CompositesWorld.com

# CW

# CompositesWorld

## Next-gen automation:

## Evolving AFP for high-rate production

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## COLUMNS



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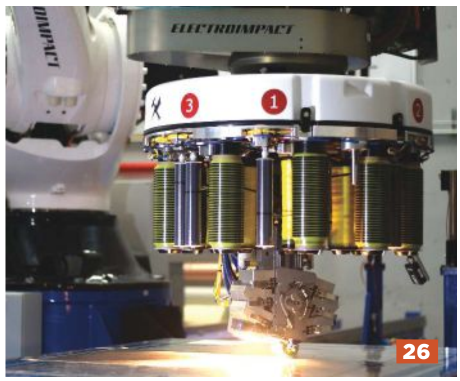
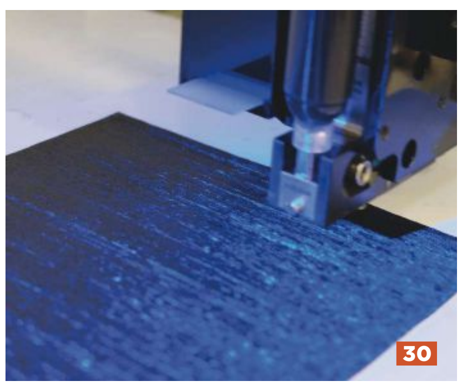



## FEATURES



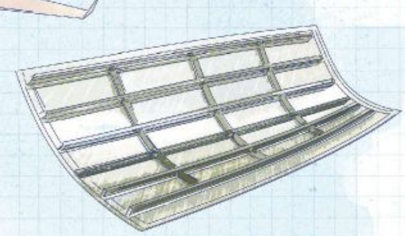
## ON THE COVER

Automated fiber placement (AFP) specialist Electroimpact is looking at next-generation aircraft manufacturing requirements and sees opportunity to increase machine utilization to meet the higher volumes anticipated by airframers. Pictured is AFP layup of an aircraft fuselage section.
See p. 26.

Source / Electroimpact

## FOCUS ON DESIGN





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» It's June 11 as I write this. I am on United flight 81 en route to the 2019 Paris Air Show (June 17-23) by way of Manchester, U.K. I have attended the Farnborough Air Show before, but this will be my first time at the Paris event.

I am going this year because the show, it appears, is poised to be a propitious one on many levels. First, on the composites level, there is the possibility that Boeing will informally announce the NMA (New Midsize Aircraft), a double-aisle, twin-engine replacement for the now-discontinued 757. And any new aircraft program has major implications for the composites industry — namely, how and where composite materials will be applied.

> The aerocomposites industry is facing an unprecedented demand for its materials.

Second, also on the composites level, the NMA is widely assumed to be the first in a series of new aircraft program launches over the next few years. It will likely be followed by single-aisle replacements for the Boeing 737 and the Airbus A320, which are the largest volume, most profitable aircraft manufactured by both companies. A new single-aisle aircraft program is expected to have a rate of 60-100 per month.

Third, on the commercial aerospace level, is the Boeing 737 MAX, which was grounded in the wake of two crashes, one in late 2018 and the other in early 2019. Identifying the cause of the crashes, developing a solution and implementing it has absorbed almost all of Boeing's organizational energy. In fact, if Boeing does not make a major announcement regarding NMA next week in Paris, it will be because Boeing feels that it must clear the 737 MAX hurdle first.

All of this is to say that no matter how propitious the 2019 Paris Air Show is, the composites industry perspective will be the same: The aerocomposites industry is facing an unprecedented demand for its materials and services — in quantity and quality — that we are just not used to. Manufacturing 100 shipsets every 30 days of large aerostructures is not a trivial exercise.

I don't make this claim hopefully, or because the evolution of composites use in aerostructures points inevitably to such a future. I make this claim because I think the customers of Boeing and Airbus, the airlines themselves, will demand composite aerostructures. I think the customers of Boeing and Airbus appreciate the benefits composites convey — from maintenance to fuel efficiency — and want them in their aircraft going forward. And historically, what the customer wants, the customer gets.

I also think that the aerocomposites supply chain is keenly aware of this demand. In conversations we here at *CW* have had lately with composite materials suppliers and tier fabricators, it is impossible not to discuss the rate implications of next-generation aircraft programs. Take, for instance, our story in this issue (p. 26) on work automated fiber placement (AFP) specialist Electroimpact is doing to improve machine utilization, streamline in-process inspection and integrate data into process assessment and control for aerostructures fabrication.

Consider as well another story in this issue (p. 44), written by contributor Karen Mason, on work GKN Fokker has done with business jet manufacturer Gulfstream to iterate and mature a carbon fiber/PEKK fuselage panel with fully integrated stringers, designed to minimize fastener use and provide a structure better able to cope with the pressures and impacts that a fuselage suffers.

The point is that just as we are on the cusp of a series of new commercial aircraft programs, we are also on the cusp of a new wave of aerocomposites production automation, efficiency and throughput that will, I think, drive growth and maturation for years to come. And at the heart of this evolution is data — design data, materials data, process data, testing data, quality data, in-service data. And, increasingly, airframers like Boeing and Airbus will demand that their suppliers harness, organize, assess, deploy and store this data to build those digital twins we've been hearing so much about. High-quality manufacturing will require high-quality data management.

In the meantime, I will let you know what I learn in Paris — propitious or not.

JEFF SLOAN — Editor-In-Chief

# Natural fiber composites: What's holding them back?

**FIG 1** Flax fiber races ahead for NFCs

The body of this Tesla racecar has been reinforced with flax fiber, the most popular natural fiber reinforcement. Source | Bcomp

» Applications of natural fiber composites (NFC) can be traced back to the ancient Egyptians, who used to make bricks out of clay mud and straw. More recently, the use of natural fibers as a reinforcement in polymer composites has been gaining a lot of attention, especially in the research community, and there are numerous review articles published on the applications of NFCs. However, to date the commercial use of NFCs is limited to wood plastic composites and automotive inner door panels. Moreover, few clear statistics on the current market for NFCs are available, and in fact most reports I've come across discuss the envisioned *potential* markets rather than the current market.

There is still a need to explore novel natural fibers with high mechanical properties.

## World consumption of natural fibers

The world consumption of natural (also known as "vegetable" fibers since they are derived from plants such as hemp and flax) fibers that can be used as a reinforcement for composites totaled $4.3 billion in 2018, with a compound annual growth rate (CAGR) of 3.3% from 2010-2018. This low growth rate is a strong indicator that the market is not growing as quickly as anticipated, and raises a valid concern: What's holding NFCs back? In other words, what are the barriers to the adoption of NFCs in the numerous applications of composite materials? To answer this question, one should refer to the diffusion of innovation theory developed by scholar E. M. Rogers, which explains how new ideas, technologies and products spread among participants in a social system.

## What's holding them back?

According to Rogers' theory, there are five main factors that affect the diffusion of innovation: relative advantage, compatibility, complexity, trialability and communicability.

**Relative Advantage**. Natural fiber reinforcements have many advantages over their inorganic counterpart, glass fiber. For example, they have low density, high specific properties, are biodegradable, are derived from renewable resources, have a small carbon footprint and provide good thermal and acoustical insulation. Those relative advantages must be emphasized when developing new products from NFCs, and this explains why the automotive industry is at the forefront of NFC adoption — these are all requirements for modern-day vehicles, especially considering the growth of electric vehicles and the onset of stricter environmental regulations.

**Compatibility**. Where natural fiber reinforcements fall short is that their hydrophilic nature makes them incompatible with the existing hydrophobic resin systems used in the industry. Moreover, their low thermal resistance limits their compatibility with thermoplastic matrices with high melting temperatures.

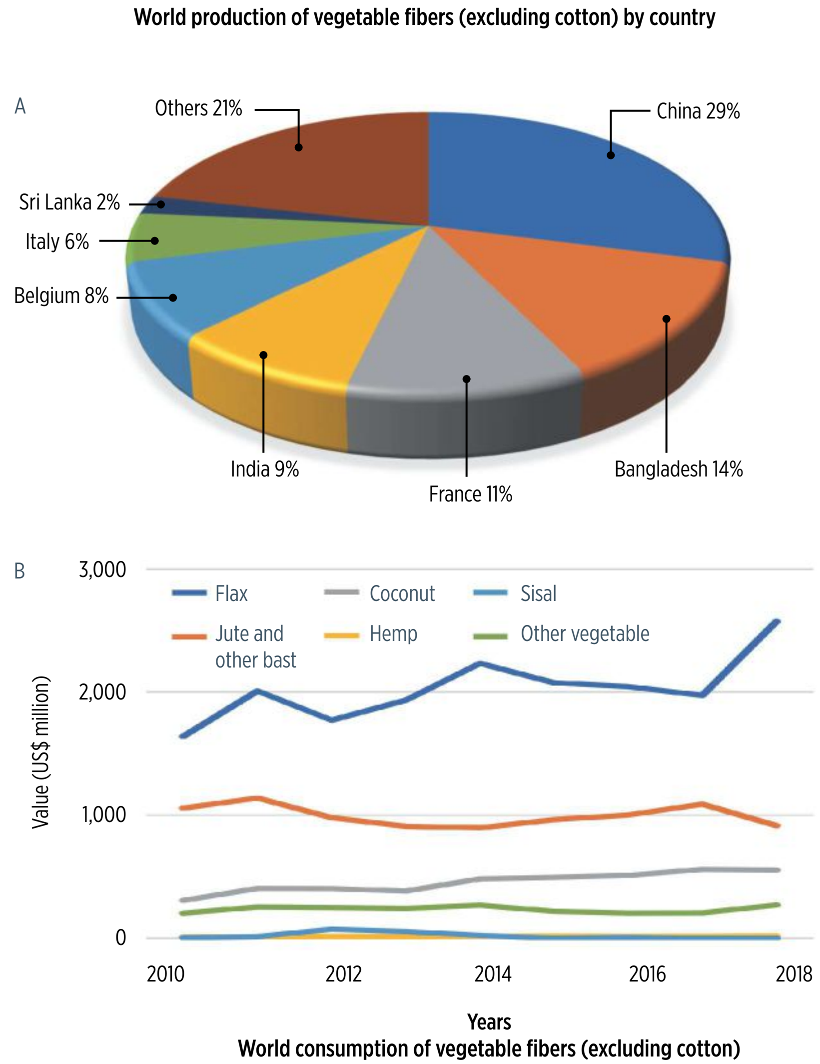


**FIG 2** Global production and consumption of natural fibers

Based on UN COMTRADE statistics, InTEXive calculates that China led global production of natural fibers in 2018 (A, above), and flax fiber was the most-consumed fiber by the end of 2018 (B, below).

Furthermore, the high variability in their mechanical, chemical and physical properties and lack of standardization limit their compatibility with the quality standards set forth by certain industries such as aerospace. In addition, their coarse texture makes them difficult to spin using existing spinning lines; they are also difficult to convert into woven preforms. Because of this, most natural fiber reinforcements are used in nonwoven form. Moreover, the incompatibility of their surface functional groups with the functional groups in existing resin systems results in poor fiber-matrix interfacial adhesion and very low load transfer efficiency. Finally, their low annual availability, as well as their seasonality, makes them incompatible with the large and consistent consumption of certain supply chains, such as the wind energy and construction industries. Overall, I believe NFCs' low level of compatibility with current manufacturing methods is the main reason preventing the widespread diffusion and adoption of NFCs.

**Complexity**. There are few in the composites industry with enough experience and knowledge of natural fiber reinforcements to work with them confidently; moreover, there is a large gap between different levels of the value chain. For example, processors of fibers often operate with comparatively low-tech equipment, while composites manufacturers are relatively high-tech. Given this difference, there is a compelling need to bridge this gap between the different value chain actors and to educate the farmers, fiber processors and fabric makers on this new end-use of natural fibers, and to educate composites manufacturers on this new type of reinforcement and how it differs from manmade fibers.

**Trialability**. Natural fiber reinforcements are mostly derived from plants grown in developing countries such as China, Bangladesh, India and Sri Lanka, while composites manufacturers are mostly located in the United States, western Europe and Japan. This geographic barrier makes it difficult for composites manufacturers to easily access natural fiber reinforcements for research. Moreover, the wide ban on planting hemp in certain countries significantly limits its trialability. Flax is an exception, since it's mostly grown in France and Belgium, regions where many composites manufacturers are located. In fact, these regions' easy and quick access to flax has significantly increased its trialability and has made it the most widely used natural fiber reinforcement.

**Communicability**. This term refers to how easy it is for the user to *see* the benefits of using NFCs. The most important benefits of using natural fiber reinforcements revolve around environmental sustainability. These benefits include reduced carbon footprint, biodegradability and renewability. While these benefits are important, they are not easily recognized and appreciated by the potential user. There are, however, other direct benefits that can be easily perceived, such as light weight, high specific properties, good thermal insulation and vibration damping. The fact that NFCs' most important benefits cannot be easily seen by the user, however, significantly limits their spread and adoption. »

### Overcoming the barriers

There have been several projects aimed at improving the form compatibility of natural fiber reinforcements, with the goal of providing an off-the-shelf reinforcement similar to glass fiber and carbon fiber. Projects have included using NFCs for low-twist rovings, unidirectional tapes, woven fabrics, spread-tow fabrics and prepregs, and most of these have involved flax fibers provided by Bcomp Ltd. (Fribourg, Switzerland) and Composites Evolution (Chesterfield, U.K.). Another attempt to improve compatibility within the resin is the water-based acrylic resin Acrodur, developed by BASF (Charlotte, N.C., U.S.).

Moreover, a project called QUALIFLAX — by the FiMaLin association (Gruchet-le-Valasse, France) and AFNOR certification group (Saint-Denis, France) — has been developed specifically to control and ensure consistent technical performance, reliable supply and pricing of natural fiber reinforcements. In addition, projects like Fibragen (Valencia, Spain) aim to develop a genetically selected flax with improved and consistent properties.

Furthermore, there are several institutions leading the way in promoting awareness of natural fibers in the composites industry, such as the European Confederation of Flax and Hemp (CELC; Paris, France) and NetComposites (Chesterfield, U.K.), through its EcoComp conference.

However, there is still a need to explore novel natural fibers with high mechanical properties, but with greater annual availability and lower prices than flax or hemp. Promising work is being done in this area by Sunstrand LLC (Louisville, Ky., U.S.) with bamboo fibers and by inTEXive (Cairo, Egypt) with date palm midrib fibers.

In conclusion, natural fibers are emerging as strong sustainable candidates in the reinforcement of composites due to their unique properties. However, they are still in their early adoption stages and are facing some barriers like compatibility and availability, which are preventing them from diffusing into the mass market. Hence, there is a need to clearly understand those barriers and to focus our efforts on overcoming them. Visionaries such as researchers, hobbyists, entrepreneurs and technology enthusiasts are leading the way in overcoming those barriers, and there are positive signs of adoption in the automotive and sporting goods industries. I strongly believe that the future is green, and with the industry's renewed interest in bio-based materials, natural fibers will prevail. CW

ABOUT THE AUTHOR

Dr. Mohamad Midani is an assistant professor at the German University in Cairo, and the CEO of inTEXive Consulting. He is an expert in natural fiber composites and inventor of long fibrillated date palm midrib fibers. Midani has his Ph.D. in fiber and polymer science from North Carolina State University.

# The future of composites: The next generation

» The spring season is usually busy, especially considering the number of conferences and trade shows this time of year. In March, JEC World was as active as ever, and immediately upon my return to the U.S. from Paris I headed to Detroit for the Society of Plastics Engineers (SPE) Annual Technical Conference (ANTEC). In late May, I traveled to Charlotte, N.C., for the annual SAMPE conference and exhibition. While each event gave me the opportunity to continue my own education about composites, so much of the value of attending is in catching up with industry acquaintances and numerous former colleagues, as well as meeting new folks heretofore unknown to me. The discussions help me keep up with the vibe of the industry, be that technical or commercial. SPE and the Society for the Advancement of Material and Process Engineering (SAMPE), organizers of two of the above events, are among the oldest professional societies serving the plastics and composites industries. In fact, SPE celebrated its 75th anniversary in 2017, and SAMPE its 75th this year in Charlotte. SPE represents a broad spectrum of plastics, and readers of this magazine are probably more familiar with its Automotive Composites Conference and Exhibition (ACCE) held in Detroit each September. This is organized by the Composites and Automotive Divisions of SPE. I have been on the organizing committee since 2005 and served as general chair of the conference four times. I have also been chair of the Thermosets and Composites Divisions during my many years of membership, which started back in 1992 when I attended my first SPE event, a Thermoset Division conference in Raleigh, N.C. My involvement with SAMPE goes back even earlier, with my joining the society shortly after I arrived in Detroit in 1984. Believe it or not, SAMPE was doing "automotive things" way back then! Over the years, I have been a session chair several times and have presented multiple papers at SAMPE conferences.

The future of composites is in good hands.

As it turns out, I am not alone in SPE or SAMPE longevity or engagement. Both societies are loaded with us "old timers," so it is not unusual to run into each other at conferences. So many of the conversations we have include questions like "Where are you working these days?" and sentences starting with "Remember back when we." On that note, my September 2016 *CW* column was titled "The power of personal connections." In it, I discussed the decline in membership in professional societies like SPE and SAMPE, and with that decline, the face-to-face networking that has enabled my success and that of my peers. This is not unique to our industry — it has been happening in all fields, as younger engineers and scientists rely increasingly on social media and apparently do not see the same value proposition in belonging to professional societies as I did when I joined. At the time, I noted that this shift was not lost on the leadership of SPE and SAMPE, and initiatives had been put in place to attract the next generation of members — and leaders.

You know what? Those initiatives seem to be working, at least in my observations. While both SPE and SAMPE have been very active in supporting students through poster sessions, bridge-building competitions and scholarships, getting these student members to continue as professional members has been difficult. Several years ago, SPE created the Next Generation Advisory Board, which brainstorms and implements ideas intended to engage graduate students and young professionals (up to age 35). A few of these initiatives have included targeted social events associated with ANTEC, and pairing students, young professionals and "seasoned" professionals on teams to conduct plastics or composites "quiz races," engaging exhibitors on the show floor. SPE also offers a free membership to new young professional members for up to two years. Similarly, SAMPE offered a targeted Leadership Development Series for young professionals in Charlotte and has recently created the Young Professionals Emerging Leadership Awards. SAMPE also offers a monthly payment plan for membership dues.

At both ANTEC and SAMPE, there were numerous presentations by young researchers and engineers. Some of the most salient questions in the technical sessions were coming from the younger generations, asked from a base of fundamental understanding of composites. They are eager learners and are enthusiastically engaged. These young professionals are not "encumbered by experience." They think in green terms like sustainability and resilience and, as consumers, are willing to pay a premium to achieve these objectives. Enabling technologies like automation, simulation, digitization and big data are not things they have to "get their arms around," having been accustomed to these from the start.

I'm encouraged by what I see with these rising stars. As long as we keep them engaged and foster their development as leaders, the future of composites is in good hands. CW


## ABOUT THE AUTHOR

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

# Index activity expands, led by production

## May 2019 — 53.3

» The Composites Index closed May at 53.3, extending its ongoing record of consecutive months of expanding industry activity. The latest Index reading is 7.6% lower compared to the same month one year ago, indicating slowing growth within the industry over the past year. In the year-to-date period the Index has averaged 53.8, indicating consistent but modest business activity expansion. Index readings above 50 indicate expanding business activity, while a value of 50 indicates no change and a reading below 50 indicates contracting business activity. Gardner Intelligence's review of the underlying data indicates that the Index was propelled by production, which was followed by employment, new orders and supplier deliveries. The Index — calculated as an average — was pulled lower by backlogs and exports; both contracted during the month.

May's supplier delivery data was notable for expanding more slowly than new orders, production and employment. The last time this occurred was late 2017, shortly before a record-setting surge in new orders activity in early 2018 that caused supply chains to scramble in reaction to meet demand. The latest data may suggest that upstream suppliers have largely restocked those formerly depleted inventories. CW

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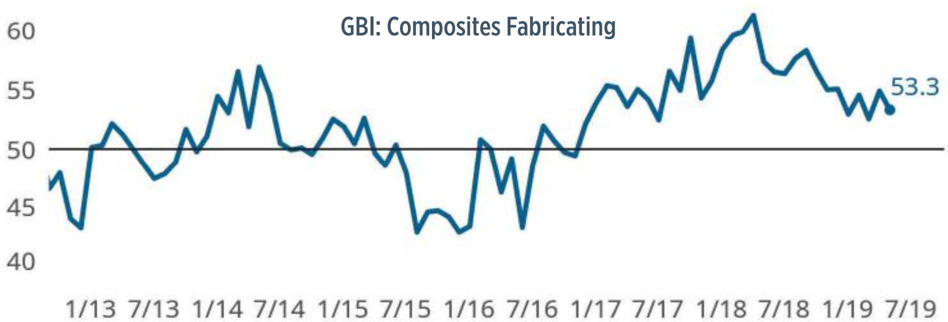
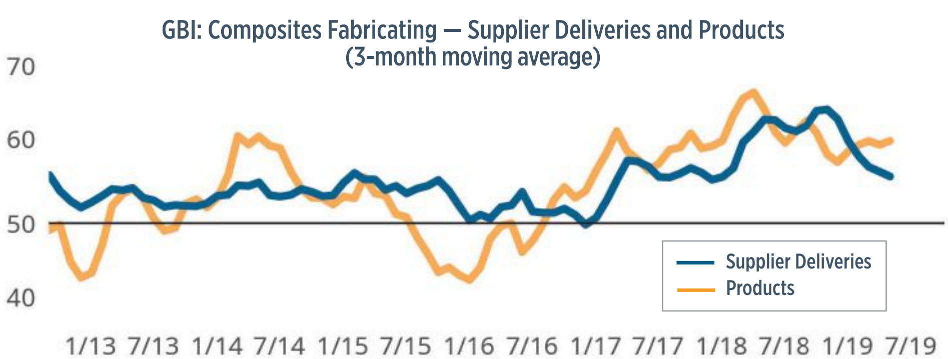



### Production activity leads expansion

Production activity led the Composites Index higher followed by employment and new orders. Four of the six index components expanded in May as backlog activity contracted from the prior month.




### Production activity no longer constrained by supplier deliveries

Slowing supplier delivery readings combined with strong production activity suggest that suppliers have replenished the industry's upstream inventories, which were depleted during the unanticipated surge in new orders that occurred in the first half of 2018.

# Mechanical testing of textile composites

» Although standardized test methods for fiber-reinforced composites are used for a wide variety of fiber forms, most of these test methods were developed with a focus on composites with continuous fibers aligned in *unidirectional* layers. Typically available as prepreg tape, these unidirectional material forms are commonly used in aerospace and other industries because they provide the highest stiffness and strength. However, many other continuous fiber forms are commonly used, including woven and braided fabric layers. For these textile composites, it's often necessary to modify the standardized test methods and consider other specialized methods as well. In this column, we consider the aspects of textile composites that require special test considerations as well as the most common modifications made to test methods to accommodate them.

Perhaps the most significant test method modifications for textile composites result from textile composites' periodic geometry, which is produced by their undulating fiber tows. This repeating pattern of the textile architecture allows for a unit cell to be identified, defined as the smallest geometric element of the textile architecture that represents the periodic textile pattern. Examples of a unit cell for a two-dimensional weave and a triaxial braid are shown in Fig. 1. Under uniform loading, these textile architectures produce strains that can vary in magnitude by a factor of three within a unit cell[1]. Since these mechanical tests are intended to obtain average or bulk properties of the textile composite, the test section of the specimen must be sized appropriately. As a result, the identification of the material's unit cell size is an important step in establishing the required dimensions of the test specimen.

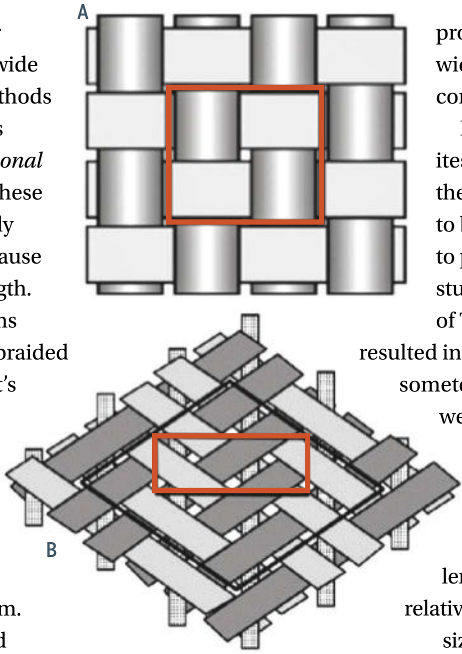



**FIG. 1** Example unit cells for textile composites. Shown are a two-dimensional weave (A) and a triaxial braid (B).

Source | ASTM D6856

Having identified the unit cell for a textile composite, the next step in sizing the test specimen is to consult the standardized test method of interest for guidance. The most commonly used ASTM test methods for tension testing (ASTM D3039[2]) and compression testing (ASTM D3410[3] and ASTM D6641[4]) specify specimen widths for different fiber orientations, including 0-degree unidirectional (10-15-millimeter), 90-degree unidirectional (25-millimeter) and specially orthotropic (balanced and symmetric, 25-millimeter) laminates. Having two or more fiber orientations, textile composites fit best into the specially orthotropic category, and therefore a specimen width of 25 millimeters is commonly used for tension and compression testing. However, additional guidance is provided in ASTM D6856[5], a standard guide for testing fabric-reinforced "textile" composites. An additional recommendation provided in ASTM D6856 is that the specimen width be at least twice the unit cell width for textile composites.

For stiffness measurements of textile composites, the measured strains should correspond to the bulk material response, and therefore need to be measured over a sufficiently large area to produce the average strain. Comprehensive studies performed as part of the NASA Mechanics of Textile Composites Program in the early 1990s resulted in guidelines for both strain gage size and extensometer gage length for textile composites[1,6], which were later incorporated into the ASTM D6856 standard guide. Research results showed that strain gages should be at least one unit cell in length, and have a width that is at least half the unit cell length. A minimum extensometer gage length of one unit cell length is recommended. For relatively coarse textile composites with larger unit cell sizes, the use of extensometers becomes increasingly attractive due to the significant increase in strain gage cost associated with increased size.

Although the periodic geometry of textile composites places additional requirements on specimen sizing and strain measurements, the reduced strength of textile composites in comparison to unidirectional composite laminates generally simplifies mechanical testing. These strength reductions result from the smaller percentage of fibers oriented in the loading direction as well as fiber tow undulations in the textile architecture. Whereas 0-degree unidirectional laminates typically require the use of tabbed tension specimens to produce a built-up specimen thickness in the gripping regions, many textile composites may be successfully tension tested using width-tapered "dog bone" shaped specimens, similar to those used for unreinforced plastics[7]. Although the use of dog bone-shaped textile composite specimens eliminates the need for bonded end tabs, they have not gained widespread acceptance in the advanced composites industry and have not been standardized by ASTM.

For compression testing, an added complication is the requirement of a relatively short unsupported test section to prevent specimen buckling prior to compression failure. The need for at least one complete unit cell length for strain measurement and the desire for multiple unit cell lengths in the test section makes specimen design challenging. However, a longer unsupported test section is possible when the specimen thickness is increased, and guidance on suitable specimen thicknesses is available in the two ASTM compression test methods mentioned previously. Note that for textile composites with reduced compression strengths relative to 0-degree unidirectional laminates, the use of untabbed specimens

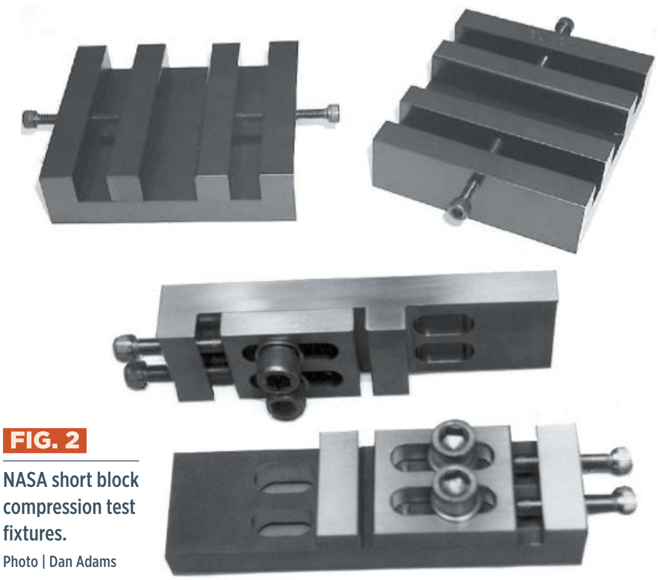


**FIG. 2**

**NASA short block compression test fixtures.** Photo | Dan Adams

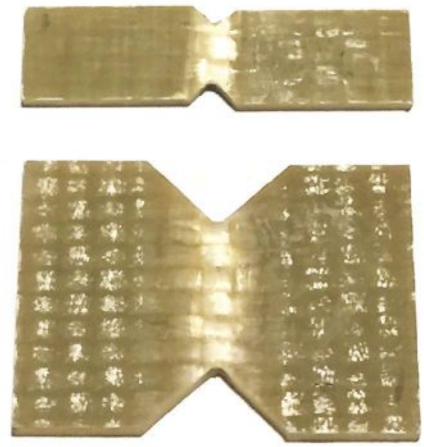


**FIG. 3**

**V-notched shear test specimens; ASTM D5379 specimen (top) and ASTM D7078 specimen (bottom).** Source | Wyoming Test Fixtures Inc.

makes the Combined Loading Compression (CLC) test method, ASTM D6641, an attractive candidate. An additional option of pure end-loaded compression testing is possible for many textile composites as well.

As an example, the NASA short block compression test[8] has been used successfully for compression testing woven and braided textile composites. The test fixture (Fig. 2) applies a small clamping force at the specimen ends to prevent brooming prior to compression failure. A 38-millimeter wide specimen is used, and end clamping takes place over 6-millimeter lengths at the specimen's ends. The length of the unsupported test section is established based on the specimen thickness and buckling considerations. Typical specimen thicknesses are in the range of 5-7 millimeters and overall specimen lengths range from 40 to 55 millimeters. Although this test is simple to perform and uses relatively small, untabbed specimens, it has not received considerable attention and has not been standardized to date.

In-plane shear testing of woven textile composites can be performed with the commonly used ±45 tensile shear test, ASTM D3518[9], but only for woven fabrics or biaxial braids in which identical fiber tows are placed in the +45-degree and -45-degree orientations, producing the required ±45-degree balanced laminate. For unbalanced weaves and other textile architectures, V-notched shear test methods are typically used. The V-notched beam (Iosipescu) shear test, ASTM D5379[10], is an attractive candidate for textile composites with relatively small unit cell sizes less than 4 millimeters. For larger unit cell sizes, the V-notched rail shear test method, ASTM D7078[11], is preferred because the test section between the V notches is scaled up by a factor of three relative to the Iosipescu specimen (Fig. 3).

In general, structural test methods using large specimen sizes may be used for textile composites without modification of the specimen size or loading method. This includes open-hole tension and compression testing for notch sensitivity and compression-after-impact testing for damage tolerance. However, the selection of strain gages and extensometers should follow the sizing guidelines provided in the ASTM D6856 standard guide and other relevant ASTM guidelines. CW

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**A review of the latest technologies on display at SAMPE 2019, a Q&A with Structural Composites' Scott Lewit, new designs for aircraft and rail cars, and more.**

## SAMPE 2019: The highlights

*CW* photo | Scott Francis

SAMPE 2019 was held in Charlotte, N.C., U.S., which represented the event's first foray to that city. *CompositesWorld* was there and offers this summary of highlights from the show and conference.

**Boeing keynote.** SAMPE kicked off with a keynote from Dr. Greg Hyslop, chief technology officer for the Boeing Co. (Chicago, Ill., U.S.). His presentation focused on the future of advanced materials and highlighted the importance of collaboration and the willingness to share information and ideas. He touched on some of Boeing's programs starting with the 777X, which features the largest carbon fiber wing ever made. The aircraft will begin flight testing later this year. Once in service, the 777X will, said Hyslop, enable continuous flight between any two points on Earth. Hyslop touted the success of the composites-intensive 787 *Dreamliner*, which he says has saved more than 20 billion pounds of fuel since its introduction and is shaping the thinking of the company as it moves forward.

*CW* photo | Scott Francis

Boeing's programs beyond commercial aircraft include the *Echo Voyager* autonomous submersible, the *T-X* U.S. Air Force trainer, the MQ-25 unmanned tanker (which will reportedly have its first flight at the end of the summer) and the XS-P *Phantom Express* reusable spaceplane, designed for the Defense Advanced Research Projects Agency (DARPA, Arlington County, Va., U.S.), which features a composite cryotank designed to reduce tank weight by 40%.

Hyslop discussed ways in which Boeing is working to address the growing problem of ground-based traffic and congestion, and an increasingly crowded airspace. He discussed the Boeing NeXt program, which is aimed at urban, regional and global mobility. In addition, in 2017 Boeing acquired Aurora Flight Sciences (Manassas, Va., U.S.), which has been working on an air taxi program. Meanwhile, Boeing is partnering with *Aerion* (Reno, Nev., U.S.) on supersonic travel.

During a Q&A session after the talk, when asked about the future of aluminum use in fuselage structures, Hyslop admitted that aluminum still has a significant role to play in aircraft fuselages, but reiterated the significant role that composites play — and will continue to play. He described the company's approach to materials as "holistic."

**NASCAR's composites evolution.** Jeff Andrews, director of engine operations at Hendrick Motorsports (Charlotte, N.C., U.S.), gave a presentation on the evolution of composites in NASCAR. Currently the sport puts an emphasis on composites use for components mounted higher in the vehicle, aiming for weight savings and achieving a lower center of gravity. Composites are used in such components as gear cooler ducting, brake ducts, battery cases and components high on the engine. Current body components include the front fascia, hood, rear deck lid and rear fascia, but Andrews expects that "implementation of all-composite bodies is in the very near future" for NASCAR, indicating that it could happen within 2-4 years. As proposed, a full composite body system would provide for a more consistent surface over the length of the vehicle with the desire of streamlining vehicle build times.

On display on the SAMPE show floor were two NASCAR racecars. Both were built by Hendricks Racing for Jimmie Johnson: his 2019 car (purple) next to his 2002 car (his first). The 2019 car has 35% more carbon fiber on it than the 2002 car, which had a few carbon ducts but was almost entirely metal. The 2019 car has a carbon fiber hood, part of the nose, trunk, seat, bumpers and some small parts. The largest carbon fiber part is the seat.

**Solvay elevates thermoplastics:** Solvay Composites

*CW* photo | Hannah Mason

*CW* photo | Scott Francis

Materials (Alpharetta, Ga., U.S.) introduced at SAMPE Fabrizio Ponte, recently named head of the company's thermoplastic composites platform. Further, Ponte said, elevation of Solvay's thermoplastic incubator to a Solvay Group Growth Platform should send a strong signal to the market about how important thermoplastics growth is to the company. He pointed out that Solvay has a long history of thermoplastics development, and is no stranger to the polyketones that dominate the aerospace market. "If it starts with a 'p' and ends with a 'k,'" he quipped, "we make it. We want the market to understand how serious we are about the thermoplastics market and that we are serious about developing products for this space." To that end, Ponte said Solvay is working on expanding its thermoplastics capacity, will soon open a thermoplastics prepreg lab, and is accelerating several new thermoplastics chemistries. Ponte also noted that Solvay is targeting its thermoplastics toward automotive and oil and gas applications as well.

**Huntsman adhesive launch.** The most prominent product announcement at SAMPE was made by Huntsman Advanced Materials (The Woodlands, Texas, U.S.), which introduced four products. Epocast 1649-1 FST A/B is an Airbus-qualified adhesive and void filler — a low-density, fast-cure paste that can be mixed and applied manually with a 2:1 mix ratio or used in a dual-barrel cartridge with static mixer. It's designed for insert potting, ditch potting, edge filling and honeycomb reinforcement. Epocast 1648 A⁄B is a Boeing-qualified (BMS 5-28, Type 18, Class 1) adhesive and void filler. It is a low-density, flame-retardant, thixotropic compound designed for use with honeycomb structures. It can be dispensed via meter mix or cartridge and sets quickly at room temperature. Applications include ditch and pot forming, core reinforcement and edge filling/sealing.

New to the Araldite acrylate adhesive line are Araldite 2050 and Araldite 2051, both are designed for use in "extreme" conditions. The 2050 product (designed for "cold and wet") is said to be ultrafast-curing from -20°C to 25°C without additional heat and can be applied under water or in humid areas. It requires no surface preparation and provides what is said to be outstanding adhesion on dissimilar substrates. It's temperature-resistant up to 120°C. Araldite 2051 (designed for "warm and humid") is fast-curing from 0°C to 40°C, also can be applied under water and also is temperature-resistant up to 120°C. Both products are targeted toward wind blade and marine repair applications.

**Web in Seattle.** Web Industries (Marlborough, Mass., U.S.) announced at SAMPE that it is building a new facility in Marysville, Wash., U.S. (near Seattle), that will provide tape slitting and winding services, as well as ply cutting and kitting, off-angle⁄off-axis tape production, and research and development services. The new facility will supply slit tape for the Boeing 777X, and positions the company to provide responsive formatting services to other businesses in the region, Web officials said. Web will break ground on the 85,000-square-foot plant in 2019 and plans to begin operations in 2021.

*CW* photo | Scott Francis

**Materials Forecast Forum.** SAMPE 2019 featured a conference track based on SAMPE's Materials Forecast Forum, which was conducted by SAMPE North America during 2018. Timed with SAMPE's 75th anniversary, the study involved representatives from OEMs, government organizations, academia, research *(continued on p. 16)*

*CW* photo | Hannah Mason

*(continued from p. 15)*

facilities and young professionals and was aimed at gaining insight into what the materials community might look like in the future. This year's conference included panels directed at taking the next steps toward that future. Topics covered included future mechanisms for R&D funding and future engineering workforce development, as well as assessment of materials for renewable energy, increasing efficiency of $CO_2$-emitting systems and biodegradable materials, and the Materials Genome Initiative, a multi-agency initiative aimed at providing resources and implementing policy to reduce the cost and development time of advanced materials.

**Building, breaking bridges.** Finally, SAMPE featured, as usual, the student bridge-building competition. Each bridge entered, conforming to established material and design criteria in several categories, was stressed to failure. The overall contest winners were, in order, Chengdu Aeronautic Polytechnic (Chengdu, China), University of Washington (Seattle) and Centro Universitário da FEI (São Bernardo do Campo, Brazil).

## CW MONTH IN REVIEW

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

**Alpex and HRC form JV to provide composite tooling services in China**
Jiangsu ALPEX Technology Co. Ltd. will support mass production of carbon fiber composites.
5/3/19 | short.compositesworld.com/Alpex_HRC

**Ultra-lightweight seat features carbon fiber structure made with 3D winding**
Weighing only 10 kilograms, the seat was presented at the "Step Change in Lightweight Construction" symposium in Germany.
5/3/19 | short.compositesworld.com/3Dwindseat

**Bombardier to divest Belfast and Morocco aerostructures facilities**
The divestiture is part of the company's strategy to focus its aerospace operations into one Bombardier Aviation unit.
5/3/19 | short.compositesworld.com/Bombardier

**Siemens announces spinoff gas and power company**
Siemens' Gas and Power will be an independent company to combine Siemens' renewable energy, oil and gas and other energy-related businesses.
5/9/19 | short.compositesworld.com/SiemensGP

**Markforged launches first FR continuous fiber-reinforced plastic for 3D printing**
V-0 rated Onyx FR to open new applications in aerospace, defense and automotive
5/10/19 | short.compositesworld.com/OnyxFR

**Evonik to build new PA12 production facility**
The Germany-based facility, intended to meet needs in automotive, oil & gas and 3D printing industries, will reportedly increase the company's overall capacity for PA12 by more than 50%.
5/13/19 | short.compositesworld.com/EvonikPA12

**Basalt fiber composite design wins NASA 3D Printed Habitat Challenge**
New York-based AI SpaceFactory's MARSHA prototype uses automation and composites to create a stronger, more durable space habitat.
5/14/19 | short.compositesworld.com/BF_Marshab

**Lilium celebrates maiden flight of CFRP air taxi**
The all-electric, jet-powered five-seater uses composites to deliver performance.
5/16/19 | short.compositesworld.com/Lilium

**UAMMI, Impossible Objects build composite parts for U.S. Air Force**
The Utah Advanced Materials & Manufacturing Initiative (UAMMI) is using Impossible Objects' composite 3D printing technology to build 3D-printed carbon fiber/thermoplastic replacement parts for defense aircraft.
5/17/19 | short.compositesworld.com/UAMMI_IO

**Web Industries' Seattle facility to speed delivery to Boeing, Toray**
The new production facility will produce precision-formatted composites for OEMs in the Pacific Northwest, including the Boeing 777X assembly plant.
5/23/19 | short.compositesworld.com/Web_PNW

**DARPA presents TFF program for low-cost composites for defense**
Results reviewed at SAMPE 2019 show new materials and side-by-side comparisons of thermoset, thermoplastic, HP-RTM and press-forming, including PtFS molding cell.
5/27/19 | short.compositesworld.com/DARPA_TFF

**Daher acquires KVE Composites Group**
The acquisition extends Daher's thermoplastics composites capabilities.
6/4/19 | short.compositesworld.com/Daher_KVE

MASS TRANSIT

## WMG prototypes CFRP frame for Very Light Rail (VLR) demonstration vehicle

Source | University of Warwick

Revolution VLR is a consortium in the U.K. — led by Transport Design International Ltd. (TDI, Stratford upon Avon) — that won funding in 2013 to develop a self-powered rail bogie with an integral, hybrid propulsion system. TDI believes that designing lighter "light rail" vehicles — i.e., very light rail (VLR) — is crucial for providing the next generation of sustainable public transport. In phase 2 of the VLR project, a complete 18-meter-long diesel-battery demonstrator vehicle will be available for testing in 2020.

An original member of Revolution VLR, WMG at the University of Warwick has developed a carbon fiber-reinforced plastic (CFRP) frame for this demonstration VLR vehicle. WMG is a long-time supporter of composites, with initiatives such as the National Automotive Innovation Centre, the Materials Engineering Centre and the International Institute for Nanocomposites Manufacturing. WMG's partners for this "BRAINSTORM VLR" project include TDI, the UK Government's Innovate UK (which funds composites), lightweight structural composite components developer Far Composites and Composite Braiding. The frame is made from a series of braided thermoplastic composite tubes that are easily assembled via adhesive bonding and simple welding.

The tube outside diameters are kept the same, with different load and attachment requirements handled by varying the wall thicknesses. This keeps tooling costs low and means that joins can be standardized. Braiding enables a highly automated manufacturing process — rates for the reinforcement alone can exceed 1 mile/day — as well as a tailorable set of materials, including other fibers (e.g., glass, aramid, thermoplastic) and thermoplastic matrix materials from low-cost polypropylene to high-end polyetheretherketone (PEEK). Meanwhile, WMG has demonstrated a complete molding cycle that can be reduced to less than five minutes, highlighting the potential of this affordable process for high-volume applications.

## Q&A: Scott Lewis, co-founder and president of Structural Composites

*Lewit and his Florida-based company Structural Composites are the creative force behind a number of innovations in marine and ground transportation composites. In a recent podcast episode, he discusses work with the U.S. Navy and with tractor-trailer manufacturer Wabash National (Lafayette, Ind., U.S.), as well as Structural Composites' stair-step innovation model, and more. You can listen to the full* CW Talks *podcast on iTunes or GooglePlay, or visit www.compositesworld.com/podcast.*


***CW:* Tell me a little about your role at Structural Composites, your title, and what are your responsibilities?**

**SL:** I'm one of the founders of the company, I'm the president of Structural Composites. My job is to keep the operation running and I do quite a bit of research work, invention work, patent work, so it's kind of a nice broad role. With all of our companies, we've got about 80 people altogether, so that keeps me pretty busy, as you can imagine.

***CW*: You're located in Melbourne, Florida, correct?**

**SL:** Yes. … We're kind of a spin-off of the Florida Institute of Technology. … We started out on campus in the '80s, and I started the company with my college professor who I did my master's in ocean engineering with, Dr. Ron Ricard. … Ron was starting to really get into composites materials for boats. Prior to that, boats were mostly run on mat and woven roving and plywood, and about the '80s a bunch of new materials were starting to come in from the aerospace industry, particularly the nonwoven and knit fabrics. The builders really didn't know how to engineer with it, and Ron kind of filled a vacuum there, providing engineering and testing services to both the supply chain and to the builders.

***CW*: So the technology that was the foundation of the spin-off, was it based on this fabric technology?**

**SL:** No, not really. We started out as just a research development company. We'd get government work, Navy work. We helped people develop products and one of the early products that we did is a product called Trevira polyester mat that came out of another industry that we put onto the composites market. And that really helped us a lot because they were a big German company. … They took us worldwide. … And that was really helpful to us … that exposure to see what all kinds of companies were doing with composites, not just boats, was really helpful. That polyester mat led to the invention of our Prisma preforms. And in Prisma, we take reinforcing fabrics and cast them into shape with expanding foam. And we found that that polyester material made an excellent interface for our preform technology.

***CW*: Early on, was the sales proposition of Structural Composites that you had some people that had some knowledge from composites and you were able to help with design and engineering of composite parts and structures?**

**SL:** One of the first things we had was a testing lab. … It started getting more popular outside of research and into commercial so we moved the lab into the commercial side with Structural Composites. … We grew into some prototype fabrication work and then in the 1990s we started getting into theme park rides. We were working with the theme parks here, repairing rides at first and then later doing new designs and new builds, and we still do that today.

***CW*: I know that composites are used pretty extensively in theme parks. … Tell me about that work. What's required for those applications?**

**SL:** … One of our first jobs there was a ride that was having a problem with the seating … We solved that problem with the ride, designed new seats, but more importantly we established design standards and quality standards that the theme park still uses today, telling them which materials to use in which places. … If it's going to be a ride system — and one of the rides I can tell you that we do is the carbon fiber motion platforms for Spider Man and Transformers, we do those — those need to be high-performance resins, just because of the duty cycles, you're going to have something go for 10 to 20 years of service.

***CW*: Structural Composites has a long history of working with the Navy. Tell me about your relationship with these military products.**

**SL:** … What we found is that the needs of the Navy really match the needs of the marine market and a lot of

## BIZ BRIEF

**Solvay** (Alparetta, Ga., U.S.) announced a cooperation agreement with Stratasys (Eden Prairie, Minn., U.S.) to develop new high-performance additive manufacturing (AM) filaments for use in Stratasys' FDM F900 3D printers.

As part of their joint product roadmap, Solvay and Stratasys will develop a high-performance AM filament based on Solvay's Radel polyphenylsulfone (PPSU) polymer that will meet FAR 25.853 compliance requirements for use in aerospace applications. Both companies aim to commercialize this new Radel PPSU filament in 2020. Additional industry-specific products are expected to follow.

Solvay's Radel PPSU grades have been developed specifically for use in aircraft cabin interior components and are compliant with all commercial and regulatory requirements for flammability, smoke density, heat release and toxic gas emissions. These grades are also said to offer optimal chemical resistance and toughness.

the composites industry. We can go solve problems for DOD and at the same time develop commercial benefit and commercial intellectual property. The government has done a really nice job of helping small businesses engage ... in the government business. ... The technology that we're going to talk about at Wabash is really all to do with that Phase I and Phase II that we did with combatant craft.

***CW*: You went to Wabash that first time and you showed them your technology. Did you or they have any sense of how your technology would be applied? ... How did you develop applications or determine how your material could be used to help them?**

**SL:** ... We have been working on composite bridge decking for a ridiculous amount of time. ... We had built structures that could support tremendous loads, so we'd done that. ... We also built a fifth-wheel RV chassis. So those two things were, I think, helpful. The chassis kind of showing that we can build something that looks like a trailer, and the bridge deck showing that we can build something that cars and trucks went over for 30 years with that kind of load-bearing. And between the two, they could visualize it.

## Industrialized continuous fiber composite printing in Delft

Source | CEAD

3D printing of continuous fiber-reinforced composites continues to expand and advance. Many new companies and developments have emerged since Markforged announced the Mark One continuous fiber 3D printer in 2014.

One of these companies, CEAD (Delft, Netherlands), was founded by Maarten Logtenberg and Lucas Janssen. They were half of the team that started the Dutch 3D printer company Leapfrog. "We've made a lot of different 3D printing machines for the industry," says Logtenberg. "I was looking into the market and felt like printing on a large scale with materials suitable for truly industrial applications was missing. You need more strength vs. thermoplastic alone." This is what printing with continuous fiber delivers. "So, we developed our own technology, which we have patented," he continues.

"We still see a need for prints with short fiber and without fiber." This is why CEAD's Continuous Fibre Additive Manufacturing (CFAM) technology enables printing with continuous fiber *and* with direct extrusion from unreinforced or short fiber-reinforced pellets *within the same print*. "We don't need to change the print head," Logtenberg explains. "We put the continuous fiber in the middle of the melt, so both are extruded at the same time. But they use different drive systems. The continuous fiber is pushed through the print head but pre-impregnated to ensure quality."

Similar to overmolded thermoplastic composites, for each print, the same polymer is used in both the pre-impregnated continuous filament and the unreinforced or short-fiber-reinforced direct extrusion. The company has processed a wide range of polymers, including ABS, PC, PEEK, PET, PLA and PP. They are now exploring PEKK and low melt PAEK.

Currently, CEAD offers the Robot extruder, featuring four heating zones, and its gantry-based CFAM Prime machine, with a build volume of 4 by 2 by 1.5 meters and 10 heating zones in the extruder. "We started development in 2017," says Logtenberg. "The print head is based on a single-screw extruder commonly used with injection molding. You need zones to gradually heat the material so that you can apply the great amount of pressure needed (50-60 bar) to extrude so much material. The pellets are transferred to the barrel, where they melt, then you compress and push. If you heat too fast, no pressure will build in the extruder."

"You can feel the difference in parts printed with continuous fiber versus those printed with chopped fiber," notes Logtenberg. "But we have not tested properties yet." That is the next task, now that machine development and initial launch have been completed. "This year we will work on fully characterizing the materials and developing data sheets with compression strength, stiffness, etc. for each material combination," he adds.

Logtenberg says the first targets for CEAD Prime's industrial production capacity are the marine and building and infrastructure markets because its printed composite parts are good enough to be directly used for end service. Indeed, its first customers are Royal Roos (Rotterdam, Netherlands), a marine engineering and construction firm, and Poly Products (Werkendam, Netherlands), a composites fabricator that works in the marine, architecture, industrial, recreational and transportation sectors.

That being said, the CFAM Prime is also being used to print molds, especially for marine structures. "This is why we proceeded with the robotic arm," says Logtenberg, "and we have added CNC milling, much like the LSAM machine [by Thermwood] but a little smaller and less expensive."

The response in the marine and construction market has been good. "We're doing a lot of projects to show what the machine can do," says Logtenberg. "After the launch last fall, sales were slower than we would have liked. But now it is moving well, with accelerating projects and machine developments."

For these new markets, CEAD is exploring new materials. For example, it is testing a material from SABIC for fire resistance and talking to train manufacturers. With the ability to print continuous fiber, could CFAM also be used to print with wire and/or sensors? "We are looking into this," says Logtenberg. "We are working with a company to embed steel fiber, which is also conductive."

Many in the traditional composites industry are questioning how 3D-printed continuous fiber composites can compete with conventional composites when they have such low fiber content and such high potential for delamination between the printed layers. "For sure, z-direction strength is one of the most challenging things for 3D printed composites," Logtenberg agrees. "We aren't competing with conventional composites currently. We believe that in the future we will be able to compete with conventional composites because our production is completely automated, but we have a long way to go. Right now, it's an addition to current manufacturing methods, giving flexibility and opening design and production possibilities."

Read more about CFAM and CEAD at **short.compositesworld.com/CEAD.**

AEROSPACE

## TU Delft, KLM develop sustainable, long-distance aircraft


Source | Edwin Wallet, OSO Studio, via TU Delft

Delft University of Technology (TU Delft; Delft, Netherlands) and KLM Royal Dutch Airlines (Amstelveen, Netherlands) have partnered for research into more sustainable aviation. They will be collaborating on TU Delft's flight concept known as the "Flying-V," designed for sustainable, long-distance flight.

The aircraft's v-shaped design will integrate the passenger cabin, the cargo hold and the fuel tanks in the wings. Its improved aerodynamic shape and reduced weight reportedly will use 20% less fuel than the Airbus A350. A flying scale model and a full-size section of the interior of the Flying-V will be officially presented at the KLM Experience Days at Amsterdam Airport Schiphol in October 2019 on the occasion of KLM's 100th anniversary.

According to TU Delft, the Flying-V will not be as long as the A350 but will have the same wingspan, enabling it to use existing infrastructure at airports, such as gates and runways, and to fit into the same hangar as the A350. The Flying-V reportedly will also carry the same number of passengers as the A350 — 314 in the standard configuration — and the same volume of cargo, 160 cubic meters. The Flying-V will be smaller than the A350, giving it less aerodynamic resistance.

"Our ultimate aim is one of emission-free flight. Our cooperation with KLM offers a tremendous opportunity to bring about real change," says Henri Werij, dean of the faculty of aerospace engineering at TU Delft.

The Flying-V is also said to provide researchers an opportunity to improve passenger experience in aircraft, from the seating layout in the wings, to the design of the seats and bathrooms, while keeping everything as lightweight as possible to maximize efficiency. The current design for the turbofan engine runs on kerosene, but TU Delft says it can be adapted for new propulsion innovations such as electrically-boosted turbofans.

# Acrylonitrile from biomass scales up

## Affordable, sustainable, efficient manufacture of biomass-based acrylonitrile — the primary feedstock of carbon fiber production — is leaving the lab and entering the real world.

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

### Producing ACN

Amit Goyal stands in front of reactors in Southern Research's small-scale manufacturing facility for the production of biomass-based acrylonitrile (ACN) in Birmingham, Ala., U.S. The facility will be able to produce up to 1 kg/hr of ACN, which will then be polymerized to make polyacrylonitrile (PAN), a precursor of carbon fiber manufacture. Source | Southern Research

» The quest for lower-cost carbon fiber has, for the last decade or so, focused on development of a carbon fiber precursor derived from non-petroleum sources that can produce a fiber with mechanical attributes comparable to — or *potentially* comparable to — fiber derived from petroleum sources.

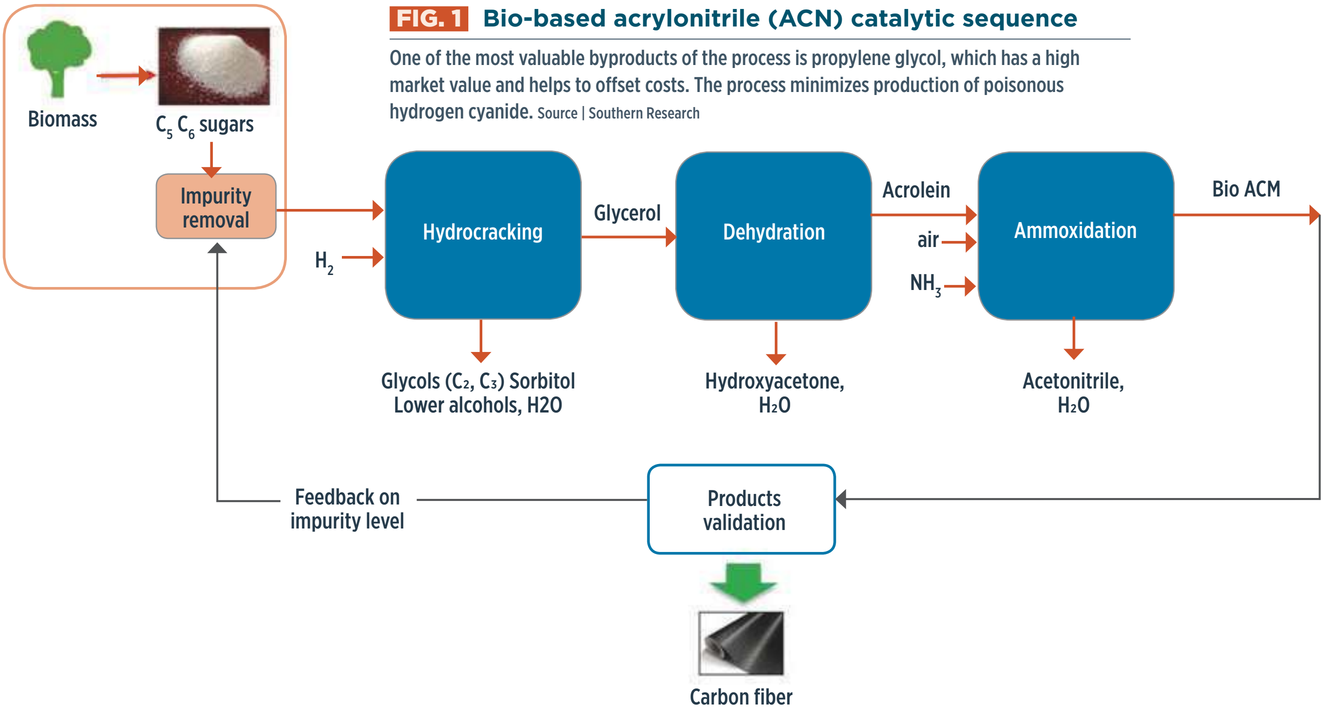
The precursor that represents the current state of the art is the monomer acrylonitrile (ACN), which is derived from petroleum and polymerized into polyacrylonitrile (PAN), which then is converted into carbon fiber via spinning, oxidation, carbonization and surface treatment.

The vast majority of the world's carbon fiber is derived from PAN made using an ACN monomer of propylene and ammonia. ACN is polymerized into PAN by combining it with plasticized acrylic comonomers and a catalyst. This entire chemical production and conversion process is complex, expensive and energy-intensive. Further, producing 1 kilogram of carbon fiber requires 2 kilograms of PAN, which gives PAN a conversion rate of just 50% — and a relatively large greenhouse gas footprint.

Research into other, less expensive, $CO_2$-friendly precursor sources has generally followed one of two paths: Find an organic material that can *replace* PAN, or find an organic material from which to *derive* PAN. The organic material most closely evaluated to *replace* PAN has

## FIG. 1 Bio-based acrylonitrile (ACN) catalytic sequence

One of the most valuable byproducts of the process is propylene glycol, which has a high market value and helps to offset costs. The process minimizes production of poisonous hydrogen cyanide. Source | Southern Research




been lignin, a highly abundant organic polymer found in nearly all terrestrial plants and sourced primarily from wood and wood pulp products (see Learn More). Lignin, although promising, appears to have significant chemical and mechanical limits as a viable precursor.

However, the path to a PAN sourced from an organic material, although still immature, is showing significant promise and has many of the hallmarks of commercial viability. Leading this effort is Southern Research (Birmingham, Ala., U.S.), a nonprofit research and development organization focused on engineering, energy and environment, drug discovery and drug development. Amit Goyal, director — Sustainable Chemistry and Catalysis at Southern Research, is directing a U.S. Department of Energy (DOE)-funded project to develop a novel, commercially viable, cost-effective thermochemical process that enables use of non-food sugars for the production of ACN.

The goal of the effort, says Goyal, is relatively simple: "Make a drop-in replacement for ACN from a non-petroleum source — make the same material competitively priced with a smaller greenhouse gas footprint." If the goal is a simple one, achieving it is not. Still, it appears Goyal and Southern Research are on track to success.

> The *goal* is simple: "Make a drop-in replacement for ACN from a non-petroleum source."

### $C_5$, $C_6$ sugars

The non-food sugars (or carbohydrates) being used in the project are known chemically as $C_5$ and $C_6$, or, more familiarly, xylose and glucose, and they are harvested from wood-based biomass. Goyal says $C_5$/$C_6$ sugars refined from biomass via hydrolysis are widely available globally and can be easily and readily sourced. The trick is the conversion of these sugars into ACN, and this is where Southern Research has done most of its developmental work. The manufacturing process the company has developed involves passing the sugar feedstock through a series of three catalysts, with each catalyst producing an intermediate material and, in the process, generating a chemical byproduct. Fig. 1 shows the inputs and outputs for each catalytic step:

- Hydrocracking (with $H_2$) to produce intermediate glycerol; byproducts are glycols, sorbitol, lower alcohols, water
- Dehydration to produce intermediate acrolein; byproducts are hydroxyacetone, water
- Ammoxidation (with air, $NH_3$) to produce ACN; byproducts are acetonitrile, water

Goyal says the "catalysts are the heart of the technology" that Southern Research has developed and are key to the viability of »

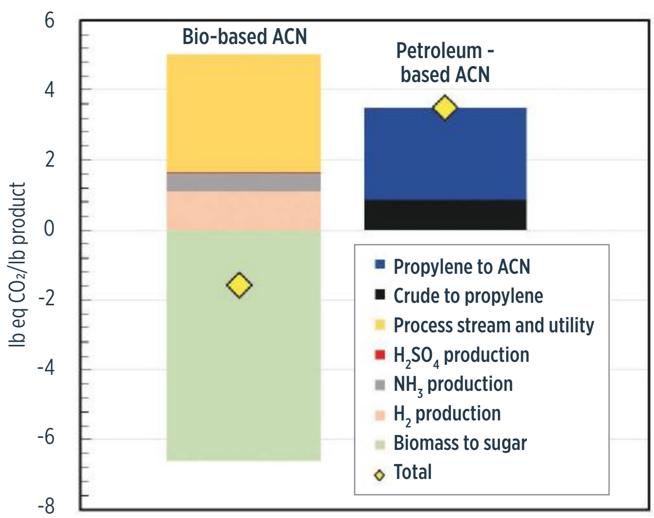



**FIG. 2 Bio-based ACN lifecycle analysis compared to petroleum-based lifecycle analysis**

Biomass-to-ACN produces -1.57 pounds of equivalent $CO_2$ per pound of finished product, compared to 3.5 pounds equivalent $CO_2$ per pound of finished product for petroleum-based ACN manufacture. Source | Southern Research

the process. One of the major advantages of the catalyzation, he notes, is the byproducts produced, including propylene glycol. "This has good value on the market, which helps reduce the cost of the process," he asserts. Also notable, he says, is the low overall hydrogen demand of Southern Research's process. "Every sugar has a lot of oxygen in it," he notes. "If you want to remove oxygen from a molecule, you have to add a lot of hydrogen. What we are doing uses very little hydrogen to remove oxygen, and then we use dehydration to remove the rest of the oxygen."

Finally, Southern Research's ACN manufacturing process should be recognized for what it does *not* produce. "When we do ammoxidation, there is no production of hydrogen cyanide, which is a terrible poison," Goyal says.

### Viability, costs, next steps

With a production process established, Southern Research next had to answer how the quality of its ACN compared to an ACN derived from a petroleum-based feedstock. Goyal says that although the bio-based ACN is highly pure, there is natural skepticism among carbon fiber manufacturers that a bio-based ACN can replace petroleum-based ACN as a pure drop-in: "When you have a first of kind technology, it's hard to find a first customer who wants to try the technology."

To that end, Southern Research worked with Solvay Composite Materials (Greenville, S.C., U.S.) to assess performance characteristics of the material, produced in a lab environment. Initial results of this assessment were highly encouraging, signaling that Southern Research should expand its efforts to commercialize this technology.

Quality and purity questions notwithstanding, there are two aspects of bio-based ACN production that appear to convey significant advantage: Life cycle assessment (LCA) and cost. Southern Research conducted an LCA of biomass-to-ACN manufacture and compared it to petroleum-to-ACN manufacture. The results (Fig. 2) show that bio-based ACN manufacture offers a carbon footprint of -1.57 pounds equivalent $CO_2$ per pound of finished product, compared to 3.5 pounds equivalent $CO_2$ per pound of finished product for petroleum-based ACN manufacture. In short, the biomass feedstock allows for a process that *conserves* carbon emissions. And to have such a carbon-conserving technology operating at the *front* end of a high-carbon-footprint manufacturing process makes it even more meaningful.

According to Southern Research's work, the cost of ACN production from biomass varies depending on the purity of the $C_5/C_6$ feedstock. As expected, the highest quality feedstock is usually the most expensive. Further, says Goyal, the cost of his bio-based ACN is most sensitive to sugar feedstock price. "The main factor that affects the cost of production is the cost of sugar, not the catalyst," he says. "The sugar price, because we are using second-generation sugars, impacts us the most." Sugar feedstock currently runs $300-$450/ton, which allows for ACN production costs of $0.60-$0.98/pound. Using what Goyal describes as "optimum sugar quality," the production cost of bio-based ACN is $0.72/pound. Compare this, says Goyal, to the production cost of petroleum-based ACN, which has a 10-year average of $0.85/pound. Further, he believes that the cost of sugar feedstock could decrease by more than 50% over the next several years.

**LEARN MORE**

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

Read more about R&D efforts to create lignin-based carbon fiber | short.compositesworld.com/Lignin_CF

In an effort to mature bio-based ACN production toward commercialization, Southern Research is currently building a DOE-funded $6 million small-scale production plant in Birmingham, capable of producing up to 1 kilogram/hour of ACN. Goyal says this facility, when fully functional in fall 2019, will produce ACN in small batches for in-house assessment as well as customer trials. Southern Research, says Goyal, is seeking carbon fiber manufacturers who are willing to work with the organization to help it assess bio-based ACN in a real-world manufacturing environment. CW

**ABOUT THE AUTHOR**

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# Evolving AFP for the next generation

'Aerospace quality at automotive pace' is the mantra of the supply chain being developed for next-generation commercial aircraft. Automation is evolving to meet the challenge.

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

**The future of AFP**

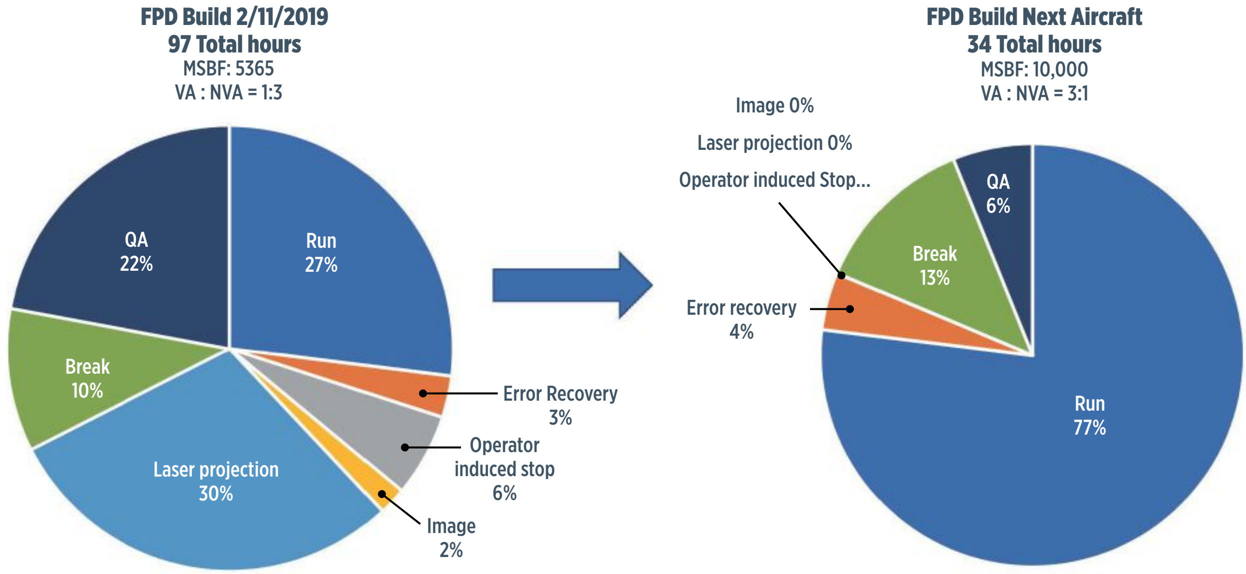
Automated fiber placement (AFP) specialist Electroimpact is looking at next-generation aircraft manufacturing requirements and sees opportunity to increase machine utilization to meet the higher volumes anticipated by airframers. Source | Electroimpact

» If automated fiber placement (AFP) and automated tape laying (ATL) were the manufacturing processes that enabled widespread application of composites in the Boeing 787 and Airbus A350, then it will also be AFP/ATL that lead the way for the next generation of commercial aircraft, now on drawing boards. The difference this time around? Rate.

Boeing estimates that, by 2037, the world will need more than 31,000 new single-aisle aircraft to meet passenger demand. Airbus forecasts a need for more than 28,000 single-aisle aircraft by 2037. Both companies are considering replacements of their single-aisle stalwarts — the 737 (Boeing) and the A320 (Airbus). Both companies are expected to employ composites significantly on any new aircraft they develop. Both companies are telling their supply chains to expect production rates for these planes of 60-100 planes per month, with emphasis on 100. The single-aisle category, for both companies, represents about two thirds of total global demand, which means that the manufacturing environment developed for single-aisle aircraft will become the default manufacturing environment for aerocomposites for the foreseeable future.

All of this means that automation technology must be developed now if it wants to keep up with the quality and production rate requirements of next-generation aircraft. None of this is lost on Electroimpact (EI, Mukilteo, Wash., U.S.) senior engineer Todd Rudberg.

Rudberg and EI entered the composites world in 2004 when the company




## A target for extreme utilization: 75%

What is important for AFP in 2019? According to Electroimpact, it's increasing utilization to 75%. The above chart on the left shows the utilization of a full production demonstrator (FPD) build in February of this year, with the target utilization goals shown on the right. Source | Electroimpact

developed AFP technology for manufacture of the 787 Section 41 forward fuselage section fabricated by Spirit AeroSystems (Wichita, Kan., U.S.). EI subsequently went on to produce AFP systems (EI focuses exclusively on AFP, not ATL) for manufacture of other 787 structures, A350 structures, engine structures and, most recently, Boeing 777X wing spars. Now, Rudberg is looking at the future of next-generation aircraft manufacture and sees opportunities for AFP to improve. Substantially.

The opportunities, says Rudberg, are obvious when one looks at the data. In fact, EI has developed several metrics to help the company understand what its machinery does well, and what it can improve. First, in looking over the 2019 AFP landscape, Rudberg sees myriad threats to current AFP technology, including ATL, hand layup, flat charges of woven fabrics and, of course, aluminum.

The AFP metrics Rudberg developed come from a full production demonstrator (FPD) project for which EI conducted four pre-production builds. Data from one of those builds, done in February 2019 with "standard" EI AFP technology, revealed a substantial machine utilization challenge, with machine use time falling into one of seven buckets:

- Laser projection: 30%
- Run: 27%
- Inspection: 22%
- Break: 10%
- Operator-induced stop: 6%
- Error recovery: 3%
- Image: 2%

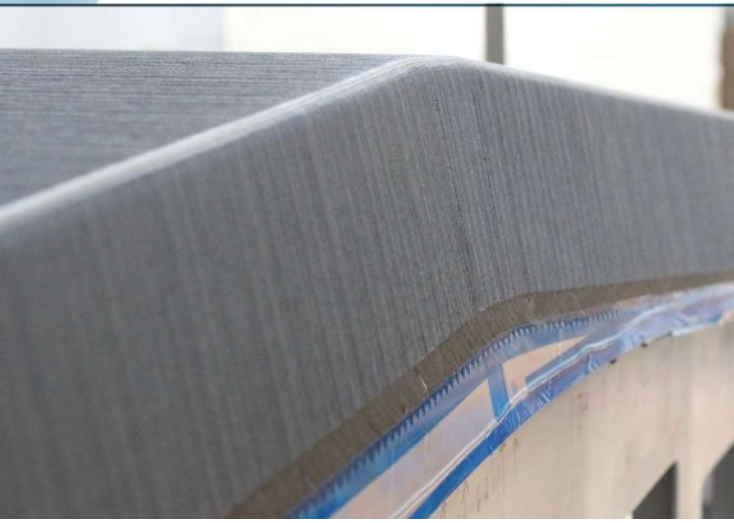
Looked at another way, with current technology, there is one value-added operation in AFP (run), with all else deemed non-value-added operations. Thus the ratio of value to non-value operations is 1:3. "The industry really wants 3:1, and so do I," says Rudberg, "and I'd like to get this done before I retire." The goal, simply, is to reduce the time consumed by non-value-added operations.

There is also one overarching AFP metric that needs explanation: mean strips before failure (MSBF). This is the average number of fiber tows placed between placement failures. The larger this number, of course, the more reliable the machine and the process is. The February FPD build, says Rudberg, had a 5,365 MSBF.

## The goals

Looking more closely at AFP operation, says Rudberg, EI has direct control over only three operations: run, error recovery and inspection. And this is where the company is focusing its efforts. That said, Rudberg points out that the airframer also has a role to play, particularly in reduction of quality inspections, breaks and operator-induced stops. "We have to realize that run times have gotten really low because machines are very fast," he says, "and anything that is non-value-added has a massive impact on your utilization. So, it turns out this is a team sport. Not only does the OEM — me — have to do better, the airframer also has some responsibility."

For next-generation aircraft manufacture, Rudberg wants to increase MSBF to >20,000, boost run time to 77% and completely eliminate laser projection, operator-induced stop and image. How? Rudberg identifies three technology areas that can facilitate »



**More efficient fiber placement**

As Boeing and Airbus consider out-of-autoclave composites manufacturing processes, the ability of AFP systems to efficiently place dry carbon fibers will be critical. This demonstrator spar shows dry fiber placed by an Electroimpact system. Source | Electroimpact

this transition: servo-driven creels, 100% in-process inspection and data management, or EI 4.0.

All three have been assessed by EI in a series of recent FPD project builds after that initial February build. Data from the FPD project itself prove that EI is headed in the right direction. Rudberg says the AFP system used — called MuSCLE — achieved 1,500 horsepower peak power, 0.5G acceleration/deceleration, a 4,000 inches/minute laydown rate, a head turn time of 1 second, a spar corner speed of 120 degrees/second and 6,000 MSBF (achieved in production).

The conversion to servo motor creels, and away from servo pneumatic creels, says Rudberg, has been done to increase tow placement speed, tow placement accuracy, tow tension control and overall build reliability. The company has spent the last two years working on a compact servo drive that can be installed on the EI modular head. The results of the technology, so far, are promising; testing shows: 15,000 MSBF, 87% faster add speed, 36% faster cut speed, better end placement accuracy. Further, EI proved that the servo motor creel system could be used to place dry carbon fibers.

The key for inspection is the "in-process" part. EI already has inspection technology, developed with Aligned Vision (Chelmsford, Mass., U.S.) and deployed on the 777X wing manufacturing line that uses laser and vision technology to check for laps, gaps, wrinkles, end-placement errors and foreign object debris (FOD). This system, however, exists independent of the AFP system and requires a clear field of view to operate — meaning the AFP head must be moved. Rudberg and EI have developed a new inspection system, called RIPIT, that is integral to the AFP head and inspects fiber placement as soon as it occurs.

EI will not divulge the nature of the technology behind RIPIT except to say that it is not laser- or vision-based. In any case, Rudberg says tests of the system reveal that it is able to detect, in real time, tow slippage to ±0.030 inch, add placement to ±0.050 inch and cut placement to ±0.050 inch. Further, says Rudberg, "We have done plenty of trials correlating RIPIT data with the existing Boeing-qualified vision system [Aligned Vision system used on 777X] and we get correlation."

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Learn More: Read this article online | short.compositesworld.com/nextgenAFP

The value of data management, says Rudberg, rests in the ability of EI's systems to help fabricators see more clearly how well the AFP process is working. To that end, EI has developed data visualization software — EI 4.0 — that offers visibility into not just how a given machine performed (based on MSBF) during a given build, but how individual tows and sequences performed. Basically, the software helps the operator see exactly where in the AFP head the problem is. "So, we will use this EI 4.0 to indicate where they [operators] need to go look in the AFP head to make changes," Rudberg says.

Using this software, it is possible to graphically display MSBF for a variety of machine functions and identify problem fiber tows and particularly challenging sequences.

The software also measures and reports other machine activities that might erode utilization. Using these data management tools, EI was able to optimize and reduce the build time for the FPD from more than 50 minutes to just less than 40 minutes. Other tools include shift performance comparisons and ply angle comparisons.

"I do believe that utilization of 75% is a realistic goal or expectation," Rudberg asserts. "But, it's going to take teamwork, it's going to take organizational initiative and follow-through from the airframer, it's going to take our improved technology, it's going to take better preventive maintenance and predictive maintenance, and better tools to analyze cell use and machine performance." CW

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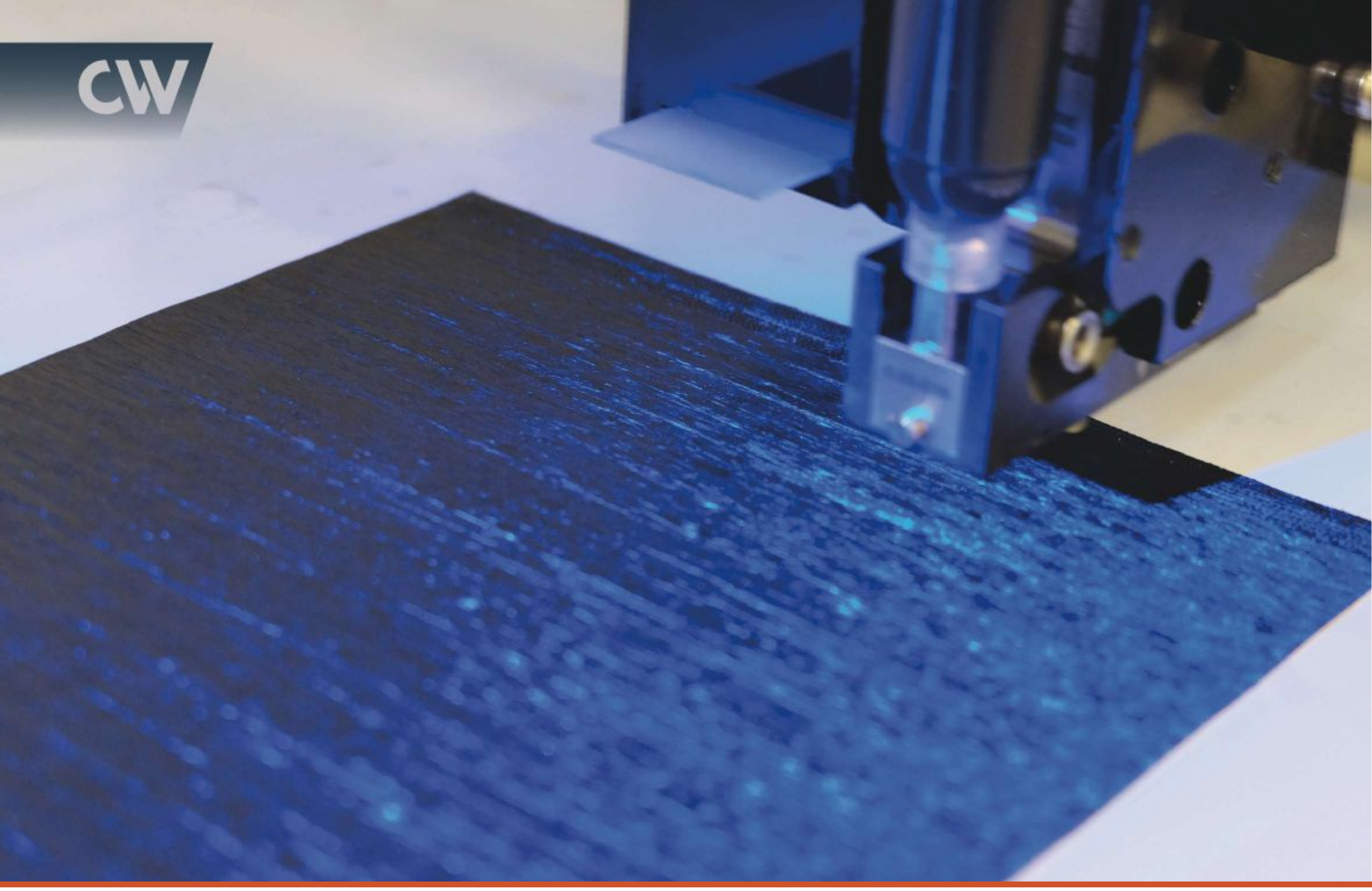


# Nanomaterials: Products, supply chain mature for next-gen composites

## Development spans 3D and thermoplastic nanocomposites, nano-CMCs for hypersonics and nanomaterials safety and toxicity.

**By Ginger Gardiner** / Senior Editor

» The promise of nanomaterials to deliver unprecedented mechanical properties, along with tailorable electrical and thermal conductivity for composites, has been heralded for decades. Because of their unique properties and tremendous surface area, nanomaterials have the potential to push product performance beyond current *macroscale* composites. Though nanomaterials such as graphene and carbon nanotubes (CNTs) are commercially available from a number of companies and websites, widespread application in composites is not as apparent.

Meanwhile, materials and terminology are rapidly evolving; *CW* provides a primer on current nanomaterials, as well as significant developments in new materials and the supply chain.

### Targeted graphene printing for composites

STRUCTURAL INK is a novel technology developed by Applied Graphene Materials that enables printing graphene into composites to target critical areas within a structure. "Graphene already has a strong track record of imparting toughness to thermoset composites," says Terrance Barkan at The Graphene Council. The aim of STRUCTURAL INK is to place graphene where it will be most design- and cost-efficient, enabling reductions in weight and total manufacturing costs.

Source | Applied Graphene Materials

### Nano landscape for composites

Nanomaterials may be metal, ceramic, polymer, carbon-based or from natural sources like cellulose. Nanomaterials form a composite when used to reinforce a

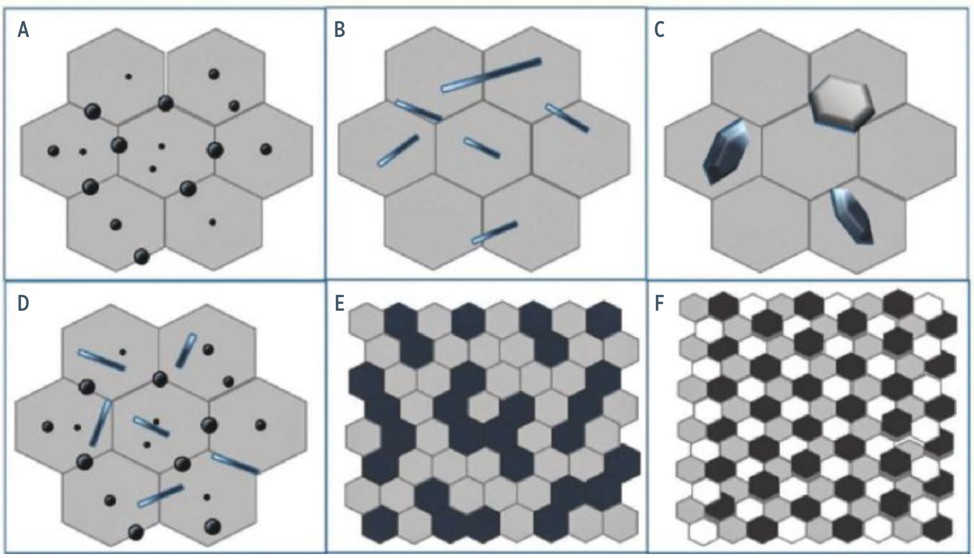



**FIG. 1** **Common micro/nano composite structures for ceramic materials**

Micro/nano composite comprising micronic matrix with (A) rounded nanoparticles, (B) high aspect ratio nanoreinforcements, (C) platelet-like nanoreinforcements and (D) both rounded and elongated nanoreinforcements; (E) bi-phasic composite made by two immiscible ultra-fine phases; (F) multi-phasic composite made by three (or more) immiscible nanophases.

Source | "Structural Ceramic Nanocomposites: A Review of Properties and Powders' Synthesis Methods" by Paola Palmero, Nanomaterials (Basel). June 2015

polymer, ceramic or metal matrix, and they are typically classified by shape (morphology) as either particles, fibers or platelets (see "Nanomaterial types and definitions," p. 32). As the material decreases in size from micrometer ($10^{-6}$ meter) to nanometer ($10^{-9}$ meter), surface area increases so that the nanomaterial-matrix interface comprises more of the composite's volume. This is why finished product property improvements of 20-50% can be achieved with one to two orders of magnitude less loading vs. micromaterials like carbon black and milled fiber. This is also why, just as the properties of a macrocomposite hinge upon mechanics at the fiber-resin interface, understanding and controlling the interfaces of a nanocomposite are even more important for managing material properties and performance.

However, the promise of nanomaterials has been hindered by difficulties in scaling up cost-effective manufacturing processes of high-quality materials with minimal flaws. In addition, achieving homogeneous dispersion of nanomaterials within matrices has been a challenge because of the tendency for nanomaterials to agglomerate. The latter can be overcome by functionalization of the nanomaterial surface (see Learn More). Common techniques, which are often combined, include modifying the electrical charge of the nanomaterial or matrix, modifying the pH or adding a surfactant.

The composites industry typically thinks of a nanocomposite as any matrix with a nanomaterial dispersed into it. However, micro-composites may be distinguished from nanocomposites based on the primary scale of the interfaces. Fig. 1 provides examples of various micro/nano composite combinations and interfaces. A micro scale (micronic) matrix is reinforced with nanoparticles, nanofibers or nanoplatelets, as seen in A, B and C, respectively, while a *nanocomposite* is differentiated as a matrix phase mixed at the *same scale* as the nanomaterial, as shown in E and F.

## 2D nano to 3D multifunctional composites

Within the nano landscape, perhaps the most active region is that comprising 2D nanomaterials. The most popular of these is graphene, which has gained substantial popularity thanks to its extraordinary properties. Graphene is the lightest weight (0.77 mg/$m^2$) and strongest known material (100-300 times steel), harder than diamond yet more elastic than rubber, with electron mobility 100 times faster than silicon, electrical conductivity 13 times better than copper and a very high surface area. Graphene appears able to bridge certain gaps in conventional property constraints. For example, when added to rubber, graphene can simultaneously increase tire grip and reduce wear. Formula 1 fans know from watching race cars swap between soft tires (high grip, less wear resistance) and hard tires (less grip, more wear resistance), that these two properties do not normally coexist. "Carbon black has been the normal filler for rubber in tires, but graphene offers a much higher performance at a much lower load factor, replacing 1-2% carbon black with only 0.01% of graphene," explains Terrance Barkan, executive director of The Graphene Council (New Bern, N.C., U.S.), an industry resource and support organization.

Researchers have been intent on evolving these materials, »

SIDE STORY

## Nanomaterial types and definitions

**Nanoparticles** (nanopowder, nanoclusters, nanocrystals) are sized less than 100 nanometers in diameter and are commonly produced by reducing ceramic or metal powder via ball milling, where media in a rotating chamber are ground finer in size. An example is nanosilica particles used in epoxy resin for 3M Fortified Tooling Prepreg that achieves multiple improvements versus epoxy without nanosilica including: 55% higher resin fracture toughness (KIC), 17% higher laminate shear strength and 59% higher composite hardness while reducing springback by 47%, exotherm by 61% and shrinkage by 33%.

**Nanofibers** have diameters less than 100 nanometers and a high aspect ratio. One example is carbon nanofibers (CNFs), which can measure up to 300 micrometers long. Nanofibers are produced from a variety of metals, ceramics, polymers and natural materials such as cellulose and chitin (the protein that makes up crustacean shells). Electrospinning is a common manufacturing technique. An example is cellulose nanofibers, which are being evaluated for low-cost, lightweight composites in ballistic armor, spacecraft, automotive body and interiors and aircraft interiors.

**Nanoplatelets** are 2D stacks of nanomaterials that may be made from metals, ceramics or graphene. Graphene is most commonly used in composites manufacturing and is comprised of a single-atom-thick layer of carbon. Graphene nanoplatelets made by Applied Graphene Materials (Redcar, U.K.) are described as 1-10 nanometers thick and 1-15 micrometers in diameter, resulting in aspect ratios up to 1:1000 and surface areas up to 700 m$^2$/g. The platelet shape provides edges that are more readily functionalized for improved dispersion in polymers.

**Nanocarbon** comprises many allotropes. These are the same element — carbon (C) — but with different arrangements of atoms (see image below), and include carbon and graphene dots, graphene sheets and platelets, and graphene rolled into high-aspect-ratio carbon nanotubes (CNTs) — sphere-like buckyballs/fullerenes and multilayered nano-onions. CNTs may be slit open to produce nanoribbons. CNTs may also be spun into macroscale fibers for use in composite laminates.

Source | "Structural Ceramic Nanocompo-sites: A Review of Properties and Powders' Synthesis Methods" by Paola Palmero, Nanomaterials (Basel). June 2015


Particulate powder

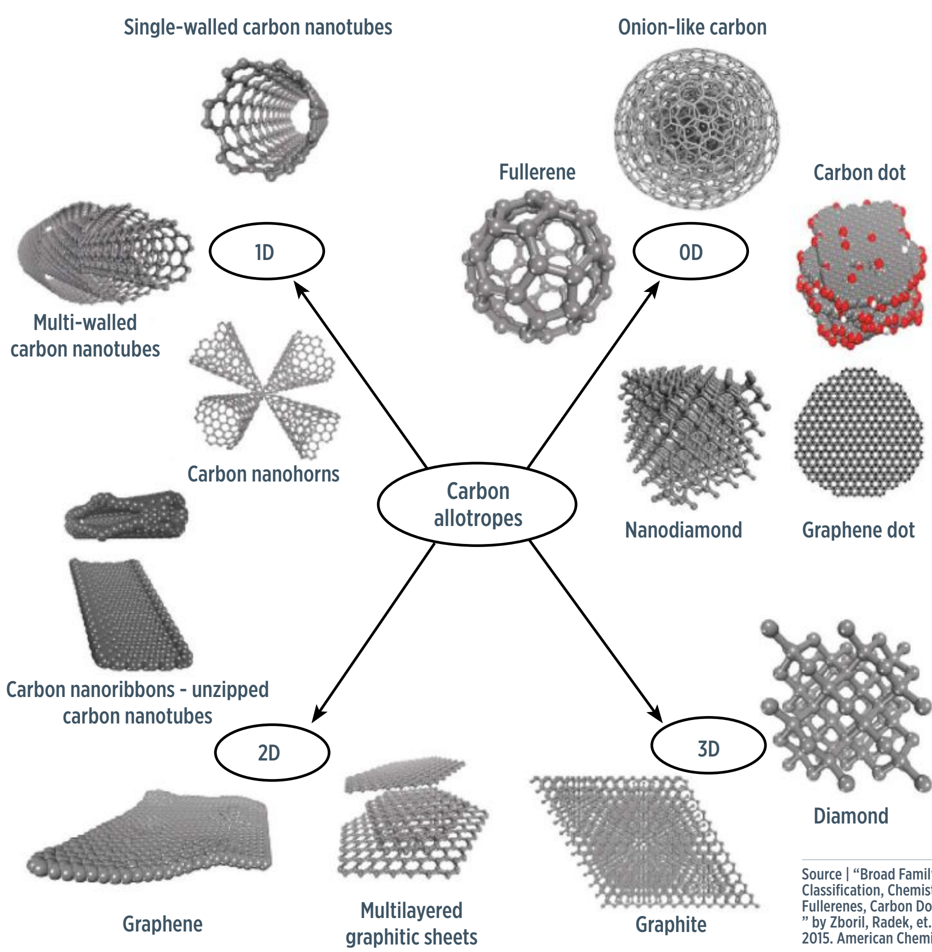
$$\frac{S}{V} = \frac{3}{r}$$


Fibrous material

$$\frac{S}{v} = \frac{2}{r} + \frac{2}{l}$$


Hexagonal Platelet

$$\frac{S}{V} = \frac{2}{0.8661} + \frac{2}{t}$$




Source | "Broad Family of Carbon Nanoallotropes: Classification, Chemistry, and Applications of Fullerenes, Carbon Dots, Nanotubes, Graphene, ... " by Zboril, Radek, et. al., Chemical Reviews, May 2015. American Chemical Society.

synthesizing hundreds of 2D layered nanomaterials over the past decade from polymers, metals and carbon allotropes like graphene (see "Nanomaterial types and definitions," p. 32). These 2D nanomaterials can then be combined, stitched together, stacked and/or arranged to form an almost infinite variety of 3D architectures to create novel, multifunctional materials. Graphene and other 2D nanomaterials have been combined into 3D architectures with large pore volumes, low density, increased mechanical properties, high specific surface areas, rapid electron and mass transport (used in cooling very hot surfaces) as well as unique optical properties and photonics capabilities.

## Early entrants move forward

NanoStitch vertically aligned CNT film products were introduced by N12 Technologies (Somerville, Mass., U.S.) in 2015. When interleafed in composite laminates, NanoStitch increases interlaminar shear strength (ILSS) by >30% and compression after impact (CAI) by 15%. *CW* reported in 2018 that N12 Technologies agreed to incorporate the 60-inch-wide, continuous CNT film production line at the University of Dayton Research Institute (UDRI, Dayton, Ohio, U.S.) as its second manufacturing facility. "We have now fully validated production operations in the Kettering, Ohio, facility," says Christopher Gouldstone, N12 director of production development, noting the company still maintains its corporate and applications headquarters in Somerville. He says one of the biggest applications highlights for NanoStitch in 2019 is becoming the official composites technology partner for the Santa Cruz Syndicate World Cup Mountain Bike Team. "After a collaborative development process to implement NanoStitch into Santa Cruz Bicycle designs, the Syndicate is racing on impact-resistant NanoStitch-reinforced wheels this season," says Gouldstone. "N12 continues to apply NanoStitch to improve impact, compression, shear and fatigue properties of composites for multiple markets including aerospace and consumer goods. We have also ramped up development for multifunctionality, using the high conductivity of vertically aligned CNTs for electrostatic grounding, strain sensitivity and surface heating."

## Thermoplastic nanocomposite replaces aluminum

Meanwhile, one of the first commercial *thermoplastic* nanocomposites was launched earlier in 2019 by Alpine Advanced Materials LLC (Dallas, Texas, U.S.). HX5 is a high-performance material designed to replace 6061 T6 aerospace-grade aluminum, improving performance while cutting weight by up to 50%. HX5 is being commercialized through an exclusive license from Lockheed Martin Corp. (Bethesda, Md., U.S.), where the product was developed as APEX (Advanced Polymers Engineered for the Extreme) and tested in parts for aircraft, helicopters, amphibious transport vehicles, missiles, rockets and satellites.

"Alpine Advanced Materials has full access and global rights to the APEX technology for both military and commercial applications," says Jon Bennett, vice president of corporate development for Alpine Advanced Materials. "HX5 can be machined, coated, painted, welded and adhesively bonded like metal, yet

**FIG. 2 Thermoplastic nanocomposite brackets**

This front and back view of a missile forward destruct bracket shows the benefit of injection molding with HX5 thermoplastic nanocomposite, reducing cost by 93% and weight by 15% compared to the aluminum baseline.

Source | Alpine Advanced Materials LLC

can be processed using injection molding." Because Alpine is not currently permitted to share many details, *CW* has compiled a history of the material's development from publicly available information.

According to Lockheed Martin's 2013 APEX brochure, HX5 is compatible with the full palette of thermoplastic composites processes including compression molding, extrusion, thermoforming, automated fiber placement, filament winding and 3D printing. It also enables joining methods such as welding and overmolding. According to articles published from 2011-2016, development of the thermoplastic nanocomposite was overseen by Dr. Slade Gardner, now chief technology adviser for Alpine Advanced Materials and previously Lockheed Martin fellow in Advanced Manufacturing and Materials for Lockheed's Space Systems Co. Gardner assembled a team of researchers that developed the formulation for APEX by 2008 and was prototyping parts for customers by 2009. The team began producing prototype spacecraft hardware in 2010, including a forward destruct bracket for missiles that was 93% cheaper and 15% lighter than the aluminum baseline (Fig. 2). "The aluminum part had a production lead time of 28 days; conversely, we molded 300 APEX parts in a » single workday," said Gardner in a 2014 Lockheed news article.

The team began working to combine injection molded APEX with long-fiber composites to fabricate hybrid structures that reportedly offer maximum affordability and high performance. In one application — a next-generation, low-cost solid rocket motor case — 40 rocket nose cones were injection molded in two work shifts to demonstrate large-scale parts capability. "Our nose cones represent a 98% cost savings and a 99% improvement in lead time," said Gardner. Lockheed reported that APEX was approved in 2011 to replace a more expensive continuous fiber-reinforced composite in the F-35 fighter jet's wingtip fairings. It also claimed the material was used in more than 1,000 clips that stabilize the A2100 satellite main structure, and for clips, brackets and cable trays in other Lockheed missile defense products.

Gardner described the APEX material as a short fiber- and nanofiber-reinforced blend of "ultrapolymer." It is also explained as a platform not limited to a single polymer, thus enabling customized, manufacturable formulations, including use with continuous woven and unidirectional fiber reinforcements. HX5 has passed fire, smoke and toxicity (FST) testing for aircraft interiors and high-temperature performance testing at 520°F/270°C.

"Alpine has plans to commercialize a variety of specialty materials, but HX5 is our flagship product for the foreseeable future," says Bennett. The company does not sell the HX5 material but designs and manufactures custom parts. "We are prototyping HX5 parts that will be deployed across many industries," he adds, noting replacement of aluminum in commercial aircraft and rotorcraft with a specific focus on interiors and piece parts for light weighting, which in turn reduces carbon emissions. Bennett notes that HX5 is well-suited for redesigning aluminum or conventional composite assemblies to reduce part count.

Though the first HX5 parts will be injection molded, Alpine plans to exploit other advanced manufacturing processes, like overmolding. "Alpine also remains committed to improving the United States' competitive position through participation in numerous defense development programs," says Bennett.

### SIDE STORY

## Verifying producers and supporting developers

One of the challenges facing a dynamic, fast-maturing technology is to build trust in the supply chain. To that end, The Graphene Council is working to mature the global supply chain through its Verified Graphene Producer program. Versarien plc (Cheltenham, U.K.) is the first graphene supplier to complete this independent, third-party verification system that involves a physical inspection of the production facilities and review of the entire production process and safety procedures. "We also take random samples of their products and submit them for blind testing to be rigorously characterized at the National Physical Laboratory (NPL, Teddington, U.K.), a world-class institution that follows ISO/TR 19733:2019 for Nanotechnologies," says The Graphene Council's Terrance Barkan. NADCAP is an analogous audit program used by the aerospace industry for the same purpose. "Without this type of program, customers have no clue what they are getting when they buy and receive graphene products," says Barkan. "Our Verified Graphene Producer program is an important step to provide a level of confidence in both products and producers worldwide."

The Graphene Council also works to improve development of graphene applications. "We connect companies with resources to help them quickly navigate products, producers, materials science and testing for faster, more successful development," says Barkan. "We also provide independent, third-party advisory services to help companies that want to use graphene, but don't know where to start. We not only have reach into our formal members, but also track more than 200 companies involved with graphene worldwide. We monitor what is being developed and the latest scientific and research results, helping to understand what type of graphene to use, how to functionalize and disperse it and how to test for performance." He notes a close relationship with the Graphene Engineering & Innovation Center (GEIC) at the University of Manchester (Manchester, U.K.), where graphene was first discovered. "This is a rapid prototyping center," says Barkan, "and helps us to leverage what graphene can do."

### Nano-CMCs for hypersonics

Further off the ground and at much higher speeds is another emerging application area for nanomaterials: Nano ceramic matrix composites (CMCs) for hypersonics. Hypersonic is an aerodynamic term for speeds much greater than the speed of sound, typically less than Mach 5. More broadly, hypersonics is a category of military weapons and vehicles designed to travel at hypersonic speeds. Such technology is in development throughout the world, including in the U.S.

Speeds beyond Mach 5 demand lightweight structural materials that can withstand 2480°C temperatures without melting or deforming, while resisting erosion and projectiles. This means they must be hard, mechanically tough and fracture-resistant. These vehicles also require specific electrical and thermal properties to conduct electricity and/or shield enclosed components. Even the latest metal technologies are struggling to meet all these demands.

Refractory ceramics — including metal carbides, metal nitrides and metal borides — have the lightweight durability to handle such extreme environments, but their synthesis and densification requires high pressures and temperatures above 1980°C, making them energy-intensive and expensive. Pure refractory ceramics are also too brittle.

The US Naval Research Lab (NRL, Washington, D.C., U.S.) is using its expertise developing novel, high-temperature and fire-resistant phthalonitrile resins to advance a potentially inexpensive method for the direct fabrication of nanocrystalline-shaped refractory ceramics. The technology uses novel polymeric compounds to synthesize and densify these ceramics in-situ, in one step without the need for sintering ceramic powders at high pressures and temperatures. This development is led by Dr. Matthew Laskoski, NRL research chemist and acting head advanced materials section, and outlined in his 2018 article "Naval Research Lab designs composites for new platforms," published in Vol. 5, No. 2 *Naval Science and Technology Future Force* magazine.

In this process, a new carbon-rich resin with polyphenol-type chemistry is blended with metallic powders via ball milling, a common technique used in nanomaterial processing. The resulting ceramic precursor can be compacted into discs, cones, spheres or other application-specific shapes. A reactive melt infiltration process — such processes are commonly used to produce (CMCs) — produces densified carbides in a 1370°C, pressureless, argon-filled furnace. The dense carbides are thus formed in a single-step reaction at lower temperature than and without the pressure of conventional sintering and hot-pressing techniques. Because the crystal size of the carbides is less than 40 nanometers, the resulting nanoceramics are not as brittle as courser-grained materials.

Another advantage is that the thermoset polymer acts as a meltable source of carbon that reacts with the metallic powder particles. It also facilitates reinforcing the ceramics with metals, carbon fibers and secondary ceramics. (An example of secondary ceramics can be seen in Fig. 1 (E) where the bi-phasic composite comprises a primary ceramic matrix and secondary ceramic reinforcement.) The resulting CMCs provide an avenue for further control of mechanical, thermal, electrical and ablative properties.

According to Laskoski, refractory carbides such as zirconium carbide and titanium carbide are unaffected by extremely high temperatures and are impervious to fire, plasma or atmospheric heating during hypervelocity travel. However, NRL's polymer-derived nanocrystalline ceramics extend beyond carbides to include nitrogen-rich resins that can react with metals to form metal nitrides. NRL has developed silicon nitride, zirconium nitride and titanium diboride composites as well as methods to reinforce resulting CMCs with tough fibers. These refractory ceramics exhibit high strength, thermal stability and variable electrical and thermal conductivities that allow them to meet the demands of hypersonic vehicle components.

Engines for such vehicles absorb large quantities of heat and must dissipate it effectively, which even the most advanced metal alloys cannot do without loss of strength and structural integrity. Laskoski asserts that metal nitride and boride components are more apt to solve this challenge, while silicon nitride composites offer potential for high-strength, oxidation-resistant communications radomes. NRL is developing additive manufacturing technology that will incorporate nanostructures into these materials and further tune dielectric, thermal and electromagnetic shielding properties at a higher resolution than possible with currently available materials.

## Nanocomposite toxicity and safe handling

Because nanomaterials are smaller than human body cells and blood cells, there are concerns about their toxicity, not just from worker exposure during materials manufacture and processing, but also when parts are machined, sanded and recycled. The Graphene Council recently published a webinar where the National Institute for Occupational Safety and Health (NIOSH, Washington, D.C., U.S.) discussed these issues and listed its resources, including three 2018 publications: "Protecting Workers during Nanomaterial Reactor Operations," "Protecting Workers during the Handling of Nanomaterials" and "Protecting Workers during Intermediate and Downstream Processing of Nanomaterials" (Learn More).

NIOSH states that it has completed extensive toxicological studies on only a few nanomaterials, including carbon nanotubes (CNTs). Because rats and mice exposed to CNTs and carbon nanofibers (CNFs) have shown persistent pulmonary inflammation, tumors and fibrosis (progressive lung scarring that makes breathing difficult), NIOSH emphasizes it is important to control worker exposure throughout nanomaterial production. Harvesting nanomaterials from reactors and cleaning reactors results in potentially high exposures. Workers may also be exposed during spraying and machining (for example, ball milling) as well as handling nanomaterials for weighing, packaging and mixing/compounding. NIOSH states that control of worker exposures appears feasible with standard techniques including source enclosure, local-exhaust ventilation, personal protection equipment (PPE) and best practices in cleaning and housekeeping for fine particulates.

> "CNTs have been quite well studied ... However, there are still a lot of challenges," says Jo Anne Shatkin.

The NIOSH recommended exposure limit (REL) for CNTs/CNFs is below 1 g/$m^3$ as an 8-hour time-weighted average (TWA). Analytical techniques such as scanning and transmission electron microscopy (SEM, TEM) may be used to ensure this threshold is maintained. NIOSH specifically advises that it is *unsafe* to use the OSHA permissible exposure limit (PEL) for graphite (5,000 g/$m^3$) or carbon black (3,500 g/$m^3$), and also that more research is needed to fully characterize the health risks of CNTs and CNFs, including long-term animal studies and epidemiologic studies in workers (Learn More).

"CNTs have been quite well studied," says Jo Anne Shatkin, president of Vireo Advisors LLC (Boston, Mass., U.S.), a workplace health and safety consultancy. "Ten years ago, we didn't know, but now studies are showing the more drastic toxicity we feared has not really materialized." She notes that the concern about high-aspect-ratio nanomaterials like CNTs is that they behave like carcinogenic silica and asbestos fibers. "But very few of the CNT materials studies meet that fiber paradigm at this point," she explains. "However, there are still a lot of challenges. We have mostly tested pristine nanomaterials, not functionalized, as they are in use. Uncertainty remains because nanomaterials are so varied in composition, form and functionalization." All these factors can affect toxicity, including the functionalization method and chemistry used. "You are creating properties that make the CNT react better with a polymer, but we don't know how that affects the material's interactions with blood or body cells," she says. "We're not yet at a predictive stage. That is what we are exploring now. Can we come up with a standardized model for evaluating exposure and toxicity that accounts for all of these variables?" »

Shatkin describes work being done and a number of standard test methods under development at the American Society for Testing and Materials (ASTM, Conshohocken, Pa., U.S.) and the American National Standards Institute (ANSI, Washington, D.C., U.S.). "The ISO/ANSI TC 229 Nanotechnology Standards Development Group has dozens of standards for testing nanomaterials," she says, "as well as occupational health and safety methods, such as how to conduct SEM and TEM for particle distribution measurements relative to PELs and RELs." Shatkin notes that both ISO and ASTM have a standard in development that looks at the risk of nanomaterial release from composites via machining, sanding and other secondary operations. Here, at least, a preliminary green light has been given. Shatkin says work completed by the industry consortia NanoRelease shows that sanding and machining parts that contain nanomaterials do not pose new health and safety threats. "You do get release of nanomaterials, but they are bound to the polymer, not free nanoscale particulates," she explains. "So, our current guidelines for particulates from machining composites are sufficient." However, companies — especially those with limited workers and resources — may not see machining dust as a serious health threat. Thus, they may not always follow guidelines and best practices for PPE and respirators, not to mention enclosures and ventilation equipment. But because there is still uncertainty, such complacency isn't an option when working with nanomaterials.

Nanocomposites are indeed enabling higher performance, greater multifunctional capabilities and potentially lower-cost and lighter-weight structures for numerous applications and markets. "There is a huge opportunity for benefit with nanomaterials, and we've learned a lot," says Shatkin, "but there's still a lot of uncertainty. Our best path forward is to be cautious, minimize exposure and make sure, as much as possible, that we make manufacture, handling and use as safe as possible." CW

**LEARN MORE**

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

Watch the NIOSH safety webinar hosted by The Graphene Council | youtube.com/watch?v=gaN8Z2XMDd4&t=463s

View NIOSH nanomaterials publications | cdc.gov/niosh/topics/nanotech/pubs.html

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# FRP PULTRUSIONS REPLACE WOOD FOR STRUCTURAL APPLICATIONS

## FRP goes where wood can't.

› Wood is revered for a reason — it is used for creating warm, inviting home environments, furniture, art and more. Remember the wooden rollercoasters of old? Despite its sentimental value, wood can't make it in most harsh industrial environments, says Eric Kidd at Bedford Reinforced Plastics (Bedford, Pa., U.S.): "When exposed to moisture or water, wood is susceptible to warping, rot, mold and mildew. And when in a seaside or coastal location, the moisture, in addition to higher winds and salt spray, creates an especially corrosive environment that can cause a wood structure to break down more quickly over time." Unlike wood, fiber-reinforced polymer (FRP) is unaffected by salt spray, moisture or prolonged immersion in water, making it a good material choice for piers, pilings, pedestrian bridges, cooling towers and other structural applications in harsh environments.

Source | Bedford Reinforced Plastics

Source | Bedford Reinforced Plastics

Insects, including termites, marine borers and carpenter ants, also pose a threat to wood structures. They eat away at the wood, affecting the integrity of the structure. To fight pests, wooden structures are often treated with hazardous preservatives or coatings, which are environmentally harmful. In contrast, FRP does not require any coatings or preservatives to withstand the effects of corrosion, rot or insects, and it has little environmental impact. And, dimensional stability in extreme weather conditions along with flexural strength make a strong case for FRP's application in geographic areas that experience harsh temperature extremes.

Kidd describes a project where Bedford's pultruded FRP materials have replaced wood for a structural application. At the Barrick Goldstrike Mines in northeastern Nevada, environmental regulations dictate that 140°F groundwater pumped from the mine must be cooled (below 80°F) before being released into the adjacent waterway. Because of this, a cooling tower was required, but the design had to allow for substantial seasonal temperature variances as well as extreme weather events.

Contractor Hamon Cooling Towers (Somerville, N.J., U.S.) selected FRP as an alternative to wood and concrete, picking the material for its high strength, light weight and dimensional stability. Hamon chose Bedford's PROForms pultruded structural shapes based on Bedford's previous experience with cooling tower structures, and its ability to deliver the product within a tight schedule. In all, Bedford shipped 29 flatbed trucks loaded with PROForms elements, including square tubes, angles, channels and deck board (images at left show the tower's construction). The composite materials were manufactured with a fire-retardant resin and surfacing veil for UV protection.

Today, the cooling tower reportedly continues to deliver excellent performance at the site with minimal required maintenance. CW

# Composites Events

**July 3, 2019 — Vigo, Spain**
MATCOMP19
matcomp19.com

**July 10-12, 2019 — Shanghai, China**
Lightweight Asia 2019
lightweightasia.com

**July 14-20, 2019 — Grenada, Spain**
ICCE-27
icce-nano.org

**July 17-18, 2019 — Alexandria, Va., U.S.**
Advanced Materials for Defense Summit
materials.dsigroup.org

**July 22, 2019 — Kelowna, British Columbia, Canada**
CANCOM 2019
CANCOM2019.ca

**July 22-24, 2019 — Osaka, Japan**
World Congress of Advanced Materials
bitcongress.com/wcam2019

**July 23-25, 2019 — Denver, Colo., U.S.**
Summer 2019 IACMI Members Meeting
web.cvent.com/event

**Aug. 11-16, 2019 — Melbourne, Australia**
ICCM22 — The 22nd International Conference on Composite Materials
iccm22.com

**Aug. 20-22, 2019 — Detroit, Mich., U.S.**
Global Automotive Lightweight Materials Summit
global-automotive-lightweight-materials-detroit.com

**Aug. 21-22, 2019 — Detroit, Mich., U.S.**
IACMI SMC 101 workshop
iacmi.org/smc

**Aug. 27-29, 2019 — Austin, Texas, U.S.**
Additive Manufacturing Conference and Expo
additiveconference.com

**Sept. 3-5, 2019 — Birmingham, U.K.**
ACIC 2019: Advanced Composites in Construction
acic-conference.com

**Sept. 3-5, 2019 — Shanghai, China**
China Composites Expo 2019
chinacomositesexpo.com

**Sept. 4-6, 2019 — Novi, Mich., U.S.**
SPE Automotive Composites Conference and Exhibition (ACCE)
speautomotive.com/acce-conference

**Sept. 5-7, 2019 — Guangzhou, China**
UTECH Asia 2019
puchina.eu

**Sept. 10-12, 2019 — Messe Stuttgart, Germany**
Composites Europe and ICC 2019
composites-europe.com

**Sept. 10-12, 2019 — Butte, Mont., U.S.**
Resodyn Technical Interchange 2019
resodynmixers.com

**Sept. 10-12, 2019 — Stuttgart, Germany**
Foam Expo Europe
foam-expo.eu

**Sept. 10-13, 2019 — Wichita, Kan., U.S.**
Resodyn Technical Interchange 2019
icolse.com

**Sept. 16-18, 2019 — Toulouse, France**
Commercial Aviation Industry Suppliers Conference Europe
speednews.com/aviation-industry-suppliers-conference-in-toulouse

**Sept. 23-26, 2019 — Anaheim, Calif., U.S.**
CW CAMX 2019
thecamx.org

**Sept. 24-26, 2019 — Birmingham, U.K.**
TCT Show 2019
tctshow.com

**Sept. 25-26, 2019 — Anaheim, Calif., U.S.**
ASTM D30 Composite Materials Meeting at CAMX
astm.org

**Oct. 1-3, 2019 — Tampa, Fla., U.S.**
IBEX 2019
ibexshow.com

**Oct. 7-9, 2019 — Orlando, Fla., U.S.**
2019 Polyurethanes Technical Conference
polyurethane.americanchemistry.com

**Oct. 8, 2019 — Enschede, Netherlands**
Future of Thermoplastics Conference
tprc.nl/events

**Oct. 8-9, 2019 — Novi, Mich., U.S.**
Lightweighting World Expo 2019
lightweightingworldexpo.com

**Oct. 8-10, 2019 — Milan, Italy**
GOCarbonFibre 2019
gocarbonfibre.com

**Oct. 9-10, 2019 — Munich, Germany**
3rd Munich Technology Conference on Additive Manufacturing
oerlikon.com/mtc-event

**Oct. 16-23, 2019 — Düsseldorf, Germany**
K 2019
k-online.com

**Oct. 22-23, 2019 — Oxford, U.K.**
Composites in Motorsport
compositesinmotorsport.com

**Oct. 30-31, 2019 — Birmingham, U.K.**
Advanced Engineering UK 2019
thenec.co.uk

**Nov. 5-7, 2019 — Farnborough, U.K.**
Vertical Flight Expo & Conference
verticalflightexpo.com

**Nov. 13-15, 2019 — Seoul, Rep. of Korea**
JEC Asia 2019
jec-asia.events

**Nov. 19-21, 2019 — Knoxville, Tenn., U.S.**
CW Carbon Fiber 2019
CarbonFiberEvent.com

**Nov. 20-21, 2019 — Vienna, Austria**
Composites in Building & Infrastructure Summit
techtextil-india.in.messefrankfurt.com

**Nov. 20-22, 2019 — Mumbai, India**
World of Composites at Techtextil India
vonlanthengroup.com/en/events

**Nov. 26-28, 2019 — Copenhagen, Denmark**
WindEurope Offshore 2019
windeurope.com/offshore2019

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See more events at:
short.compositesworld.com/events




Source | Alaka'i Technologies

# New Products

» CORE MATERIALS

## Sandwich core for infusion processes

**Sicomin's** (Châteauneuf les Martigues, France) MaxCore is a new concept of sandwich core for infusion processes. Fiber reinforcements are reportedly inserted in multiple orientations and are responsible for 100% of the mechanical properties of the core.

Sicomin says it is able to place these reinforcement fibers with precise fiber angles and positions within the core using a patented manufacturing process.

Due to the mechanical contribution of the fiber reinforcement, MaxCore reportedly does not rely on denser core material, and is therefore said to be a cost-effective option compared with classic foam cores used in composite panels. As the core material is solely a carrier for the fiber reinforcement, cores can be selected based on other required parameters such as fire and smoke behavior, water resistance, thermoformable ability, low resin absorption or sustainable chemistry.

MaxCore's patented fiber insertion method can be applied to kits in which fiber orientations are engineered within each panel to incorporate openings such as windows and doors, and to provide additional local reinforcement. The core material is also said to be compatible with a variety of manufacturing processes and can be used with epoxy, polyester and vinyl ester resin systems. Its fiber insertion technique can be applied with a variety of materials, including aramid fiber, carbon fiber, basalt fiber, natural fibers, thermoplastics and glass fibers. **sicomin.com**

» THERMOPLASTIC SOLUTIONS

## Production line for thermoplastic UD tapes

**Karl Mayer Technische Textilien GmbH** (Obertshausen, Germany) has launched a new line for mass production of thermoplastic unidirectional (UD) tapes for lightweight construction applications. The line was developed, the company says, to fulfill a need for reproducibility, quality and efficiency at a reasonable cost in the processing of fiber-reinforced plastics (FRP).

More specifically, Karl Mayer has extended its spreading technology to include suitable heating and impregnating modules, resulting in a machine system that is said to deliver a continuous mode of operating, a high production speed and large tape widths. **karlmayer.com**

» CURING ACCESSORIES

## Composite curing control system

Source | Lewco

**LEWCO** (Sandusky, Ohio, U.S.) has developed a composite curing control system for use with Lewco industrial ovens. The PC-based system has been designed to be a simple-to-use system with options available to enable control over every aspect of composite cure for high-performance components in aerospace and other industries. The end user is said to be able to more fully control, document and archive the process in order to ensure parts are cured to specification.

The system offers a variety of touchscreen options, supports non-editable data files and file recording, and enables selection of vacuum configuration at each port. Additional features include redundant data logging on the hard drive of the PC as well as the process controller, the ability to calibrate all recording devices, optional variable vacuum pressure control, and programmable ramp/soak recipes and cascade controls. The system also generates customized reports with user information. **lewcoinc.com**

Source | Impossible Objects

» ADDITIVE MANUFACTURING

## Faster composite 3D printer

The CBAM-2 3D printing system from **Impossible Objects** (Northbrook, Ill., U.S.) reportedly produces complex parts on an industrial scale with speeds up to 10 times faster than is possible with other additive manufacturing systems. The CBAM-2 combines high-performance polymers with long carbon fibers and fiberglass sheets to rapidly produce 3D composite parts that are said to be stronger and lighter, with better temperature performance and more durability than parts produced via other 3D printers.

Additional features of the CBAM-2 include: support for high-strength composites including high-performance thermoplastics like PEEK and nylon, the ability to print sheets up to 12" × 12" in size, increased precision and greater quality control from three cameras, streamlined maintenance achieved through automatic powder filling, and bulk ink cartridges enabling more efficiency and longer duration between refilling. CBAM-2 machines will be available for customers beginning in the third quarter of 2019. **impossible-objects.com**

» CUTTING & KITTING

## Dry ice blaster for precision cutting

**Cold Jet's** (Loveland, Ohio, U.S.) PCS 60 dry ice blasting machine features a patented Particle Control System (PCS) to precisely cut dry ice into diamond-shaped particles between 0.3 and 3 mm in size. The machine is designed to give the user complete control as well as the ability to find the most effective setting for each application.

Source | Cold Jet

The PCS 60 is also designed for easy use. With a 7" LCD color screen and digital controls, its display enables the user to easily view and adjust blasting parameters and machine settings. The machine also features programmable and password-protected application recipes, enabling users to set and save blasting parameters such as blast pressure, particle size and feed rate for increased efficiency.

The design, which includes a "straight-through" air system and redesigned SureFlow feeding system, minimizes air pressure loss and dry ice sublimation within the machine, maximizing air supply yield and reducing dry ice waste.

PCS 60 is IoT-enabled via Cold Jet's Industry 4.0 solution, Cold Jet CONNECT. The system provides remote monitoring and diagnostics while allowing users to collect and manage data and employ tools for optimum performance and productivity. The machine enables automation and integration via an optional accessory package that combines the PCS 60 with a Cold Jet dry ice production unit and a robot for continuous and fully automated blasting.

Additional design considerations include reduced weight and size compared to competing machines, wheels designed for mobility and maneuverability, and reduced noise levels. coldjet.com

» ADDITIVE MANUFACTURING

## Large-format composite 3D printers

**3D Platform** (Roscoe, Ill., U.S.) has introduced two platforms to its 3D-printing lineup: the WorkCell and the larger WorkCenter 500.

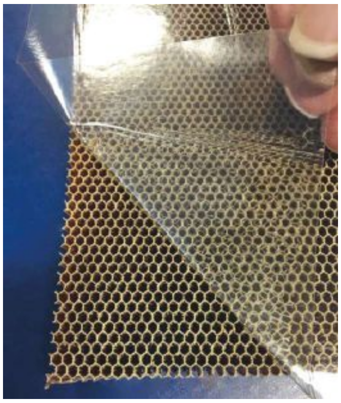
The WorkCenter 500 offers a single gantry machine with a print volume of 1.4 m × 2.8 m × 700 mm. The modular gantry system enables users to install either a pellet or filament extruder into each of the two tool slots on the gantry, with tool customization available. The machine has been designed for customers needing a large-format printer but at a lower price point and smaller size than the company's extra-large Excel 3D printer.

The WorkCell incorporates high-end mechatronics and an enclosure said to enable printing of high-temperature engineered polymers within a large format.

Both printers are reportedly able to accommodate a range of thermoset and thermoplastic materials including those reinforced with chopped carbon fiber, glass fiber, and organic fibers such as wood and bamboo. 3dplatform.com

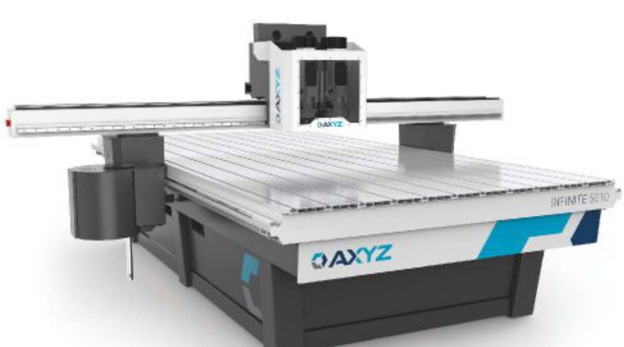
» CORE ACCESSORIES

## Tape designed to secure cores during machining


Source | Airtech International Inc.

**Airtech International** (Huntington Beach, Calif., U.S.) introduces its Corehold P-HA pressure-sensitive tape, a core holding film designed to hold honeycomb core and other core materials during machining. It is a polyester film coated on one side with a silicone-free synthetic rubber adhesive. The film is supplied with a yellow backing release paper on one side.

Ideally paired with a vacuum table, Corehold P-HA secures the core against movement during machining. It can be used for contoured applications and is said to provide high adhesion properties while leaving little residue. Benefits are said to include high peel adhesion, ability to withstand high temperatures and high strength. Stability provided by the film helps improve part quality and avoid process errors, and its rubber-based adhesive simplifies removal and clean-up. airtechonline.com



Source | AXYZ International Inc.

» CUTTING & KITTING

## Redesigned high-precision CNC router

**AXYZ International Inc.'s** (Burlington, Ontario, Canada) Infinite Router is designed for high-precision cutting of fiber reinforcements for a variety of end market applications.

Using the Infinite Router, process areas can vary in size up to 128" (3,251 mm) wide and more than 50 ft. long (15.24 m), depending on application requirements. For cutting with high precision and accuracy, options include a high-speed spindle, automatic tool changer and oscillating knife.

The Infinite Router is said to be a robust, heavy-duty and reliable machine for marine and other end market applications. It has been redesigned for easier service, created from a redesigned welded carriage to ensure sturdiness and offer a sleeker aesthetic. A new dust extraction system is intended to reduce clogging and enable use of longer tables. axyz.com


Source | Artec 3D

» TESTING, MEASUREMENT & INSPECTION SYSTEMS

## 3D laser scanner for large applications

**Exact Metrology** (Cincinnati, Ohio, U.S.) announces the availability of Artec Ray laser scanners, developed by Artec 3D (Luxembourg). The laser scanner is reportedly capable of scanning large objects like wind turbines, ship propellers, airplanes and buildings while still offering high precision, sub-millimeter and angular accuracy, and speed. Artec Ray is able to scan up to 110 meters away. Data capture is said to be cleaner than with other 3D scanners and noise levels are minimal, reducing post-processing time.

The scanner is designed for simple use, requiring only its placement on a tripod and the press of a button. Portable and compact, the laser scanner can be set up indoors or outdoors, and it features an internal battery that lasts up to four hours.

Additionally, Artec Ray is equipped with the Artec Studio software solution. Once scanned, the scan is processed directly into Artec Studio and then is exported to reverse engineering software.

To obtain maximum benefits, Artec Ray can be paired with Eva or Space Spider handheld Artec scanners to scan hard-to-reach areas such as the interiors of cars or to add intricate detail to large-scale 3D models. **exactmetrology.com**

» AUTOCLAVE ACCESSORIES

## High-temperature thermocouple for PEEK composites curing

Source | TE Wire & Cable

**TE Wire & Cable's** (Saddle Brook, N.J., U.S.) PEEKSense thermocouple sensor is a high-temperature autoclave thermocouple assembly for polyetheretherketone (PEEK) composites applications. Retaining the temperature-sensing capabilities of the company's AccuClave product line, PEEKSense was designed to withstand temperatures up to 400°C for longer cycles.

Applicable materials include PEEK, polyaryletherketone (PAEK), polyetherketoneketone (PEKK) and polyimide composites. Available in lengths between 3 and 100 feet, PEEKSense conforms to Special Limits ASTM E230/E230M, Class I IEC 60584 and BAC 5621. Additional features are said to include high tensile strength, chemical resistance and abrasion resistance; better handling for operators; and standard wire construction of flame retardant-applied liquid polyimide. **tewire.com**

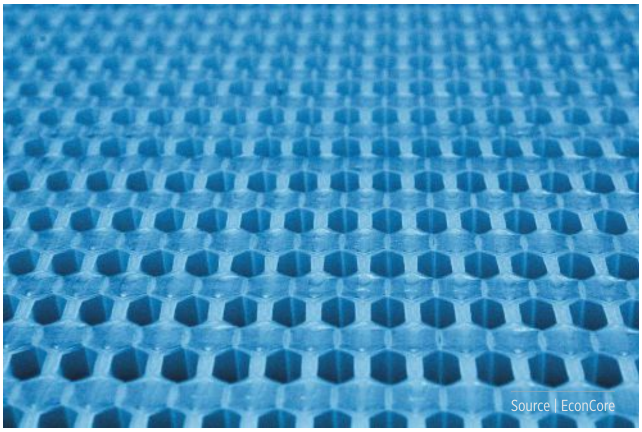
» CORE MATERIALS

## Thermoplastic honeycomb panel production technology

**EconCore's** (Leuven, Belgium) ThermHex honeycomb technology converts thermoplastics to high-performance, lightweight honeycomb core structures and, combined with inline lamination of skins, produces lightweight sandwich panels. The true honeycomb structure is said to outperform other low-density cores such as fluted or cup-shaped structures sometimes used in packaging and automotive applications.

EconCore's continuous honeycomb panel production technology consists of feeding (by direction extrusion or pre-extruded flat film/sheet), vacuum forming of the film/sheet to a half-hexagonal "half honeycomb" pattern, folding of the pattern to a technical honeycomb core structure and bonding of skin materials onto the honeycomb core to make sandwich panels. The high-speed, inline process is said to enable users to develop products at minimal cost, minimal weight and minimal environmental impact.

The technology is said to provide ideal thermoformability, thermal insulation and acoustic absorption for automotive applications such as reusable packaging with collapsible sleeve packs. A range of core



Source | EconCore

materials can be used with this technology, including polyolefins like PP and PE, thermoplastics including PET, PVC, ABS, PMMA and bio-based PLA, and high-performance polymers such as PC, PA, PPS and PEI. The versatility extends to skin materials including thermoplastics reinforced with glass fiber, carbon fiber or natural fibers. **econcore.com**

## MANUFACTURING SUPPLIERS



## RECRUITMENT/ HELP WANTED



## TESTING

## ADVERTISING INDEX



## SHOWCASE

# Thermoplastic primary aerostructures take another step forward

## Employing new manufacturing techniques and the design freedom they create, GKN Fokker has joined forces with Gulfstream to assess thermoplastic composites for primary aircraft structures.

**By Karen Mason** / Contributing Writer

» Advantageous features of thermoplastic composites, such as toughness, comparatively high out-of-plane strength and sustainability/recyclability, have attracted aircraft design engineers to the notion of thermoplastic composite primary structures for decades. But aircraft manufacturing engineers have been uncertain about finding a cost-effective way to advance them from CAD simulation to the production floor. They are not, however, deterred: Efforts to develop the necessary manufacturing technologies have continued across the globe — perhaps nowhere as tenaciously as in the Netherlands.

In 2009, nine Dutch industrial companies and research institutes, together with Airbus (Toulouse, France), formed the Thermoplastic Affordable Primary Aircraft Structure (TAPAS) Consortium. The initiative expanded to 12 partners in 2014 and continued as TAPAS2. Targeting Airbus-developed applications under TAPAS2, GKN Fokker (Hoogeveen, Netherlands) recently developed a fuselage demonstrator using what it calls a "butt-jointed orthogrid technology" that enables cost-effective production of a thermoplastic composite fuselage design.

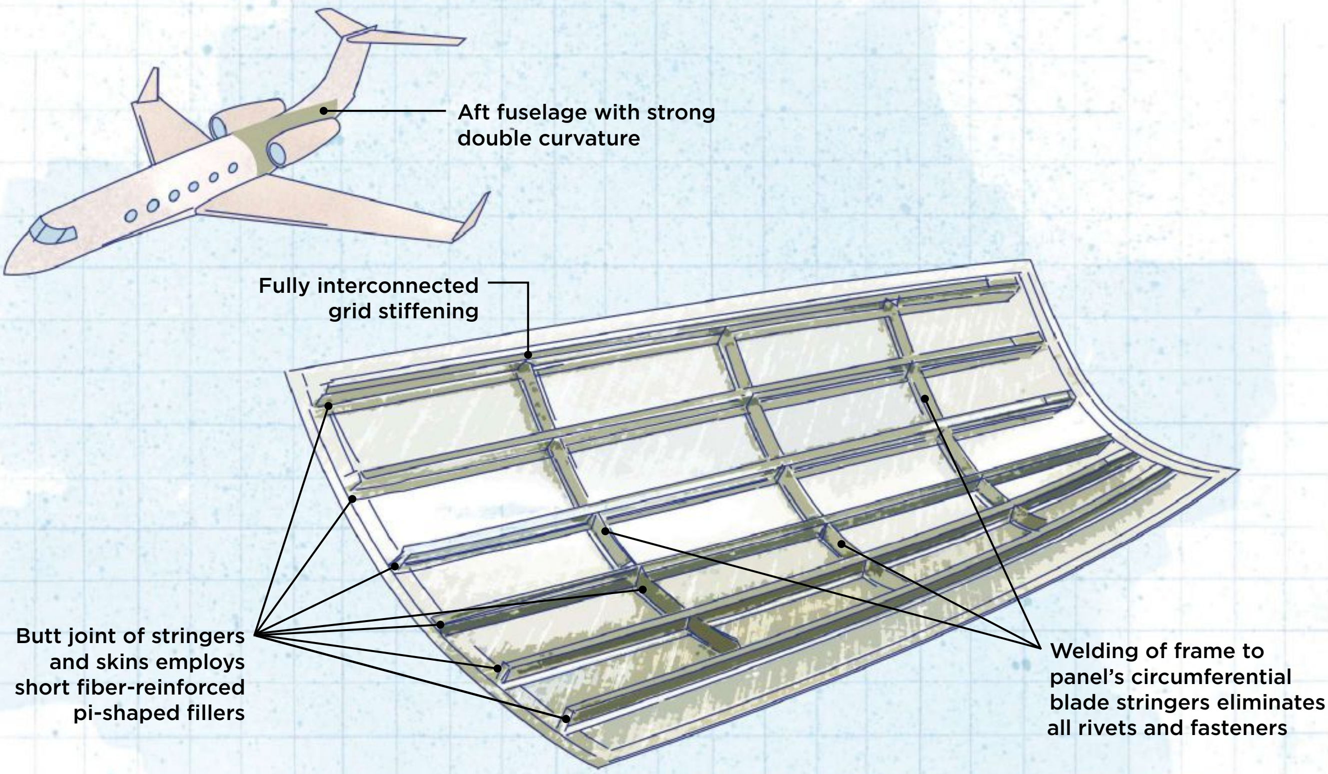
The full payoff of a thermoplastic composite primary aircraft structure — though still years away — may now be within sight as Gulfstream Aerospace (Savannah, Ga., U.S.) has partnered with GKN Fokker to advance its TAPAS2 fuselage technology, pointing the way toward possibly applying the materials and process to a full fuselage. The story behind the newly developed fuselage panel (which was displayed at JEC World earlier this year) is one of advancements in design and manufacturing methods, and further, in a more thoroughly integrated design-manufacture engineering approach.

"Traditionally," explains GKN Fokker chief engineer Andries Buitenhuis, "whether they were using fabrics or unidirectional tapes, designers mostly stuck to conventional layers of 0-, 90- and 45-degree orientations. They would work from their ply layup tables, independent of other disciplines." The new approach is an integrated, digitalized design-manufacture software platform (developed through TAPAS) in which engineers from various disciplines are all looking at the same digital model and have the ability to conceptualize more complex part designs. "This opens up a whole new world of unprecedented optimization possibilities," Buitenhuis continues. "On complex shapes, fiber directions may be all over the place. We can build unconventional laminates and take a fresh look at design allowables, manufacturing gaps and overlaps, radiuses. And you can optimize the structure's strength locally." These expanded design options more fully employ the fiber steering capability of automated fiber placement (AFP) machines, and advances in other manufacturing capabilities discussed below.

**Integral L-stringers**

The GKN Fokker carbon fiber/PEKK fuselage, designed and built for Gulfstream, incorporates curved longitudinal L-stringers with a slightly obtuse angle to enable tool release. *CW* photo | Jeff Sloan

The design freedom afforded by this integrated digital system has proven indispensable to the design and manufacture of business jet panels. In the TAPAS2 fuselage designs, the carbon fiber/polyetherketoneketone (PEKK) panel (made with Solvay's APC PEKK-FC) features a welded, fastener-free frame-to-skin joint, which is an essential contributor to the design's cost-effectiveness. "We predict achieving cost parity with aluminum fuselage shells," explains Arnt Offringa, head of thermoplastic composites technology at GKN Fokker, "and this is because aluminum shells are riveted." The elimination of mechanical fasteners is expected to generate a 20% cost




**DESIGN RESULTS** | **Gulfstream thermoplastic composite fuselage panel**

- Elimination of rivets/fasteners generates expected 20% cost reduction and 10% weight reduction.
- Integrated design-manufacture engineering approach enables greater design freedom, including advanced fiber steering.
- New grid design and grid-to-skin joining mechanism create needed manufacturing cost efficiency.

Illustration / **Karl Reque**

reduction and a 10% weight reduction in aircraft primary structures as compared to conventional composite solutions. Of course, much of the cost and weight savings come from the elimination of the fasteners themselves, as well as labor costs for installing them. Also of great importance is the elimination of holes in the composite components to accommodate the fasteners — holes that require added reinforcement and therefore added weight.

GKN Fokker reached technology readiness level (TRL) 3 (proof of concept) with Airbus for a pressurized fuselage, demonstrating cost parity with aluminum fuselage panels, under TAPAS2 in December 2017. Along the way, the GKN Fokker team expanded its vision for this thermoplastic fuselage technology from commercial airliners to business jet applications.

### Gulfstream's interest

GKN Fokker's history of successful work for Gulfstream on thermoplastic composite components made a partnership with the business jet manufacturer a logical next step. "It is widely known that Gulfstream has been flying thermoplastic composite parts for years," says Mark Chapman, manager of Gulfstream's Advanced Structures and Materials Initiative (ASMI). He adds that the fuselage panel project "is a natural progression from what we've been doing, starting with simpler parts and moving toward primary structural parts." GKN Fokker has partnered with Gulfstream in the development of numerous thermoplastic composite secondary components, including tail elevators and rudders as well as floor panels on the G650.

In 2015, Offringa and Buitenhuis presented TAPAS2 project developments to Gulfstream, and Chapman and his team recognized the potential for garnering the benefits of TAPAS2 results. "We saw the potential weight reduction benefits, better impact resistance and toughness, and enhanced performance," Chapman recalls. Fastener-free design is also appealing. "Welding technology would enable us to assemble the fuselage more efficiently" than a mechanically fastened assembly, Chapman says.

The partnership with GKN Fokker supports Gulfstream's research and development of more complex fuselage shapes that may not be economically feasible to produce with metal structures. "You can only stretch-form metal so far," Chapman notes. "The splices and supporting structure necessary for complex shapes are not very efficient." Offringa agrees: "Such complex geometries are difficult to manufacture with conventional technologies." »

■ **Double curvature**

The thermoplastic composite fuselage panel accommodates the complex geometry of a Gulfstream business jet aft fuselage with fiber-steered AFP layup of the skin and co-consolidation of the orthogrid. Note the circumferential blade stringers, to which separate frame elements will be welded to, completing the frame. Source | GKN Fokker

### Joining design and manufacture

To achieve a fastener-free, producible design, GKN Fokker's approach focuses on withstanding the two key forces to which the fuselage joints are subject: cabin pressure and impacts such as tool drops. Cabin pressure places radial force on the fuselage, creating high loads in the frame-to-skin joint. In conventional designs, fuselage frames include "mouse holes" through which the longitudinal stringers pass. Under the force of cabin pressure, these mouse holes serve as discontinuities that are subject to high peel forces — a major concern for a fastener-free design, given composites' low out-of-plane strength compared to metals. Impacts also generate high loads in the frame-to-skin joint because the frame does not flex under impact.

The GKN Fokker/Gulfstream team knew it was infeasible to meet the challenges created by a complex curvature either with metal or with conventional composite design-manufacture approaches. In particular, Buitenhuis points out, "A complex fuselage design would not be possible without fiber steering." This capability of AFP machines is what freed the designers to optimize fiber orientation locally based on the shell's complex shape, and to diverge from the standard 0/45/90 fiber orientation options. "Fiber steering for shapes and weight optimization is one of the most significant advancements of this project," Chapman believes.

GKN Fokker made the fuselage panel's skin on an ultrasonic AFP machine that the company developed for rapid thermoplastic tape layup. The tape is unidirectional, which also enhances laminate performance compared to fabric tapes.

Successfully handling the high loads created by cabin pressure and impact forces, as well as other performance demands, the new concept developed under TAPAS and TAPAS2, and that is now employed in the Gulfstream panel, is what is described as a "butt joint orthogonally stiffened skin with welded frames." Unpacking this description highlights three key design features and the manufacturing developments needed to implement them: (1) the orthogrid, (2) the butt joint and (3) welding technology.

### Orthogrid

The panel's strength requirements are met in part through fully interconnected orthogonal grid stiffening. This orthogrid eliminates the peak loads associated with the mouse holes, ridding the design of points at which peel forces are magnified. The orthogrid consists of continuous longitudinal stringers and frames comprising two distinct components: discontinuous but connected circumferential blade stringers and frames welded on top of these.

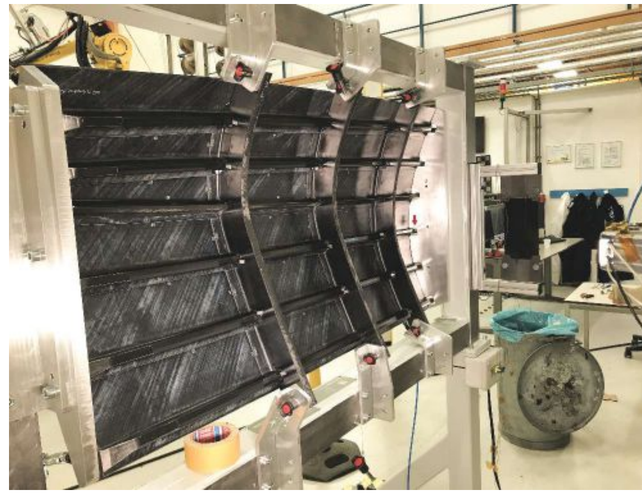
Thus, this represents a new generation in fuselage stiffener design which has evolved during years of orthogrid development. Initially, GKN Fokker used T stringers in which the caps of both longitudinal and circumferential members were continuous and overlapped at the corners. Joining with the frame, however,


■ **Cost-effective butt joint**

GKN Fokker innovated and patented a butt joint that enables orthogrid and orthogrid-to-skin joining using cost-effective short-fiber injection molded elements and continuous-fiber flat laminates for the stringer web and cap (here a T stringer; the Gulfstream panel incorporates L stringers with the same technique). Source | GKN Fokker

**Automated welding**

Contributing to the economic feasibility of the thermoplastic composite fuselage panel, GKN Fokker developed and employed a robotic welding technique to weld the frame elements to the circumferential stringers. Source | GKN Fokker



**Completed component**

After the frame has been welded on top of the stringers, the Gulfstream fuselage panel is ready for testing, assessment and continuing development as the companies work toward production thermoplastic composite fuselages. Source | GKN Fokker

required the removal of the circumferential cap. Thus, T stringers became L stringers and frames became circumferential blade stringers with frames then welded to them.

Another modification is required because the curved stringers used both longitudinally and circumferentially make tool release much more challenging. Thus, the L stringers are designed with a cap-to-web angle of more than 90 degrees, so that tool pieces can always slide sideways out of the stringer grid.

### Butt joints

GKN Fokker developed not only the orthogrid design, but also a new manufacturing approach for the grid as well as the grid-to-skin joining mechanism. "The grid can be prohibitively expensive to fabricate," Offringa notes, "but our grid is built up of flat laminates and simple injection molded 'fillers.'"

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More specifically, GKN Fokker applied its patented butt joint technology to the Gulfstream panel (also to the preceding TAPAS panels). The web and cap of the T or L stringer components, as well as the blade stringer components, are fabricated from preforms that are waterjet-cut from a flat carbon fiber/PEKK laminate. The joining elements (skin to web and web to cap) are injection molded, pi-shaped fillers made from a short-fiber carbon/PEKK material. Both the resin and the carbon fiber type match those in the grid members.

Skin and orthogrid are co-consolidated in an Invar inner mold line (IML) tool. The tool features grooves into which the orthogrid components and tooling blocks are loaded. The AFP-formed skin is then placed on the IML, and the entire assembly is bagged and autoclave-consolidated.

### Welding

The combination of the orthogrid and butt joint design enable fastener-free joining of the orthogrid and frame via welding. Several welding technologies were developed by TAPAS team members during the TAPAS2 phase, including induction, conduction and ultrasonic welding technologies. The Gulfstream panel employed conduction welding to join the frame web to the circumferential blade stringer. This task is performed with the weld head mounted to a robot — another development that contributes to cost-effective manufacturability.

### One step of several

GKN Fokker started its collaboration with Gulfstream in 2017, creating design concepts for the fuselage panel. Design and fabrication of several curved panels followed in 2018 and 2019, with the milestone first panel demonstrator displayed at this year's JEC World.

GKN Fokker is continuing to build panels and expects to achieve TRL4 (component validation) later this year. Pointing out that the panel design does not target a particular platform, Chapman reports that panel testing will help deepen Gulfstream's understanding of material properties and performance. Regarding the broader business case for thermoplastic composite primary structures, Chapman remarks, "We will get a better understanding of those as we get further down the research-and-development road. For now, our focus is on making these complex shapes cost-effectively." CW

**ABOUT THE AUTHOR**

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