable. It will continue to grow at a startling pace for a very long time to come. Solar will vastly increase the resilience of our power and communications grids, and for the billions of people worldwide who have no access to reliable electricity, it will usher in a wave of prosperity for the people who need it most." CW

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