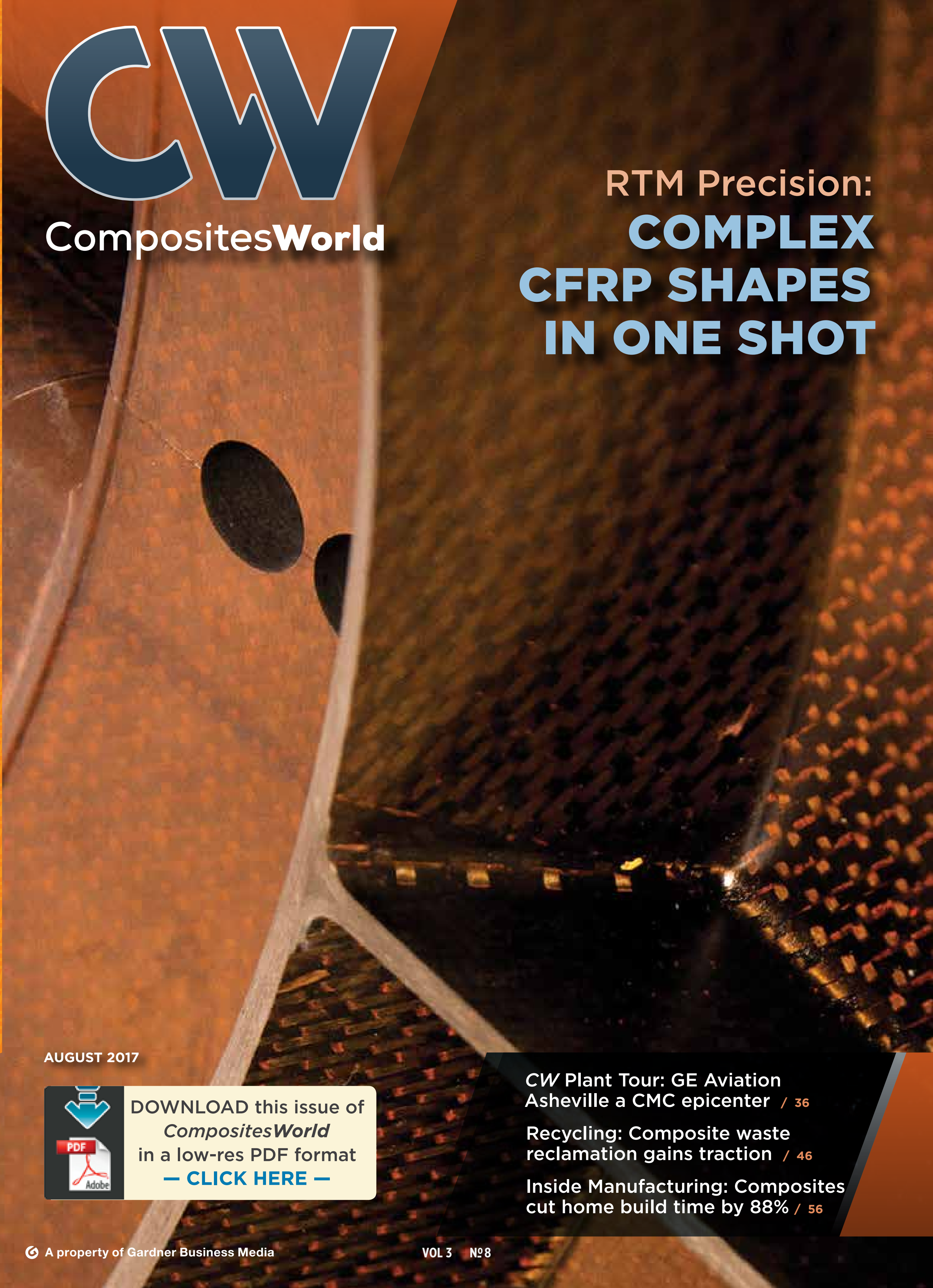
CompositesWorld.com

CW
CompositesWorld



RTM Precision:

COMPLEX CFRP SHAPES IN ONE SHOT

AUGUST 2017

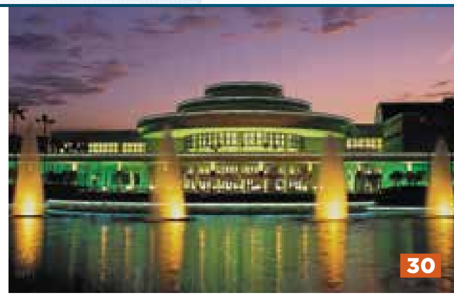
A property of Gardner Business Media

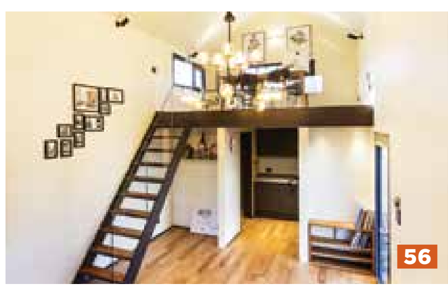
VOL 3 №8

AUGUST 2017 / Vol: 3 №: 8

COLUMNS

DEPARTMENTS





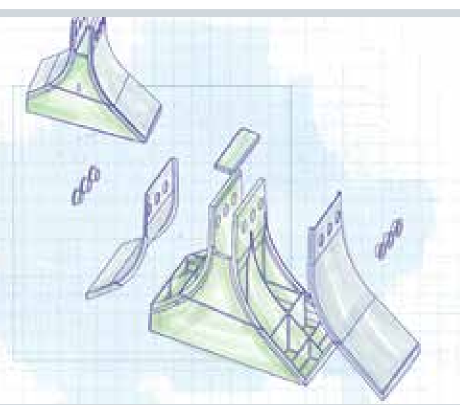
FEATURES

ON THE COVER

This close-up of a high-temperature composite structure molded by Matrix Composites (Rockledge, FL, US) for an aircraft engine shows the complexity and flawless surfaces possible in single-piece moldings, using the company's internally developed resin transfer molding (RTM) process. *CW's* Focus on Design illustrates the difference that capability made at the world's largest wind tunnel facility, on p. 68.

Source / Matrix Composites

FOCUS ON DESIGN



CompositesWorld (ISSN 2376-5232) is published monthly and copyright © 2017 by Gardner Business Media Inc. 6915 Valley Ave., Cincinnati, OH 45244-3029. Telephone: (513) 527-8800. Printed in U.S.A. Periodicals postage paid at Cincinnati, OH and additional mailing offices. All rights reserved. POSTMASTER: Send address changes to *CompositesWorld* Magazine, 6915 Valley Ave., Cincinnati, OH 45244-3029. If undeliverable, send Form 3579. CANADA POST: Canada Returns to be sent to IMEX Global Solutions, PO Box 25542, London, ON N6C 6B2 Canada. Publications Mail Agreement #40612608. The information presented in this edition of *CompositesWorld* is believed to be accurate. In applying recommendations, however, you should exercise care and normal precautions to prevent personal injury and damage to facilities or products. In no case can the authors or the publisher accept responsibility for personal injury or damages which may occur in working with methods and/or materials presented herein, nor can the publisher assume responsibility for the validity of claims or performance of items appearing in editorial presentations or advertisements in this publication. Contact information is provided to enable interested parties to conduct further inquiry into specific products or services.

MEMBERSHIPS:

CW
CompositesWorld

CompositesWorld.com @CompositesWrld

PUBLISHER	Ryan Delahanty rdelahanty@gardnerweb.com
EDITOR-IN-CHIEF	Jeff Sloan jeff@compositesworld.com
MANAGING EDITOR	Mike Musselman mike@compositesworld.com
SENIOR EDITOR	Sara Black sara@compositesworld.com
SENIOR EDITOR	Ginger Gardiner ggardiner@compositesworld.com
DIGITAL MANAGING EDITOR	Heather Caliendo hcaliendo@gardnerweb.com
GRAPHIC DESIGNER	Susan Kraus skraus@gardnerweb.com
MARKETING MANAGER	Kimberly A. Hoodin kim@compositesworld.com

CW CONTRIBUTING WRITERS

Dale Brosius	dale@compositesworld.com
Donna Dawson	donna@compositesworld.com
Michael LeGault	mlegault@compositesworld.com
Peggy Malnati	peggy@compositesworld.com
Karen Mason	kmason@compositesworld.com
Karen Wood	kwood@compositesworld.com

CW SALES GROUP

MIDWESTERN US & INTERNATIONAL	Ryan Mahoney / DISTRICT MANAGER rmahoney@compositesworld.com
EASTERN US SALES OFFICE	Barbara Businger / DISTRICT MANAGER barb@compositesworld.com
MOUNTAIN, SOUTHWEST & WESTERN US SALES OFFICE	Rick Brandt / DISTRICT MANAGER rbrandt@gardnerweb.com
EUROPEAN SALES OFFICE	Eddie Kania / EUROPEAN SALES MGR. ekania@btopenworld.com

COMPOSITESWORLD IS A PROPERTY OF

GARDNER
Business Media, Inc.

HEADQUARTERS
6915 Valley Ave., Cincinnati, OH 45244-3029
Phone 513-527-8800 Fax 513-527-8801
gardnerweb.com
subscribe@compositesworld.com

CEO	Rick Kline, CBC
COO	Melissa Kline Skavlem
PRESIDENT	Rick Kline, Jr.
DIRECTOR OF CUSTOM CONTENT	Tom Beard
DIRECTOR OF MARKET INTELLIGENCE	Steve Kline, Jr.
TREASURER	Ernie Brubaker
CHIEF TECHNOLOGY OFFICER	Phil Louis
ADVERTISING MANAGER	Bill Caldwell
DIRECTOR OF EDITORIAL OPERATIONS	Kate Hand
DIRECTOR OF MARKETING AND EVENTS	Dave Necessary
CREATIVE DEPARTMENT MANAGER	Rhonda Weaver
CREATIVE DIRECTOR	Jeff Norgord
ADVERTISING PRODUCTION MANAGER	Becky Helton

GARDNER BUSINESS MEDIA ALSO PUBLISHES

Modern Machine Shop
Moldmaking Technology
Plastics Technology
Automotive Design & Production
Production Machining
Products Finishing
Additive Manufacturing

Redefining Structural Materials

The world continues advancing and requires lighter and stronger structures. Hexcel answers those demands with innovative technologies and better production capabilities to support the growth of the composites industry. Hexcel is the market's most integrated composite solutions provider. We are experienced at all stages in the composites chain, from fiber to fabrics and resin formulation to thermosetting prepregs, new solutions for out-of-autoclave processing, molding materials, composite tooling, honeycomb and machined core.

Learn more by visiting us at
CAMX 2017 in Orlando, FL, September 12-14 in booth F18

HEXCEL®

» *CW Talks: The Composites Podcast* is up and running. If you have not yet listened in, you can give it a try at www.compositesworld.com/podcast, or via iTunes and Google Play. We have recorded seven episodes, thus far, talking to a variety of people who represent a variety of interests in the composites industry. Our discussions have ranged widely, covering many topics, depending on the interviewee's background and composites expertise.

> *CW Talks* is "on" and already proving to be well worth a listen.

I was, therefore, somewhat surprised, recently, when three *CW Talks* interviewees brought up the same subject in response to my question about challenges facing the composites industry and how they might be addressed. The challenge each mentioned? The need for standardization in composites manufacturing.

Notably, the three in question represent diverse industry segments: Greg Mark, founder and CEO of 3D printer manufacturer Markforged; James Austin, CEO of technical fabrics manufacturer North Thin Ply Technology (NTPT); and Frazer Barnes, managing director of carbon fiber recycler ELG Carbon Fibre.

Before I tell you what they said, a little background about standardization. If you know even a little bit about composite materials, you know that they are famous for their ability to provide engineered solutions to many manufacturing challenges. This is thanks primarily to the many combinations of resins, fibers, tooling, and manufacturing processes available. The bespoke nature of these engineered solutions is a blessing and a curse — a blessing because of composite materials' high adaptability, and a curse because of the extreme complexity that results, making it difficult for non-composites engineers and designers to understand and use the material effectively. In fact, materials standardization, it is argued, would help reduce that complexity and make adoption of composite materials easier and quicker.

This idea was first raised in my *CW Talks* conversations by Mark (Markforged), who described market reaction when he first introduced the Mark One, his 3D printer that applies continuous carbon fiber reinforcement in a thermoplastic resin matrix. Discussions about the Mark One revolved around the anisotropic nature of the material, which Mark says was readily understood and appreciated by a vast majority of attendees at the composites tradeshows where Markforged exhibited. But at noncomposites tradeshows, Mark says many engineers he spoke to, although they understood the words he was saying, could not wrap their minds around anisotropic material properties. As a result, they had difficulty immediately understanding the benefit or application of a 3D printer that applies continuous carbon fiber reinforcements. Which means, in essence, they had difficulty understanding composites.

For Austin (NTPT) and Barnes (ELG), their calls for standardization grew out of a simple question: What's required of the composites industry to help speed maturation and adoption? Austin lists innovation and cost as his top two challenges, but follows with this: "A piece of the industry that is still missing is a standardization of materials. And I think half the industry is with me on that and half the industry is not with me." Austin notes that metallic alloys are already standardized, which makes them easy to specify. And although composite materials might not be standardizable in the same way, they can be standardized in *some* way. He says, "Whilst the world is not overburdened with highly refined and skilled composite engineers, the rate of uptake is, I think, limited . . . and stardardization is one way through that."

For Barnes, material standardization would be at the top of his to-do list, were he named CEO of the composites industry for a year, and he also draws a correlation with cost: "Every material we treat as an individual material. We don't have standard grades . . . and that brings a lot of cost in initial evaluation and characterzation." And then, echoing Mark and Austin, he says, "We need to make this material easier to use by people who may not be composites experts."

This last point is a difficult one against which to argue, particularly for an industry starved of engineering talent. Standardization, perhaps, deserves serious consideration.

JEFF SLOAN — Editor-In-Chief

An autonomous future for composites?

» In July of 2013, the title of this column was "The future of aerial combat" (short.compositesworld.com/R87MQrP2). At the time, I postulated that the F-35 would be the last manned fighter aircraft developed by the US, and that future versions will be unmanned, perhaps piloted (or guided) remotely by ground-based operators, out of harm's way. I still believe that will be the case, and earlier in 2017, the US Air Force demonstrated autonomous combat capabilities with specially outfitted F-16 aircraft, complementing other developments in this area.

In parallel, there have been numerous developments in autonomous vehicles for ground transportation. Many are familiar with the self-driving technology recently introduced by Tesla (Palo Alto, CA, US), a major step toward true autonomous operation. The physical driver has not been eliminated, but for much of the trip, the operator can let the vehicle steer, accelerate and brake toward the destination. Google has been testing driverless cars, and ride-share company Uber conducted similar tests in Pittsburgh, San Francisco and Phoenix earlier this year, with mixed results (some accidents were caused by human drivers of other cars). Several companies are already testing driverless semi-trucks, and France's SNCF has announced plans to test autonomous trains on its famous TGV lines sometime in 2019. Although there are still many issues yet to be resolved, autonomous transportation is coming, whether we like it or not.

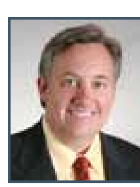
> Autonomous transportation is coming, whether we like it or not. Composites should play a significant role.

Last year, ride-share operator Lyft predicted that a majority of its trips will be self-driving by 2021 and, recently, that it will provide more than 1 billion rides per year using autonomous electric vehicles by 2025. I see real opportunity for autonomous taxi services, especially for children and senior citizens, given that the former are not licensed to drive and the latter could benefit from not having to drive, when eyesight or other physical abilities are impaired. Today, one can use a phone app, such as those provided by Uber or Lyft, to request a vehicle to transport children to or from music practice, as well as to after-school jobs, without inconveniencing a parent. Similarly, a senior citizen can use the service to see their physician, go shopping or attend a social event with friends or family. While convenient, today's fleet of driver-owned vehicles is somewhat expensive for "everyday" trips, and a fleet of custom-designed, autonomous electric vehicles could perform such services more economically. How? Look at battery costs. According to a 2017 report from Benchmark Minerals (London, UK), costs of lithium-ion batteries have dropped from US$542 per kw-hr in 2012 to US$139/kw-hr today, and are expected to fall below $100/kw-hr by 2020. Based on this, *Bloomberg* sees the costs of battery-electric vehicles equaling gasoline-powered cars by 2025.

What role might composites play in this autonomous future? First, unless battery chemistry changes, there is not much room for improvements in power density for lithium-ion technology. Even if batteries become "cheap as chips," they will still be heavy, creating lightweighting opportunities for composites to extend driving range. Second, in autonomous electric vehicles, power source storage in the floor and the lack of a driver expands the interior design space. Passengers could sit facing each other, and cars could travel bidirectionally. Vehicles might feature multiple entertainment options, or screens that allow a student to log on, using biometric data, and work on her homework on the way to or from soccer practice. Composites here offer styling improvements metals can't: soft-to-the-touch appearance and the ability to create a modern "feel."

What about crash energy management and repair, which are oft-cited drawbacks to composites in automobiles? Autonomous vehicles eventually will be equipped with extensive sensors that enable them to maintain appropriate distance from other vehicles, and they'll have crash avoidance technology, making impacts and repairs significantly less frequent. However, driverless cars cannot control the actions of human drivers in conventional vehicles, so autonomous vehicles will need, at least for a decade or more, to be built to withstand crash situations, partially through structure, and with *predictive* passenger protection, such as airbags that inflate before impact, rather than after. Such technologies are already being deployed on many conventional cars to automatically brake or steer clear for increasingly distracted human drivers.

Autonomous local passenger transport may not be limited to the ground. Airbus has released a video demonstrating how a pilotless "flying taxi," using vertical takeoff and landing (VTOL) technology, could supplant intermediate-distance commutes, hinting at a prototype by the end of 2017. No doubt these flying machines will be composites-intensive. It seems the future is autonomous travel, and composites should play a big role, on the ground and in the air. CW



ABOUT THE AUTHOR

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


PRODUCTION
CHALLENGES?
Bring us yours.
29. GEL COAT PRE-RELEASE
30. CLEANING NEEDS
31. TRANSFER
32. POOR FLOW
33. ABRASION

Choosing the most suitable methods for composites testing

» When first introduced to mechanical testing of composite materials, one can be confused, even overwhelmed, by the number of available test standards. One reason for this large variety of tests is the number of stiffness and strength properties that must be determined. Material properties for a unidirectional fiber-reinforced composite (Fig. 1) might not only be required in the fiber direction (1), but also the transverse direction (2) and possibly the out-of-plane direction (3). Similarly, shear properties might be required in the in-plane (1-2) orientation as well as two interlaminar (1-3 and 2-3) orientations. Adding to the list of properties, tension and compression strengths are usually different and are determined by performing separate tests.

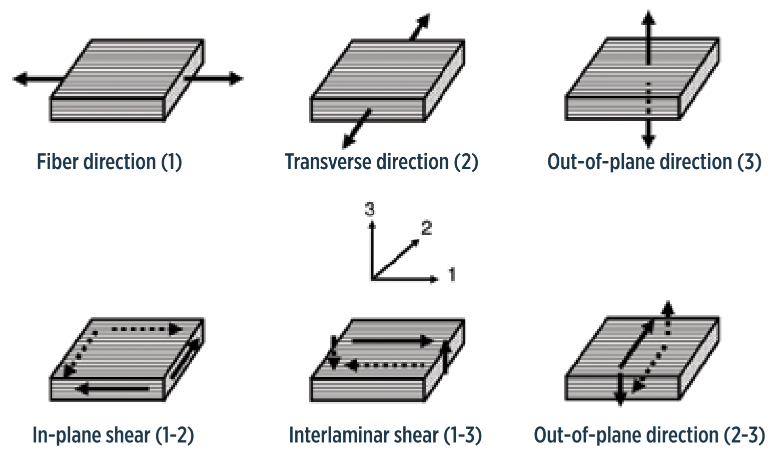


FIG 1 Loading orientations for material property testing in unidirectional composites. Source | Dan Adams

Further complicating matters, there are multiple standardized tests available for determining each of these material properties. Differences between tests include the size and shape of the test specimen, the manner in which the load is applied to the specimen, and the procedure followed when performing the test. Compression and shear testing of unidirectional composites provide good examples of these differences.

For compression testing of composites in the fiber direction, commonly used standardized tests exist that introduce the compression load into the specimen through either shear loading of the specimen faces (ASTM D 3410[1]), compression loading of the specimen ends (SACMA SRM[2]) or a combination of shear and compression loading (ASTM D 6641[3]). When performed properly, all three load-introduction methods are capable of producing the same stiffness and strength properties. In the case of in-plane shear testing, standardized tests exhibit more fundamental differences. The most-used in-plane shear test methods are the ±45° tension shear test (ASTM D 3518[4]) and the V-notched shear tests (ASTM D 5379[5] and D 7078[6]). In the ±45° tension shear test, tensile loading of a composite laminate fabricated from ±45° layers produces the desired shear stresses in the 1-2 orientation of each layer (Fig. 2). In contrast, shear stress is produced in V-notched shear specimens through either edge loading (ASTM D 5379) or face loading (ASTM D 7078) as shown in Fig. 2. Despite big differences in specimens and loading methods, all three shear test methods can be used to generate in-plane shear modulus and shear strength of composite materials.

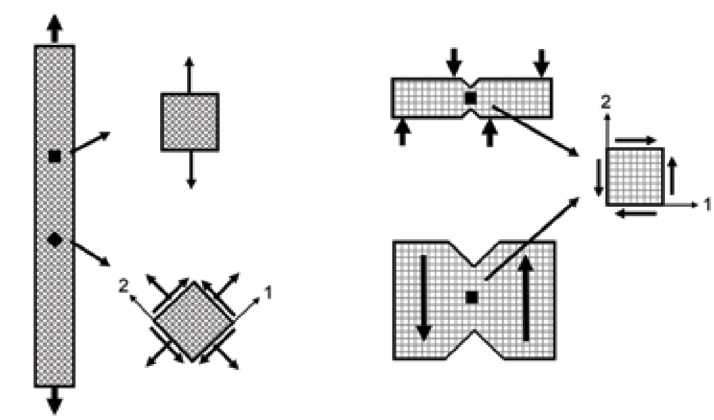


FIG 2 Commonly used in-plane shear test methods for composites: On the left: ±45° tension shear test (ASTM D 3518). On the right: V-notched shear tests (ASTM D 5379 and D 7078). Source | Dan Adams

In addition to mechanical tests used to determine material properties of composite materials, additional testing is typically performed to obtain structural properties associated with multidirectional composite laminates. Similar to the material property tests described above, multiple standardized test methods exist for each type of structural test. However, additional complications arise when selecting a test method based on differences in the intended use for the test results.

For example, consider the variety of bearing test methods commonly used for composites testing and summarized in my July 2016 column (short.compositesworld.com/DTJuly16). For material comparisons, the relatively simple double-shear configuration with a hardened pin and loaded in tension is commonly used. When testing to represent an intended use, however, bearing testing may »

feature the specific fastener, countersinking and bolt torque to be used along with a representative joint configuration and loading.

So how does one go about selecting the most suitable test method for a particular type of test? The initial step includes identifying the available standardized test methods and understanding the important differences between them. For standardized test methods published by ASTM International, a useful guide to the various composite test methods is available in ASTM D 4762[7]. The 108 ASTM test methods summarized in the guide are arranged into six test categories:

- Lamina/Laminate Static Properties
- Lamina/Laminate Dynamic Properties
- Laminate/Structural Response
- Sandwich Constructions
- Constituent/Precursor/Thermophysical Properties
- Environmental Conditioning/Resistance

For each test category, a table is presented listing the associated ASTM standardized test methods, along with a summary of the specimen configuration, the measured properties, a brief test description, advantages and disadvantages of the test and other comments. Although the table entries are relatively brief, they provide useful overviews and comparisons of the standardized test methods.

> An initial step in selecting suitable test methods involves consulting the available test literature.

A significantly more detailed source of information for standardized tests is the *Composite Materials Handbook*[8], commonly referred to as *CMH-17*. Volume 1 of the *Handbook*, titled, "Polymer Matrix Composites Guidelines for Characterization of Structural Materials," includes detailed discussions on a variety of composite test methods. Of particular interest are Chapter 6 ("Lamina, Laminate, and Special Form Characterization") and Chapter 7 ("Structural Element Characterization"). Although a majority of the test methods discussed in *CMH-17* are ASTM standards, other commonly used test methods are reviewed, including those published by the former Suppliers of Advanced Composite Materials Assn. (SACMA).

Having identified candidate standardized test methods and developed an understanding of their capabilities, the final selection of the test method most suitable for a particular situation typically is based on a variety of considerations:

- The composite material to be tested, including the type of constituents (fiber and matrix) and the material form (continuous or discontinuous fiber, unidirectional, random mat, woven, etc.). »

NOT JUST VERSATILITY. OMAX VERSATILITY.

OMAX abrasive waterjets can cut a wide range of materials and do more thanks to advanced technology and accessories.

PLASTIC-CARBON FIBER-COPPER-STEEL
GLASS-COMPOSITE-GRANITE-TITANIUM

Get the whole story at omax.com/versatility

OMAX®
ADVANCED WATERJET SYSTEMS

- The material or structural properties desired — stiffness properties strength properties, or both.
- The time, equipment and expertise required to perform the test.

Perhaps the most important consideration, however, is the intended use of the test results. When intended for use in quality control or for comparative testing of candidate materials, the simplicity of the test method and its ability to identify material variations are important considerations.

However, when test results are intended for use in material databases or for structural design and analysis, the stress state produced in the test specimen and the production of the desired failure mode(s) are of primary importance. Further, test method consistency is an important consideration for all intended uses and, therefore, one must consider what methods and procedures were used in previous testing. As a result of these considerations, different standardized tests may be deemed most suitable when used for different purposes. CW

REFERENCES

[1] ASTM D 3410/D 3410M-16, "Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by Shear Loading," ASTM International (W. Conshohocken, PA, US), 2016 (first issued in 1975).

[2] SACMA Recommended Method SRM 1R-94, "Compressive Properties of Oriented Fiber-Resin Composites," SACMA (Arlington, VA, US), 1994.

[3] ASTM D 6641/D 6641M-16, "Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials Using a Combined Loading Compression (CLC) Test Fixture," ASTM International (W. Conshohocken, PA, US), 2016 (first issued in 2001).

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

[5] ASTM D 5379/D 5379 M-12, "Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method," ASTM International (W. Conshohocken, PA, US), 2012 (first issued in 1993).

[6] ASTM D 7078/D 7078 M-12, "Standard Test Method for Shear Properties of Composite Materials by the V-Notched Rail Shear Method," ASTM International (W. Conshohocken, PA, US), 2012 (first issued in 2005).

[7] ASTM D 4762-16, "Standard Guide for Testing Polymer Matrix Composite Materials," ASTM International (W. Conshohocken, PA, US), 2016 (first issued in 1988).

[8] *Composite Materials Handbook* (*CMH-17*), Volume 1: "Polymer Matrix Composites: Guidelines for Characterization of Structural Materials," Composite Materials Handbook 17 Organization (Wichita, KS, US), Rev. G, published 2012.

ABOUT THE AUTHOR

Dr. Daniel O. Adams is a professor of mechanical engineering and has been the director for 20 years of the Composite Mechanics Laboratory at the University of Utah and vice president of Wyoming Test Fixtures Inc. (Salt Lake City, UT, US). He holds a BS in mechanical engineering and an MS and Ph.D in engineering mechanics. Adams has a combined 37 years of academic/industry experience in the composite materials field. He has published more than 120 technical papers, presents seminars and chairs both the Research and Mechanics Divisions of ASTM Committee D30 on Composite Materials and the Testing Committee of the *Composite Materials Handbook (CMH-17)*. He regularly provides testing seminars and consulting services to the composites industry.

WISCONSIN OVEN

Your Composite Curing Oven Specialists

Interior Supply and Return Ducts with Interior Lighting

Interior Thermocouple Jack Panel & Vacuum Stubs

Pressure Transducer Monitoring Lines and Data Acquisition Control System

Vacuum Lines for Composite Bag Applications

Vacuum Piping System w/ Pressure Transducer & Thermocouple Jack Panel

American Composites Manufacturers Association

2675 Main Street • PO Box 873 • East Troy, WI 53120 USA
www.wisoven.com • sales@wisoven.com • 262-642-3938

TPS™ Thermal Product Solutions

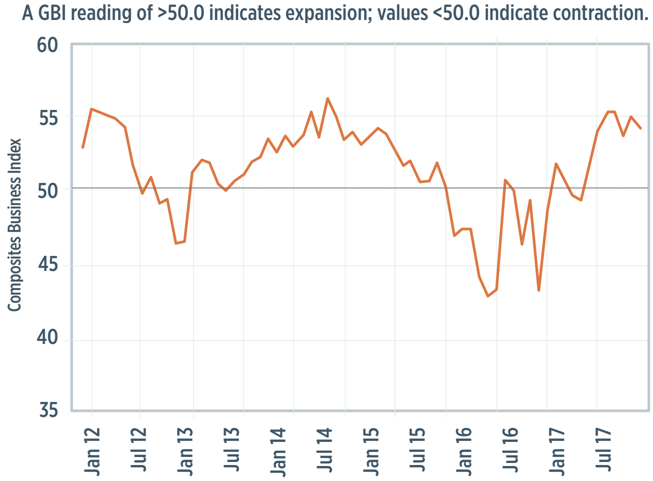
Wisconsin Oven is a brand of Thermal Product Solutions, LLC

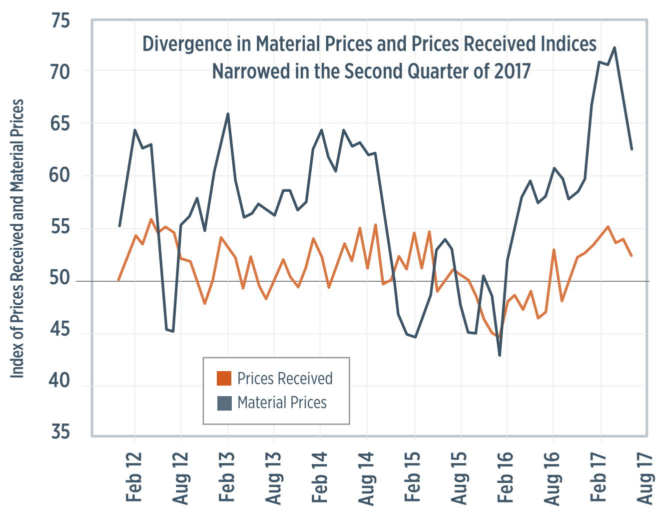
June 2017 — 54.2

The Index is up from the same period in 2016 and subject to less volatility.

» Overall, the US composites industry continued to expand in June (54.2), but did so at a slightly slower rate than it did in May. That's the story told by the numbers recorded in the Gardner Business Intelligence Composites Business Index. In addition to the significant improvement seen over the past 12 months, the behavior of the Composites index in 2017 also has been far less volatile than in the past. When a three-month moving average is used to help smooth out the volatility experienced in 2016, it can be seen that the Index has increased by 17%, moving from a three-month (April-June) average of 46.4 in 2016 to 54.3 for the current April-June average. Since the beginning of the year, all Composites Index components have signaled expansion except Exports, which in the year-to-date period has signaled either small decreases or no change. For the current month, the Index was supported by growth in Backlogs, Supplier Deliveries and Production while the subindices for New Orders and Exports moved lower.

A GBI reading of >50.0 indicates expansion; values <50.0 indicate contraction.





Index components continue to move favorably

During the first half of 2017, the total Composites Index benefited from growth in Production, Supplier Deliveries and New Orders. Each of these Index components have posted values in 2017 that compare favorably to their cyclical highs from 2014. The Backlog and Export components of the Composites Index which lost their footing beginning in mid-2014 before moderating and improving in 2016, made further gains during the first half of 2017. For the first time in more than five years, Backlogs have registered five consecutive months of growth or steadiness (readings at or above 50). Year-to-date Export readings also have continued to show improvement compared to the same six-month period in the past three years.

End-market demand for composites has generally grown for much of the past five years as more composite products find their way into aerospace and automotive industry applications. Less known is that the marine industry experienced substantial growth in 2016 across many of its watercraft categories. Unit sales of new watercraft in a variety of categories increased between 6% and 11.5% during 2016. The 2017 and 2018 sales forecast released by the National Marine Manufacturers Assn. (NMMA, Chicago, IL, US) in May 2017 predicts that sales growth over the next two years will be comparable to that of 2016. The Gardner Business Intelligence team will continue to monitor this development and assess its impact on composites fabricators and their suppliers.

Pricing divergence: closing a gap

A significant gap between the Index values for Material Prices and Prices Received, a trend first witnessed in early 2016, was reduced in the second quarter of 2017 as the subindex for Material Prices fell from a high of 72.0 in April to 62.4 in June. During the same months, the subindex for Prices Received changed only slightly, moving from 53.5 in April to 52.3 in June. CW

ABOUT THE AUTHOR

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

With the contrails of the Paris Air Show behind and SPE's Automotive Composite Conference in the headlights, innovation is the underlying theme in every headline.

AEROSPACE

2017 Paris Air Show an aerocomposites showcase


Source | The Boeing Co.

The event's 52nd edition, this year's Paris Air Show (June 19-25, Paris-Le Bourget Airport, France) delivered a wealth of composites industry-related announcements, including new aircraft and material innovations. On the event's first day, June 19, The Boeing Co. (Chicago, IL, US) announced the launch of the 737MAX 10 (photo at right). The newest member of the 737MAX family, it is 66 inches (168 mm) longer than the MAX 9 and, according to Boeing, not only provides the lowest seat-mile cost of any single-aisle airplane ever produced but has already gained wide market acceptance, attracting more than 240 orders and commitments secured from more than 10 customers worldwide. Customers' order details were announced throughout the week, including CDB Aviation Lease Finance's (CDB Aviation) signing of a Memorandum of Understanding (MoU) for 52 737s and eight 787-9 *Dreamliners*, a commitment valued at US$7.4 billion at list prices.

Regarding Boeing's big news — its projected New Midsize Airplane, still many years away — the company did confirm to *Aviation Week's ShowNews* that the new craft will feature composite wings *and* a composite fuselage. According to the published story, the fuselage will be distinguished by a "hybrid" composite with an "unusual" cross-sectional shape — specifically, not the conventional circular or ovoid shapes.

Meanwhile, Airbus announced that it had completed a developmental study for an enhanced version of its big A380, the A380*plus*, which will include larger winglets and other wing enhancements that will ensure more economical fuel burn. The company claims that the changes will provide a 13% reduction in the overall cost per seat, compared to the current A380. Also announced on the show's first day was that GE Capital Aviation Services (GECAS), the commercial aircraft leasing and financing arm of General Electric, had signed a firm order for 100 A320*neo* aircraft. GECAS selected CFM's LEAP-1A engine for all the planes in that order.

Solvay (Brussels, Belgium), which includes Solvay Composite Materials (Alpharetta, GA, US), and GKN Aerospace's (Redditch, UK) Fokker business (Papendrecht, The Netherlands), announced that the companies have teamed up to promote and accelerate the adoption of thermoplastic composite (TPC) materials on aircraft. Solvay will become a preferred supplier of innovative, lightweight TPC materials to Fokker. Under the agreement, Solvay and GKN Aerospace's Fokker business will collaborate in efforts to advance technological developments in TPCs, as well as improve processes and process cost-competitiveness. The businesses reportedly have complementary materials expertise in thermoplastic polymers and fiber-reinforced composites. GKN Aerospace's Fokker business also brings leadership in component design and manufacturing, to translate the technology into innovative solutions for aerospace customers.

"Solvay's partnership with GKN Aerospace's Fokker business is an important step in our goal to become the leading supplier of thermoplastic composite materials to the aerospace, oil and gas, and automotive industries. A deeper understanding of the market's needs and challenges in adopting these new materials, together with Fokker's expertise in design and manufacturing, will enable us to develop technologies to industrialize the manufacturing of thermoplastic composites and parts," says Carmelo Lo Faro, president of Solvay's Composite Materials Global Business Unit.

The F-35 *Lightning II* made its first appearance at a Paris Air Show. A subsequent aerial flight demonstration was designed to silence critics and disprove what Lockheed Martin's (Bethesda, MD, US) test pilot Billie Flynn called "years of misinformation" about the plane's capabilities.

Lockheed Martin executive Jeff Babione told the press at Le Bourget that his company is close to a deal worth nearly US$40 billion to supply additional F-35s to the US and its allies during the next several years. If that deal goes through, it would *more than double* the total number of F-35s currently under contract.

In another first, Mitsubishi Aircraft Corp.'s (Nagoya, Japan) *Mitsuibishi Regional Jet* (*MRJ*) was on static display. Its sharply pointed, aerodynamic nose was attracting attention after the single-aisle, targeted (obviously) at air carrier's regional routes, completed its first trip to Europe from the company's flight test center, located in Moses Lake, WA, US. Equipped with Pratt & Whitney (East Hartford, CN, US) geared turbofan engines, the aircraft has accomplished many of its scheduled testing milestones on the way to full certification. The company says the *MRJ* uses 20% less fuel than competitors, thanks to its aero design and the P&W engines. First delivery is scheduled for mid-2020.

Airbus Helicopters (Marignane, France) announced that autonomous flight trials of its *VSR700* Optionally Piloted Vehicle (OPV) demonstrator have begun, with a safety pilot on board, paving the way for a first flight of the actual *VSR700* prototype in 2018. Developed as a light military rotary wing tactical unmanned aerial vehicle (UAV) with a low-fuel-consumption diesel engine, the craft is a joint development of Airbus Helicopters and Helicopteres Guimbal (Aix-in-Provence, France), the original manufacturer of the civil *Cabri G2*, from which the *VSR700* is derived. Airbus says the autonomous rotorcraft was developed to meet naval requirements for cost-effective shipborne tactical aerial surveillance and reconnaissance.

Source | Airbus

Another autonomous helicopter debut came from Workhorse Group Inc. (Loveland, OH, US), maker of the *HorseFly* package delivery drone that has been tested by United Parcel Service (UPS). The larger *SureFly* helicopter concept is designed for short hops, aimed at commercial transportation, emergency responders, the military and even city commuters. Called a "personal helicopter/VTOL aircraft" by Workhorse, *SureFly* is a two-seater, capable of vertical take-off and landing, and equipped with a hybrid-electric drive, designed to be *(continued on page 18)*

(continued from p. 17)

safer and more stable than typical helicopters, thanks to its redundant design. Its four arms atop the cabin are each equipped with two contra-rotating propellers powered by electric motors. A backup battery system can drive the motors in the event its gas combustion engine fails; in an emergency, a ballistic parachute can be deployed. It is designed to be easy to pilot, and is capable of carrying pilot and passenger or cargo up to 70 miles. Early models will be pilot-operated, says Workhorse, with flight tests scheduled for this year, but the goal is to eventually introduce autonomous versions capable of carrying payloads up to 182 kg. The fuselage, propeller arms and propellers themselves are fabricated from carbon fiber composites.

A new all-electric, all-composite-airframed aircraft (photo, top right) from startup EViation (Kadima Zoran, Israel) made its first appearance in Paris. Company founder Omer Bar-Yohai claimed, "Transportation as we know it is set to change. The dominant solutions available today are deeply flawed and demand disruption." EViation believes it can offer a corrective in high-speed, sustainable and convenient regional commuting, using light aircraft, tightly integrated with on-demand ground transport solutions. Currently, a subscale prototype is undergoing testing and risk-reduction evaluations. The company expects its first firm orders from its lead customer next year, says Bar-Yohai.

Three designs are in development. *Alice*, able to carry nine passengers, will be optimized as an air taxi, with a proposed sale price of US$1.4 million. *Alice ER* is a six-passenger, pressurized luxury version positioned to compete with existing business jets. *Orca* is an unmanned variant, with very-short-takeoff-and-landing (VSTOL) characteristics and long-duration capability. The aircraft's all-composite airframe design and efficient aerodynamics, combined with compact energy storage, using high-energy-density batteries, will be built to fit into the regulatory environment, says Bar-Yohai, including the US Federal Aviation Admin. (FAA) electric aviation committees: "With this aircraft, air taxi operators will be able to give customers on-demand travel [to] the nearest landing strip for the price of a train ticket." EViation partnered with established manufacturers for production and certification risk sharing, including Magnaghi Aeronautica SpA (Napoli, Italy), the manufacturer of the SkyAero aircraft, and FBM Composite Materials Ltd. (Kiryat Gat, Israel), a producer of carbon-based composites, which manufactured the prototypes.

Source | EViation

Textron Systems (Providence, RI, US) unveiled a new tactical unmanned aircraft system (UAS) called *NightWarden*, which builds upon and improves the company's developmental *Shadow M2* UAS, says Textron. With a range of 1,100 km and 15 hours of endurance, the new UAS has a payload capacity of up to 59 kg and can be configured in multiple ways, including carrying munitions.

MTorres (Torres de Elorz, Navarra, Spain) exhibited its revolutionary new composite fuselage and wing manufacturing concept (see *CW's* report on it at **short.compositesworld.com/NuFuselage**). The concept appears to involve production of C-frames or ring frames in a separate process, with frames held together to create an outer mold line (OML) surface, over which the fuselage skin is fiber placed, using MTorres' fiber placement head and dry carbon fiber tape. The assembled frames are reportedly integrated into the fuselage. The structure is then infused, says MTorres, and oven-cured. The company says that the "final phase" of the material used in production, possibly the dry tape itself, is made by MTorres, which could reduce raw material cost by up to 50%, according to published reports. By eliminating rivets, fuselage weight can be reduced by 10-30%, said MTorres before the show, and tooling costs as well as labor costs would be significantly reduced. Press reports from Spain quote MTorres as saying that 6,000 hours of work were saved with this new fabrication concept, compared to existing methods.

CORRECTION

In *CW*'s January 2017 article, titled "Size-unlimited OOA composite process enables next-gen launch system" (short.compositesworld.com/VulcanOOA), credit for work on the robotic systems used by Ruag Space (Zurich, Switzerland) for inspection of its OOA manufacture of payload fairings that were the subject of the article was mistakenly given to Robot Technology GmbH (Grossostheim, Germany). However, when Ruag purchased its NDI system from Eugen Ostertag Automation (Gruibingen, Germany), it was, instead, **Robo-Technology** (Puchheim, Germany) that acted as the subcontractor, working closely with Ostertag on its deliverables to Ruag.

Notably, Robo-Technology was responsible for overall project management, the design and implementation of the complete software and control system, and delivered two robots (acquired from Stäubli Tec-Systems GmbH in Bayreuth, Germany), after first replacing the original aluminum arms on those robots with arms of CFRP to extend their reach.

Our apologies to Robo-Technology. *CW* regrets the error.

AUTOMOTIVE

Society of Plastics Engineers ACCE 2017


Source | Pam & Mike Brady for Society of Plastics Engineers

The Society of Plastics Engineers' (SPE, Bethel, CT, US) long-running Automotive Composites Conference & Exhibition (ACCE) continues to draw a global crowd. It returns to the Detroit suburbs for the 17th time on Sept. 6-8. This year, a scheduling issue required that the Composites & Advanced Materials Expo (CAMX), typically held later in the fall, take place, instead, the week immediately following ACCE. Although the unfortunate timing likely will hurt both events in terms of sponsors/exhibitors, presentations and attendance, CAMX organizers — the Society for the Advancement of Material & Process Engineering (SAMPE, Diamond Bar, CA, US) and the American Composites Manufacturers Assn. (ACMA, Arlington, VA, US) — say it couldn't be helped. Regardless, the ACCE team, made up largely of volunteers from the Society's Automotive and Composites Divisions, has been hard at work organizing this year's conference.

With a mandate to educate the global transportation-composites supply chain on the latest developments in polymer-based composite materials, processes, machinery and applications, ACCE typically draws nearly 1,000 attendees from the Americas, Europe and Asia. Owing to its Motor City location and the fact that entry fees are waived for transportation OEMs, the event boasts an enviable number of attendees who work directly for automotive, commercial truck, agricultural equipment, off-highway and aircraft manufacturers, making it a perennial favorite for suppliers who target these markets.

Organizers schedule numerous breaks between technical programming for booth visits, and offer evening receptions to facilitate networking and discussion by members of the entire transportation-composites supply chain.

Pre-event social outings on Sept. 5 will be built around a day-long golf outing at Fieldstone Golf Club (Auburn Hills, MI, US) and a tour of the Institute for Advanced Composite Manufacturing Innovation's (IACMI, Knoxville, TN) newly opened facility in Detroit's Corktown neighborhood.

At *CW* press time, the three-day event had booked almost 80 presentations on the final program. These will be scheduled in 11 sessions, under the *(continued on p. 22)*

(continued from p. 21)

headings listed below, split into three technical tracks:
- Additive manufacturing and 3D printing.
- Advances in reinforcement technologies.
- Advances in thermoplastic composites.
- Advances in thermoset composites.
- Business trends and technology solutions.
- Bonding, joining and finishing.
- Enabling technologies (process/machinery).
- Nanocomposites.
- Opportunities and challenges with carbon composites.
- Sustainable composites (recycled, bio-based and natural fiber-reinforced).
- Virtual prototyping and testing.

Keynote speakers are slated from Ford Motor Co. (Dearborn, MI, US), the University of Maine's Advanced Structures and Composites Center (Orono, ME, US) and IACMI. In addition, attendees will have the opportunity to sit in on one of the lively panel discussions for which the ACCE is known.

SPE's educational focus will be exemplified in its Best Paper awards and student scholarships (both presented during opening ceremonies), plus student posters and best composite parts awards (presented, respectively, after lunch on Day 2 and during closing ceremonies).

Learn more at **speautomotive.com/acce-conference**.

View 16 years of ACCE proceedings free at **www.temp.speautomotive.com/aca.htm.**

AEROSPACE

Carbures beats 2016 aerospace production record


Source | Carbure

Spanish Tier 2 composites producer Carbures (El Puerto de Santa Maria, Spain) announced recently that it has reached an historical record for production of composite aircraft parts, with 45,695 parts produced at its plants in Illescas and Jerez de la Frontera in Spain. This production volume was an increase of 16.2% compared to the 39,322 parts manufactured in 2015.

Carbures, the subject of a previous *CW* Plant Tour (see endnote) manufactures structural parts for Airbus (Toulouse, France) models A320, A320*neo*, A330, A340, A350, A380, among other commercial aircraft, and for the A400M, A330MRTT and C295, for military use. The parts manufactured by Carbures for these models are diverse and range in size from a few centimeters to more than 4m in length. Some examples include the engine oil cap, beams and panels, omegas for fans cowls and aircraft nose parts.

Although the Illescas facility has the highest production rate in absolute terms, Carbures' factory at Jerez de la Frontera has seen its production increased from 6,478 manufactured parts in 2015 to 9,328 in 2016, a 44% increase in one year. This is due to Carbures' rate ramp-up for its manufacturing programs by 25% in 2016. The facility, which opened in 2013, has a total footprint of 15,000m^2, of which 7,800m^2 belong to the factory floor, and has reached 70% of its productive capacity in only three years. More growth is expected this year to accommodate work for new Airbus models as

(continued on p. 24)

(continued from p. 23)

well as those of other Tier 1 manufacturers, which are increasingly incorporating lighter materials to decrease plane weight/fuel use, says Carbures executive president Rafael Contreras: "Carbures continues to be very strong in the aeronautics sector. We have more than 15 years of experience in aeronautics, which is where the company was born, and we continue working to give greater quality to our customers."

Company sites in Illescas, Jerez, El Puerto de Santa María and the engineering facilities in Seville have passed quality audits imposed by the aeronautic and defense sector during 2016, including Nadcap Composite AC7118, Nadcap NDT AC7114, Nadcap Laboratory AC7122, UNE-EN 9100: 2010, ISO 9001:2008, ISO 14001:2004, OSHAS 18001:2007). From its experience in the aeronautic sector, the company also continues to produce carbon fiber parts for the automotive sector, through its Carbures Mobility division.

Read *CW's* Carbures Plant Tour | short.compositesworld.com/Carbures

BIZ BRIEF

METYX Composites has relocated its headquarters team to new offices in Kozyatağı, in the heart of Istanbul, Turkey. Since startup in 2003, METYX Composites had been co-located with its parent company Telateks AS at the Group headquarters and factories in the Tuzla industrial area of Istanbul. The new space will accommodate growing sales, purchasing, finance, accounting and management departments as they manage expansion from one to three factories, adding new technical textile products and added-value services. Corporate plans are to double the business by 2025, and there is space for additional head office staff that will be needed in the foreseeable future. "This move to our own headquarters marks an important milestone in our company's history," Ugur Üstünel, METYX co-director, "and signals our commitment to future investment and growth objectives." Further, the location's centrality and proximity to public transportation make it more more convenient for staff, visiting suppliers and customers. Further, the new offices will be equipped with the latest telecommunications, integrated IT hardware and software.

MARINE

Composite-hulled water taxi prototypes launched in Paris

Source | Décision SA

Décision SA (Ecublens, Switzerland) recently launched the first of five *SeaBubble* water taxi prototypes on the River Seine in Paris, France. Work on the prototype, which began in February, was completed in record time (4 months), reaching the final production design stage, the composite structure, and the final assembly of the first *SeaBubble* for an initial test run in Paris in mid-June. Envisioned by pioneering *(continued on p. 26)*

(continued from page 25)

hydrofoiling yachtsman Alain Thébault and champion windsurfer Anders Bringal, who imagined a revolutionary, green, urban transit network that uses waterways in major cities, *SeaBubbles* taxis will fly silently *above* the water surface, powered by a clean-charging electric drive system.

The project reportedly has secured some impressive funding, and is currently one of the fastest growing startups in France. Plans are to have the water taxis operating in 50 major cities within the next 5 years.

To realize the ambitious growth projections for the *SeaBubbles* endeavour, it was vital for Décision to consider a robust and cost-effective serial-production route from the very beginnings of the project. Working alongside the *SeaBubble* team, Décision analyzed the initial design and delivered a production-ready process for toolmaking and composite manufacturing. Décision also was able to complete the assembly of the first prototype on a very tight deadline for its launch at a Viva Technology exhibition in Paris.

In addition to satisfying the composite engineering targets for weight and stiffness, the *SeaBubble* manufacturing process was also required to include a significant percentage of bio-based materials. Here, Décision tapped its long experience with a wide range of bio-based epoxy resins and natural fibers and natural cork core. The *SeaBubble's* composite parts are produced using a vacuum infusion process. Décision says it is on target to complete the remaining prototypes before the end of September.

Following on from the success of this first phase of the project, Décision is expecting to work with the *SeaBubbles* team on its latest concept, a larger 15-seat vessel prototype, also planned for delivery this year.

MONTH IN REVIEW

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

Huber expands fire retardant manufacturing capacity
Huber Engineered Materials is increasing by 20% its alumina trihydrate production at the company's facility in Bauxite, AR, US.
07/10/17 | short.compositesworld.com/HuberPlant

FACC signs multi-year Rolls-Royce contract for engine composites
The supply contract with Rolls-Royce (London, UK) for the supply of composite components is worth more than €35 million (US$39.9 million).
07/10/17 | short.compositesworld.com/FACC-RR

Gurit signs licensing agreement for Armacell's ArmaFORM PET GR technology
As part of the contract, Gurit will be granted a global license for the patented ArmaFORM PET GR technology.
07/10/17 | short.compositesworld.com/GuritArma

Innovate UK launches graphene commercialization effort
Innovate UK's Knowledge Transfer Network aims to help composites fabricators work graphene into finished parts.
07/10/17 | short.compositesworld.com/InnoUKComm

NIAR adds nondestructive inspection capabilities
The National Institute for Aviation Research (Wichita, KS, US) has expanded its onsite capabilities with digital X-ray and 3-D computed tomography technologies
07/10/17 | short.compositesworld.com/NIARaddNDT

Spirit AeroSystems expands manufacturing operations in Malaysia
The Wichita, KS, US-based aerostructures manufacturer will commence plant construction in Kuala Lumpur in October, targeting operational readiness in 2018.
07/10/17 | short.compositesworld.com/SpiritExp

OCSiAl expands CNT production with Luxembourg plant
The investment for the 250-MT carbon fiber nanotube plant and a companion R&D facility will total €80 million-€100 million (US$68.4 million-US$91.2 million).
07/10/17 | short.compositesworld.com/OCSiAlexp

Orro bike features Sigmatex fibers
The Great Britain-based bike manufacturer's new *Terra C* road bike features sigmaIF, a combination of Innegra and Sigmatex fibers.
07/10/17 | short.compositesworld.com/OrroSigma

Teijin materials support solar car racer
Its Toho Tenax unit provided materials, including carbon fiber, for Kogakuin University Solar Team's racer, entered in the Bridgestone World Solar Challenge.
07/04/17 | short.compositesworld.com/TohoSolar

Quickstep to supply parts for new *LM-100J*
The Sydney, Australia manufacturer will be a supplier to Lockheed Martin for the latter's new commercial freighter, which made its debut at the 2017 Paris Air Show.
07/03/17 | short.compositesworld.com/QS-LM100J

Low-cost carbon fiber producer forges long-term agreement

LeMond Composites (Oak Ridge, TN, US), founded and under the leadership of CEO Greg LeMond — yes, that's the same Greg Lemond of Tour de France bicycling fame — has entered into a global, exclusive 20-year licensing agreement with Deakin University (Burwood, Victoria, Australia) to commercialize Deakin's patent-pending carbon fiber manufacturing process. The licensed process will enable LeMond Composites to commercialize and deliver its high-performance, low-cost Grail carbon fiber faster and in greater quantities, beginning in September of this year.

"Deakin University's process oxidizes carbon fiber faster, with lower capital and energy costs and greater output of carbon fiber over a shorter period," explains Nicolas Wegener, COO of LeMond, who negotiated the US$44 million deal. "The process requires 75% less energy, and also reduces the amount of process equipment by 75%," he points out. "These factors make the production of low-cost carbon fiber scalable at a velocity that can keep up with the market demand."

"The ability to scale production of our low-cost carbon fiber is what will allow LeMond Composites to deliver this material to the masses," says LeMond, adding the smaller footprint of the Deakin process offers opportunities for manufacturing flexibility. "Deakin University's manufacturing process will make it possible to localize manufacturing and make carbon fiber technology more accessible to a wider range of industries, including transportation, renewable energy and infrastructure — or any industry that benefits from using lighter, stronger, safer materials."

Deakin University vice-chancellor and president Prof. Jane den Hollander believes the novel oxidation process, developed by its carbon fiber research center, Carbon Nexus, is a game-changer: "This new technology could revolutionize the advanced manufacturing sector around the globe, because it will make carbon fiber more affordable to produce, which will make it more accessible for consumers."

The company's team of experienced carbon fiber experts and researchers, including Jamie Riddle, VP of operations, David Church, VP of engineering, Larry Peters, VP of manufacturing, and Mike Hamby, facility operations and equipment manager, searched for the most innovative, efficient and cost-effective carbon fiber manufacturing process, which led them to Deakin University. Deakin's process will result in low-cost carbon fiber product delivered in a standard format that is consistent with the requirements of today's composites industry, initally, direct from the Carbon Nexus facility. LeMond will begin construction of a new commercial carbon fiber facility, located in Oak Ridge, TN, later this year and will consider development of a US$30 million plant in Geelong, Victoria. The specialized carbon fiber production machinery for that plant would be manufactured by Furnace Engineering in Clayton, Victoria.

AUTOMOTIVE

IACMI, Michelman seek sizings for styrene-free autocomposites

The Institute for Advanced Composites Manufacturing Innovation (IACMI, Knoxville, TN, US), in partnership with Michelman (Cincinnati, OH, US) and other key IACMI consortium members announced a project focused on the optimization of vinyl ester resins and fiber sizings for the fabrication of carbon fiber composites. The effort will identify styrene-free prepreg formulations with longer room-temperature shelf life, shorter cycle times; and reduced cost. Advancements in these areas will increase productivity, decrease scrap and material costs; and enable adoption into a large market target: the multi-billion-dollar automotive industry.

Joining IACMI and Michelman are Ashland Performance Materials (Dublin, OH, US), Zoltek Corp. (St. Louis, MO, US), the University of Dayton Research Institute (UDRI), as well as JobsOhio and Michigan State University (MSU).

As part of this technical collaboration, researchers at MSU and UDRI will identify cost-effective combinations of Michelman's fiber sizings, Ashland's resins, and Zoltek's carbon fibers that can be used to fabricate prepregs for compression molding of composite parts. The goal is to develop styrene-free resin/sizing/fiber combinations that have room-temperature storage capability of at least 3 months and can be cured less than 3 minutes.

Success on this project, IACMI believes, will help catalyze adoption of carbon fiber/vinyl ester composites into automotive applications by presenting automakers a more cost-effective, production-worthy fiber/resin combination that also addresses governmental concerns about styrene in the workplace. These technology innovations should prove to be an attractive value proposition for automakers as they try to hit their targets for vehicle lightweighting.

What:
Composites and Advanced Materials Expo (CAMX)

When:
Sept. 11-14, 2017

Where:
Orange County Convention Center Orlando, FL, US

CAMX 2017 Show Preview

At North America's premier composites conference and exhibition, the business at hand is definitely not business as usual.

By Sara Black / Senior Editor

» If there's a single word that best characterizes this year's Composites and Advanced Materials Expo (CAMX), that would be the word *disruptive*. First indication? A disrupted schedule. The event, now in its fourth year and organized jointly by the American Composites Manufacturers Assn. (ACMA, Arlington, VA, US) and the Society for the Advancement of Material and Process Engineering (SAMPE, Covina, CA, US), will be held earlier than in previous years. It has been scheduled for Monday, Sept. 11 through Thursday, Sept. 14, 2017. So, adjust those expectations, mark your datebooks and plan to be there at the Orange County Convention Center in Orlando, FL, US in mid-September.

The CAMX program is rapidly taking shape and, *CW* has learned, valuable opportunities for networking, collaboration and education await. Particular emphasis will be placed on the latter. The opening General Session on Tuesday morning will feature three keynote speakers who will focus on the theme of "Disruptive Innovation." The speakers will represent Boom Aerospace (Englewood, CO, US), the developer of a new, composite-intensive design for a supersonic commercial passenger jet; Oracle Team USA (Redwood Shores, CA, US), the 2016 winner of the coveted America's Cup competition; and Composite Panel Solutions (CPS, Eagle River, WI, US), the developer of the first commercial composite foundation wall system for residential homebuilding. The session will explore the concept of changing one's approach and doing things differently — whether it's in the arena of design, manufacturing or materials selection.

Before those Opening Day events, on Monday, Sept. 11, there will be a day of pre-event tutorials. And following Tuesday's General Session, three days of conference programming will feature more than 250 technical papers and presentations, arranged in nine technical tracks: Additive manufacturing, advances in materials, bonding and joining, business/regulatory/workforce development issues, design/analysis/simulation, green and sustainable manufacturing and processing technology, market applications and nondestructive evaluation and testing.

The results of disruptive design and development activities will be plentiful in the expansive CAMX exhibit hall, which opens at 9:30 a.m. on Tuesday, Sept. 12; it will remain open during business hours through 1:00 p.m. on Thursday, Sept. 14. A CAMX closing luncheon will wrap things up at 1:00 p.m. on Thursday.

More than 40 companies and institutions have already submitted game-changing products for the CAMX and ACE Award competitions, which will be on display in the exhibit hall. Also, again this year, the CAMX poster session will highlight how students and researchers are advancing materials and processes to serve the industry. The CAMX Race competition, aimed at students and young professionals, will pit small teams against each other, each with a smartphone app to navigate the exhibit hall and answer »

questions at various booths. The three groups that answer the most questions correctly within the allotted timeframe will win up to US$500 in cash prizes. Entrants get a free CAMX Race T-shirt and the chance to connect with peers and leaders in the industry.

Also for university student members, SAMPE's University Research Symposium showcases technical research presentations from undergrads, graduate students and doctoral candidates. Papers deemed the best in each category will be awarded cash prizes, while winners in the Ph.D category will have sponsors paying their way to present their papers at SAMPE conferences in Europe and Japan. Awards for selected outstanding technical papers will be presented at the opening General Session on Tuesday morning.

This year, xC Consultants GmbH (Taufkirchen, Germany) will hold a start-up competition focused on innovation and value creation using composites, the role of partners in development, benefits for end-users and the innovation's market potential. (Start-up entrants must pass a pre-selection round, and attend CAMX in person.) The 10 best teams will be invited to CAMX to present a pitch, for 10 minutes, in front of a panel of judges. Each participating team will have a booth in which to show its marketing materials as well as samples of products/materials. The finalists will be announced at the evening Welcome Reception on Tuesday, Sept. 12. The three highest-ranked start-ups will share as much as US$10,000 in prize money.

As always, SAMPE's Fellows Award will be presented to distinguished members who have served the organization as well as contributed to the fields of materials and processes. The 2017 Class of Fellows will be presented at the SAMPE Awards dinner, held Monday evening. Likewise, ACMA will present its Membership Awards and Recognition Ceremony at a reception the same evening.

A significant perk of attending CAMX is the Virtual Career Fair, which connects job seekers with CAMX attendee companies looking to hire. Employers should submit their job openings information to CAMX prior to Aug. 25, and each participating company can submit 10 jobs free of charge.

For updates, logistical information, conference schedule, a list of exhibitors, lodging information and to register for the show, visit the CAMX Web site | **thecamx.org**

And be sure to check out the MyCAMX Planner on the CAMX site. It allows you to flag events, presentations and exhibitors of interest, schedule meetings and build an agenda in advance of your visit. CW

ABOUT THE AUTHOR

Sara Black is a *CW* senior editor and has served on the *CW* staff for 19 years.
sara@compositesworld.com

PRESENTED BY

AUTO BEAT DAILY

AD&P AUTOMOTIVE DESIGN&PRODUCTION

IN PARTNERSHIP WITH

AMP ADVANCED MOBILITY PROJECT

GARDNER Business Media, Inc.

CONTENT SPONSOR

NEXTENERGY ask us what's next

AMC AUTONOMY & MOBILITY CONFERENCE

Reimagining Transportation

OCTOBER 25, 2017
THE NEXTENERGY CONFERENCE CENTER
DETROIT, MI, USA

A one-day deep dive into the economics, technologies, and other factors changing automobility

At the Autonomy & Mobility Conference, you will learn & discuss:

Are Robot Cars a Good Idea for Anyone?

Economics, Regulations & Other Issues

How to Do It and How It Is Being Done: Addressing Technology & Implementation

How to Change 100-Year-Old Companies: Silicon Valley Doesn't Think Like Detroit

What Have We Learned? And What Do We Still Need to Know?

For more information or to learn about sponsorship opportunities, contact Mike Vohland: mvohland@ADandP.media

A Property of Gardner Business Media

AutonomyandMobility.com

IT'S ALL AT **CAMX**

North America's Largest Composites and Advanced Materials Expo!

www.**theCAMX**.org

CAMX

THE COMPOSITES AND ADVANCED MATERIALS EXPO

September 11-14, 2017: Conference / September 12-14, 2017: Exhibits
Orange County Convention Center / Orlando, FL

CAMX is the one source for connecting and advancing all aspects of the world's Composites and Advanced Materials communities: R&D, engineering, manufacturing, service providers, and end-users. Regardless of the application – transportation, aerospace, marine, wind energy, software, construction and infrastructure, medical, academics, sports and leisure – CAMX is America's go-to event for products, solutions, networking, and advanced industry thinking.

At CAMX you will:

- Discover cutting-edge commercial and industrial applications for advancing the use of innovative, new materials.
- Take part in the most extensive conference program for the industry anywhere in the world.
- Identify new products and geographic markets that can increase sales and your organization's bottom line.
- Explore and cultivate the CAMX network – enhance you career growth opportunities.
- Uncover areas of untapped growth for your organization.
- Gain the confidence needed to take critical next steps in your business development, while preparing to accommodate new customers.
- Get Business Done - Meet with new customers, current clients and your staff onsite.

SCHEDULE AT-A-GLANCE

MON. SEPT. 11

9:00 AM – 12:00 PM – Pre-conference Tutorials
1:00 PM – 4:00 PM – Pre-conference Tutorials
5:30 PM– 7:00 PM – ACMA Awards Ceremony & Reception
6:00 PM – 8:00 PM – SAMPE Awards Ceremony & Reception

TUE., SEPT. 12

8:30 AM – 9:30 AM – Opening General Session
9:30 AM – 5:00 PM – Exhibit Hall Open
2:00 PM – 2:30 PM – ACE Awards Presentation
2:30 PM – 5:00 PM – Conference Programming
2:30 PM – 3:30 PM – ACE and CAMX Awards Competition
5:00 PM – 6:00 PM – Welcome Reception

WED., SEPT. 13

8:00 AM – 11:00 AM – Conference Programming
9:30 AM – 5:00 PM – Exhibit Hall Open
10:30 AM – 1:30 PM – CAMX Race
2:30 PM – 4:30 PM – Poster Session – Meet the Authors
2:30 PM – 5:00 PM – Conference Programming
4:30 PM – 5:30 PM – CAMX Race Reception
5:00 PM – 6:30 PM – Market Segment Reception

THUR., SEPT. 14

8:00 AM – 12:00 PM – Conference Programming
9:30 AM – 1:00 PM – Exhibit Hall Open
1:00 PM – 2:00 PM – CAMX Closing Luncheon
2:30 PM – 4:30 PM – Conference Programming

Experience the Future of the Industry

At CAMX, you'll find the best of ACMA and SAMPE – game-changing products and applications, research highlighting uncharted uses for composites and advanced materials, ways to improve tried and true technologies, as well as trends and market analysis. CAMX gives you the unique opportunity to engage with all the experts – as well as the next generation of experts – who are shaping the future of composites and advanced materials... all in one place.

Awards & Innovations

Find the newest, most innovative products, applications, and research on display at CAMX.

The **CAMX Award** recognizes cutting-edge innovations that are shaping the future of composites and advanced materials in the marketplace. *Sponsored by:*

Ashland
always solving

Hosted by ACMA, the **Awards for Composites Excellence (ACE)** offers six total awards recognizing excellence in Design, Manufacturing, and Market Growth. *Sponsored by:*

COMPOSITES ONE®

The 2017 **Poster Session** will feature the latest industry research conducted by students, universities, and companies.

Visit **www.theCAMX.org** and connect with CAMX on social media.

CAMX IS MORE THAN A **TRADE SHOW**

Pre-Conference Tutorials

Arrive a day early and participate in Pre-conference Tutorials! These 3 hour courses are held on Monday, September 11 and fully immerse participants in a specific area of focus. See the full Conference Program and tutorials at **www.theCAMX.org.**

General Session & Keynote Address

CAMX 2017 will kick off with an exciting General Session and Keynote Addres and awards ceremony featuring the industry's most impressive innovations.

Conference Program

Delivering detailed Technical Papers, Education Sessions hosted by industry thought leaders, the CAMX Conference Program offers timely topics and industry experts – sharing their knowledge of over 100 different topics.

Attendees can expect the latest applications and research from key areas throughout the industry, arranged within the following tracks:

- Additive Manufacturing
- Advances in Materials
- Bonding and Joining
- Business, Regulatory & Workplace Development
- Design, Analysis, & Simulation
- Green & Sustainability
- Manufacturing & Processing Technologies
- Market Applications
- Non-Destructive Evaluation and Testing

Featured Sessions on Cutting Edge Topics:

- **Recycling/Sustainability**
- **Next Generation Manufacturing/ Composites 4.0 (Digitalization of Manufacturing Process)**
- **Success Stories and Cases Studies**
- **Simulation and Modeling**
- **Additive Manufacturing**
- **Hybrids and Bonding**

NEW FOR 2017! NOT TO MISS:

xC Start-up Award

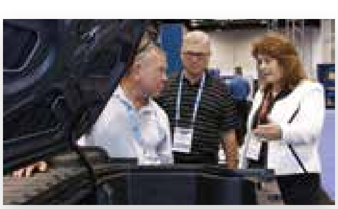
The competition is focused on innovation, the **value created by the use of composite materials** in the innovation, the role of the partners in the development phase, the benefits for the end-users and market potential of the innovation. The three best-ranked teams can **win up to a total of $10,000 prize money.** Winners will be announced during the CAMX Luncheon.

CAMX Exhibit Hall Attraction – Innovation Park

- New Exhibitors
- Presentation Theatre
- Consultants Corner
- Fireside Discussions

Register Online Today!

www.theCAMX.org



Plant Tour: GE Aviation, Asheville, NC, US

An *avant garde* approach to CMC parts production promises unprecedented opportunities for its employees, supply chain partners and jet-engine OEM customers.

By Ginger Gardiner / Senior Editor

» GE Aviation (Evendale, OH, US) has spent more than US$1.5 billion to bring to market ceramic-matrix composites (CMCs) that can be mass produced. The quantity of CMC raw material GE uses has increased twenty-fold in the past decade alone. By 2020, GE Aviation expects to have established the first vertically integrated CMC supply chain in the US, with roughly 750 employees producing up to 20,000 kg/yr of CMC prepreg and 10,000 kg/yr of SiC fiber.

More than 20 years in the making, this CMC technology originated at GE's Global Research Center (GRC, Niskayuna, NY, US), was incubated at its CMC Lean Lab and FastWorks Lab (Evendale, OH, US), and was scaled up at GE's CMC low-rate initial production (LRIP) center (Newark, DE, US).

Such early insights have put GE in position to exploit advanced CMCs' full potential to deliver the increased performance, reduced weight and emissions, and reduced operating costs now demanded for the jet engines that will power tomorrow's aircraft. That same foresight into the future of advanced manufacturing has more recently stimulated heavy investments in 3D printing and digital thread/digital twin/Big Data technology, as well.

These efforts have resulted not only in a deliberate development of its supply chain structure (see Figs. 1 and 2, p. 37), but also in its team-based character.

"We have a tight linkage between GRC through to our Asheville production," explains Michael Kauffman, GE Aviation's general manager for composite and ceramics manufacturing. "This means product yield is tracked collectively through the supply chain."

Production issues also are addressed collectively, using the full breadth of GE's CMC resources to maximize speed and efficiency (see the Side Story, titled "Vertically integrated CMC supply chain," on p. 38).

FIG. 1 GE Asheville: Key to long-term strategy

GE Aviation's new CMC components factory — currently producing the open shrouds for LEAP 1B engines and box shrouds for LEAP 1A/C engines shown here — illustrates the company's deliberate, team-driven effort to ramp up to *36,000* CMC engine parts per year by 2020.

Source (both photos) | GE Aviation

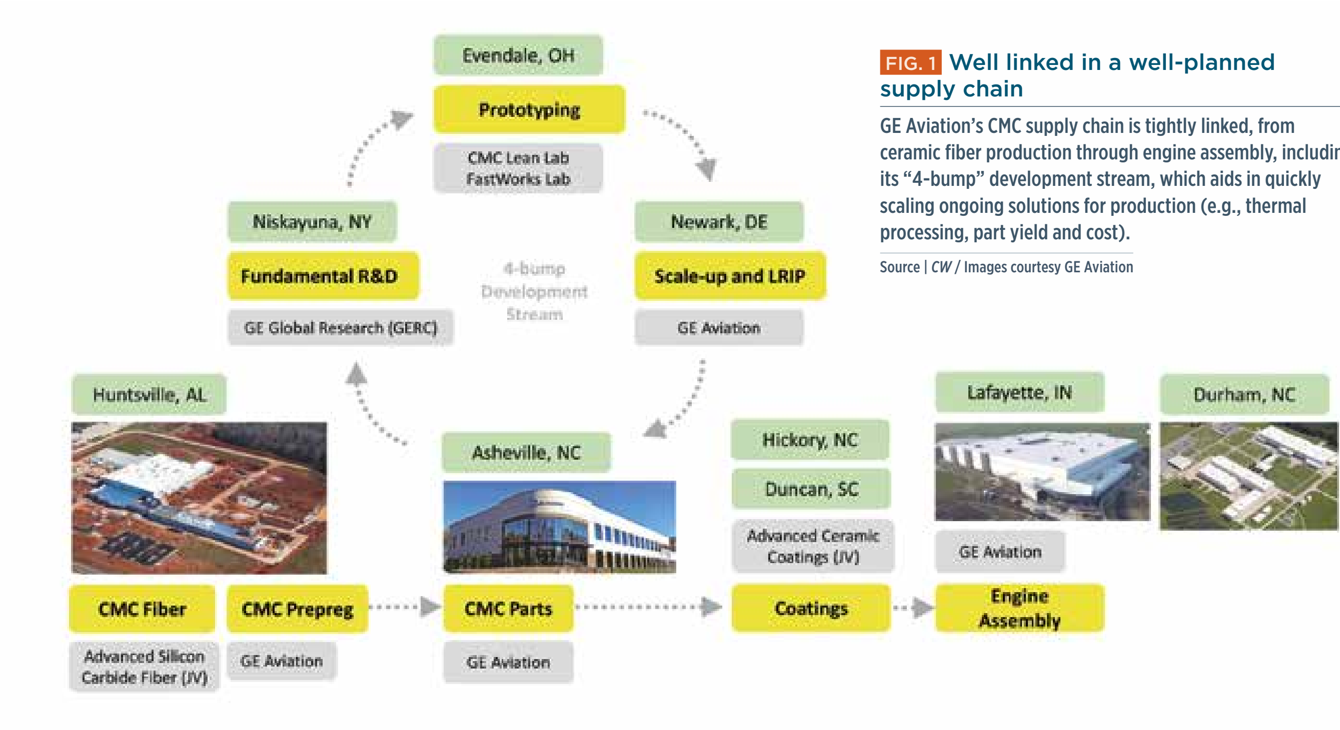


FIG. 1 Well linked in a well-planned supply chain

GE Aviation's CMC supply chain is tightly linked, from ceramic fiber production through engine assembly, including its "4-bump" development stream, which aids in quickly scaling ongoing solutions for production (e.g., thermal processing, part yield and cost).

Source | *CW* / Images courtesy GE Aviation

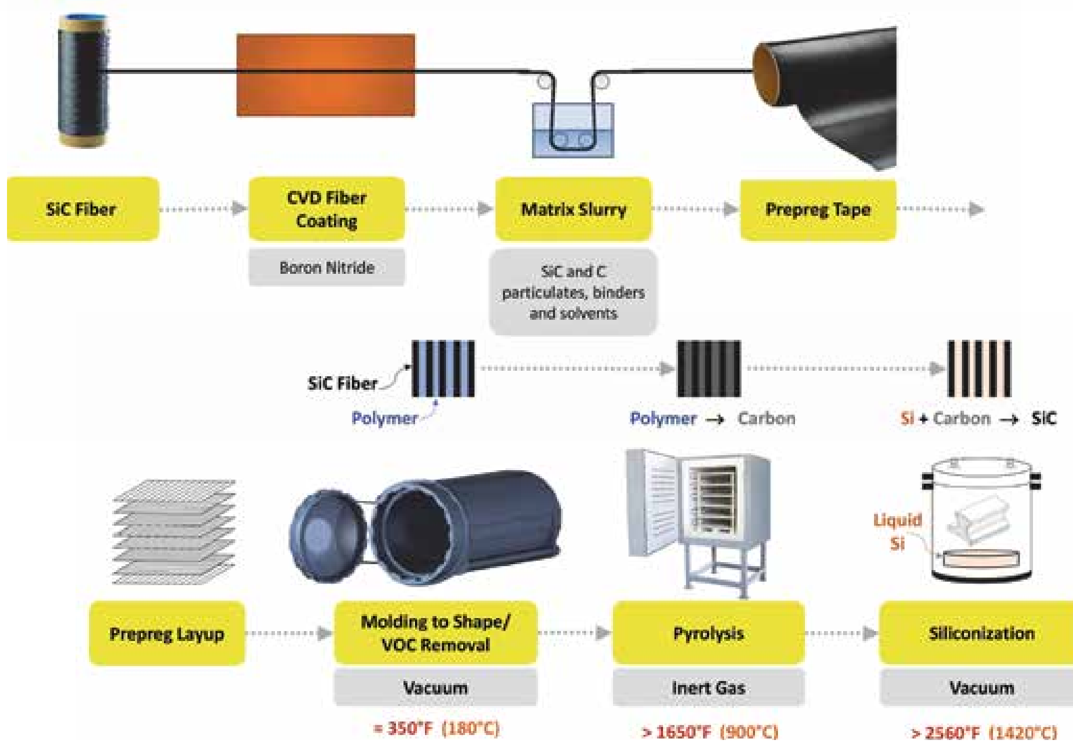


FIG. 2 SiC-reinforced SiC matrix process chain

The SiC/SiC process involves three thermal processing steps, the last and most heat-intense of which — melt infiltration of liquid silicon into the carbonized composite preform — is the key to forming the densified SiC/SiC ceramic composite.

Source | *CW* (Icons are used to help visualize a general process, not intended to depict realistic detail)

Located halfway between the CMC development lab in Evendale and CMC fiber and prepreg facilities under construction in nearby Huntsville, AL, GE Aviation's new US$125 million, 16,000m^2 CMC parts production plant in Asheville, NC is set alongside a GE Aviation rotating parts plant that has a 70-year local history. *CW* was invited to tour the facility and see the first-of-its-kind CMC parts production process.

Team-driven approach

CW's tour is led by Ryan Huth, GE Aviation's manager for CMC production. A North Carolina native, Huth has amassed significant manufacturing and engineering experience during his 12 years with GE Aviation. Well-schooled in engine assembly and certification, in the Six Sigma Tollgate process for manufacturing problem-solving, and in troubleshooting engine performance issues during » testing, Huth was excited to see GE choose the legacy Asheville site as the center of its CMC supply chain. "It's not just well-situated geographically," he explains, "it also draws from a long-established local culture of tenacious, hardworking people who rely on ingenuity and community to overcome obstacles."

This character is a key asset in GE's team-driven approach to achieve this plant's objectives, which are nothing if not daunting. The facility was announced in 2013 and first opened in 2014. Now completed, the plant's 13,000m² production area will produce 18 high-pressure turbine (HPT) Stage 1 shrouds per engine for 500 LEAP engines this year. Production will ramp up to 1,100 engines in 2018 and should exceed 36,000 shrouds per year for more than 2,000 engines by 2020.

LEAP production will dovetail with that for the GE9X engine, which will power The Boeing Co.'s (Chicago, IL, US) 777X commercial passenger plane when it enters service in 2020. Here, CMC components extend beyond the HPT Stage 1 shrouds to include the Stage 1 nozzles as well as the HPT Stage 2 nozzles, one combustor inner liner and one outer liner per engine. The count for these CMC components, five, is roughly the same as that for the metal counterparts used in the previous GE90 engine. Note that these high-pressure nozzles are airflow nozzles, not fuel nozzles. The 19 fuel nozzles per engine, on both the LEAP and GE9X, are 3D-printed metal.

To meet this growth in production, a rapid ramp up in work-force is in progress. "We started shipping parts in 2014 with 20

SIDE STORY

Vertically integrated CMC supply chain

With its full-rate CMC parts production facility in Asheville, NC, already in operation, GE Aviation (Evendale, OH, US) is investing more than US$200 million to construct silicon carbide (SiC) ceramic fiber and unidirectional ceramic matrix composite (CMC) prepreg facilities on a 100-acre campus in nearby Huntsville, AL, US. This is, in fact, the most vertically integrated material supply chain GE has constructed in the US to date (Figs. 1 and 2). The ceramic fiber plant is supported by US$21.9 million in funding from the US Air Force Research Lab (AFRL, Dayton, OH, US) Title III Office. The CMC tape operation is financed solely by GE.

The new SiC fiber plant will license fiber-production technology from NGS Advanced Fibers Co. (Toyama, Japan), the only other large-scale SiC ceramic fiber factory currently in operation. Formed in 2012, NGS, a joint venture between Nippon Carbon (Tokyo, Japan), GE Aviation and Safran (Paris, France), has an expansion at its Japanese factory in final qualification to meet growing worldwide demand.

"NGS will continue forward," says Michael Kauffman, GE Aviation's general manager for composite and ceramics manufacturing. He explains that the new SiC fiber plant, Advanced Silicon Carbide Fiber, will be a joint venture like NGS and will feature the same partners, but the ownership percentages differ: GE owns 50%, and it is a US entity. The SiC fiber plant in Huntsville is seen as complementary and will coordinate the sale of fiber with its NGS partners. Both businesses will continue to sell SiC fiber for GE and to all external customers. "Selling fiber externally is required per the AFRL Tile III funding," says Kauffman.

The adjacent prepreg tape facility, however, will remain an exclusively GE Aviation operation. "The tape will be split into multiple widths, as needed, for nesting efficiency in the parts we make," notes Kauffman. "This prepreg tape will support GE Aviation military and commercial products as well as components for GE power turbines."

The CMC prepreg facility reportedly will begin operations in the summer of 2018. The CMC fiber facility should follow in the spring of 2019. When fully operational, the two facilities will employ as many as 300 people.

At full capacity, the CMC prepreg and fiber facilities are expected to produce 20,000 kg of material and 10,000 kg of SIC fiber per year, respectively. Each LEAP engine uses ~1 kg of CMC material. GE Aviation also is incorporating CMC components into advanced military engines, including the innovative turboshaft demonstrator FATE (Future Affordable Turbine Engine) and the GE3000 for the US Army's Improved Turbine Engine Program (ITEP) program, which aims to provide 50% more power, a 65% increase in power-to-weight, a 20% longer engine life and as much as a 25% reduction in fuel consumption, plus reduced production and maintenance costs for the US military's *Black Hawk* and *Apache* helicopter fleets.

The five CMC parts in the GE9X, which will power The Boeing Co.'s (Chicago, IL, US) 777X twin-aisle passenger plane, will have roughly the same operating temperature as the LEAP parts. "We're in certification of these parts now," says Kauffman. "We've shipped four sets already during the supply chain scale-up." He adds that GE Asheville will continue as the principal industrial conversion site for CMC components, "until we have enough products to outgrow this facility."

4-bump development stream

Kauffman explains that ongoing R&D is a key part of the CMC supply chain (see top "circle" in Fig. 2, p. 36). "It's what we call our 4-bump development stream," he says. "We have a tight linkage between GRC through to Asheville, which means a tight-knit value stream. For example, we track product yields collectively as a supply chain. If we need to work an issue, we send a hypothesis upstream, they work it out, test it and send back amended specifications, standard operating procedures, etc." He notes that each unit can problem-solve, and solutions then can be trialed in low-rate production at the Newark CMC lab. "So this could be for fine-tuning our thermal cycles in manufacturing various CMC parts, for example," says Kauffman. "We don't experiment in our parts production line. We experiment in our labs, prove out in our LRIP center and then we bring it in to our high-rate production facilities."

At the same time, Kauffman stresses, this R&D development stream enables a completely new approach to structural design. "These are disruptive design concepts," he reports, "which are being vetted and tested. We will mature these and push toward industrialization. Thus, we have a push and pull advancement in CMC technology."

GE also seeks continuing improvements to the material. "We're working on advancing the temperature capability of the SiC/SiC system in support of military applications, Kauffman says. This requires a different SiC/SiC microstructure, higher temperature environmental barrier coating (EBC) and potentially a higher temperature fiber. We have a roadmap to achieve this."

Manufacturing floor: Room to grow

The facility's open 13,000m^2 production area, mostly empty during *CW's* tour, is quickly filling with new CMC part production lines. A U-shaped flow will begin with incoming materials at rear and right, channeled into dedicated lines for each part type, and then back out at left rear for transport to coating and engine-assembly facilities. Source | GE Aviation

employees," Huth reports. "Every year since, we have at least doubled our employee base over the previous year." By 2019, the facility could employ 300 people.

Walking from the first-floor lobby to the second-floor office area, Huth points out a series of photographs mounted along the walls, taken by employees as part of an effort to show "What Asheville means to me." He also notes that the office space, flooded with natural light from myriad windows, was designed to be as open as possible to encourage collaboration. Low-walled cubbies, arrayed down one side of the L-shaped area, are being filled with production and support engineers as the workforce increases. "We need chemists and ceramics engineers, mechanical engineers for the various machining processes as well as specialists in laser and ultrasonic machining processes and nondestructive testing engineers," says Huth.

Although engineers and specialists are trained within GE before they arrive in Asheville, production technicians are hired and trained locally at Asheville-Buncombe Technical Community College (AB Tech). "We have a close relationship with AB Tech," says Huth, "which is about 10 minutes away. They built a composites center of excellence for our employee training, complete with autoclave and cleanroom." »

Climate-controlled cutting and laminating

Incoming unidirectional prepreg tape is cut into ply shapes and laid up in glass-enclosed cleanrooms. Source | GE Aviation

The training process starts with a skills assessment and behavior evaluation, followed by 40 hours of coursework at AB Tech. "From here, we invite selected candidates for an onsite interview with a panel of peers," he adds. "If they do well, they get an employment offer and complete another 40 hours of training at AB Tech. We finish off their training here and certify them to begin work."

The candidate behavior test and interview with potential teammates stands out. "We do not have a traditional supervisor structure here but, instead, have team leaders, with up to 50 people per team," explains Huth. "This is a 100% team environment," he adds. "Our employees are high-performance and self-directed, responsible for goals, manpower coverage, problem solving and conflict resolution." Thus, it is important that every new employee meshes well and that each team is confident in each new-hire's ability to work collaboratively. "We also cross-train everyone so that we can have as much flexibility as possible," says Huth.

The remainder of the second floor comprises an employee gym and collaboration rooms and an outside deck for lunch meetings and breaks. "As we fill up the building with technicians and engineers, we wanted teams to have collaboration space," says Huth, giving examples, such as meetings at shift startup and for quality management and improvement (QMI) programs and "war rooms for cost-out" — GE's shorthand for targeted cost-reduction projects.

Layup and thermal processing

From the second floor, the tour descends back downstairs into the facility's 13,000m^2 open production area. Although the space is mostly empty, Huth says it is beginning to fill, with new additions daily. "We have a single production line right now," he observes, "but this will be duplicated, with each line modified for the type of part being made." He explains that the CMC technology remains the same, but the part designs differ. "This first line is making box shrouds and open shrouds for the LEAP 1A/C and LEAP 1B, respectively," says Huth. "In the future, we will build combustor liners, blades, nozzles and other parts."

He notes that raw material comes in from the building's south end and eventually will feed multiple lines, forming a U-shaped production flow. Turning to where the shroud production line spans the north end of the production hall, Huth lists four basic steps in making the SiC fiber-reinforced SiC matrix composite: cutting and layup of prepreg tape, multi-stage thermal processing, post-machining of parts and nondestructive inspection (NDI).

The line begins on the left, with a glass-enclosed, contamination-controlled cleanroom. "The material comes to us as a unidirectional tape and into this cleanroom, where a Gerber [Tolland, CT, US] automated cutter cuts ply shapes for each part's layup." Today, the incoming material ships from Newark, DE. First tape from Huntsville,

Thermal processing for the jet-engine hot zone

Prepreg layups are transformed via a three-stage thermal process into CMC parts, each stage with its own type of autoclave/furnace. An autoclave (white, with its door open) can be seen at center, and silver, cylindrical, melt-infiltration furnaces (for the third-stage of processing) are at lower left and center. Source | GE Aviation

AL, is due May 2018. The tape does not come on a roll, but in flat sheets, which are fed into the laser cutters. These plies are then laid up on a metal tool to form the composite laminate.

"Right now, layup is done by hand," says Huth. Opposite the cleanroom is a second, glassed-in layup cell, with a Virtek Vision (Waterloo, ON, Canada) laser projection system to aid in ply orientation and placement. Both cells have computer terminals, with part drawings on the screen, and technicians are seated inside, applying the cut plies to tools. But Huth says automated layup is on the way. "The automation for this cell is being developed apart from this site and is being vetted now," he explains. "It will be in place by fourth quarter to complement manual »

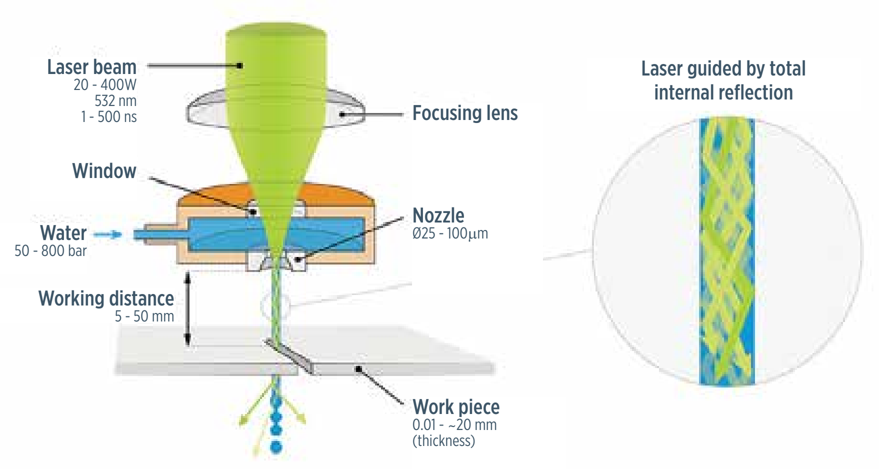
■ Maximizing machining capability

An automated line has been optimized for maximum productivity as it machines a variety of different parts with high precision. Source | GE Aviation

operations and then be scaled up, step by step, as production rate increases."

Next is the thermal processing area, which takes up at least one-third of the production line. Thermal processing is completed in three different steps with three different grades of thermal equipment. After layup, parts are prepared for this by sealing them underneath a reusable vacuum bag made by Torr Technologies (Auburn, WA, US). "Physics dictates our cycle time in each thermal step, so we have no ability to cut time here," Huth explains. "We can impact door-to-door time, however, so we want all furnaces running as continuously as possible. This is why we use reusable bags." Efficiency also is improved by processing parts in groups of 12. Further, thermocouples map out lead and lag spots in the bag, and the vacuum schedule includes a reusable breather material, four thermocouple ports and two vacuum ports.

The first thermal processing step removes volatile organic compounds (VOCs) and molds part shape, via conventional autoclave. The ASC Process Systems (Valencia, CA, US) autoclaves are run at temperatures typical of the high end of polymer-matrix composites processing.



Preventing post-process bottlenecks

Although conventional mechanical grinding of its superhard CMC parts could take an hour, GE employs Laser MicroJet cells (right) to drill high-accuracy holes, for example, in only 2 minutes, shooting a laser down a column of water (illustrated above). The water column does double duty by cooling the part and carrying away debris. Source | GE Aviation and Synova

In the thermal processing cycle's second step, "burnout" furnaces pyrolize organic material to form carbon bridges in the CMC's microstructure. Temperatures are much higher than typical autoclave processing, and an inert gas is used.

The third and final thermal step takes place in melt-infiltration (MI) furnaces, which cook the parts at temperatures above their 1316°C operating temperature. They resemble metal household pressure cooker pots with clamp-on lids, albeit much larger. During MI, molten silicon is wicked through the parts and reacts with carbon to form silicon carbide (SiC). The final product is an SiC fiber in a SiC matrix.

"We have 12 furnaces in this line," Huth observes. "In the next two months, we will duplicate this line, adding another 12." He notes year-over-year production increases of 900% »

from 2015-2016, and 400% from 2016-2017, just for LEAP engine shrouds. “We are also making parts for the GE9X.” Walking past the furnaces, Huth points out a display board for this production area that tracks Lean Manufacturing metrics. “Each team is constantly working the process for continuous improvement, and each has a facilitator who manages safety, quality, delivery, cost and cash aspects,” says Huth.

Precision machining and inspection

Huth then picks up a box shroud for the LEAP 1A/C engine. Lightweight, silver on the outer surface, white on the inner surface, it looks metallic and yet is not. He also shows a LEAP 1B open shroud, which has a little curvature. Stage 1 HPT shrouds form the annulus around the HP turbine blades. The LEAP 1B shrouds do not have the closed box on top but are open with four curved projections, which are flanges, each with a hole drilled through for attachment in the engine.

“After melt infiltration, you have a fully cured CMC part,” says Huth. The next step is machining. “We use a 3R interface with vacuum chuck on each machine in the line so we can get as close as possible to single-piece flow.” This “3R” interface refers to a workpiece chucking system that enables quick setup and maximum productivity in machining lines that handle a variety of different parts. “We do simple, less-complicated machining to complete a single feature at a time,” Huth explains. “We superglue the part [workpiece] to the interface so that the robot picks it up and transfers it from station to station through the automated machining line, with no additional setup required per station. At the end, you have a fully machined and marked part.”

> The pace in Asheville is fast, but not frenzied. GE has thought out all things necessary … to deliver parts.

Conventional grinding on these types of parts would take an hour, according to Huth. “So, we use Laser MicroJet cells which shoot the laser down a column of water.” The water cools the part and carries away debris. It also helps to maintain a high level of accuracy in the hole diameter. “The MicroJet can drill these holes in two minutes,” says Huth. The technology results from a partnership using innovative laser-cutting systems from Synova (Lausanne, Switzerland), high-precision machining technology from Makino Milling Machine (Tokyo, Japan) and GE’s fine-hole drilling software.

Shroud underside surfaces along the airflow path, which have glue dots from the 3R interface, are machined smooth using diamond abrasives. But Huth notes this is the subject of an ongoing cost-out project, “We won’t be doing this for long.”

The final step in the production line is NDI, using computed tomography (CT) machines from GE. Every part is inspected with an approximate scan time of 15 minutes, followed by 30 minutes for completion, including data evaluation.

Big picture and Big Data

The pace in Asheville is fast, but not frenzied. GE has thought out all things necessary not only to deliver parts for engines already ordered, but also to ensure the facility remains at the forefront of production for the next 70 years.

A case in point for the long-term is the network of silver tubes that runs from each machine in the plant up to the ceiling. "These house Ethernet cables are all tied to our database system," says Huth. "So layup times, relative humidity in cleanrooms, furnace cycles, machining metrics and CT scans are all logged for each part's digital thread, and also for analysis to help us refine processes, both for speed and cost reduction."

Kauffman says GE's Big Data capability is a cornerstone of its ongoing strategy. "This is key for our CMC supply chain," he explains, because SiC/SiC "is highly process-sensitive, and there are thousands of input variables with continuous variations. The beginning elements in fiber spinning affect not only fiber coating and prepregging, but all the way to how consolidation occurs in the components." The collection and integration of Big Data throughout the supply chain also directs product and process simulation models. "We let the data find its correlations," says Kauffman, "and it often finds things we, frankly, didn't predict in our models."

Why commit so much to the design and establishment of this supply chain? "Because we have invested a great deal of money over the last decades, and this technology is a differentiator for our products," Kauffman replies. "We want to protect this investment and our intellectual property. We are familiar with what our competitors are doing, and we are the only ones to use this approach to infiltration of a reinforcement, which we believe achieves better densification." He notes that another driver was to make sure GE's partners were willing to industrialize CMCs as well. "Industry's commitment to CMCs has been off and on," says Kauffman, "but we believed there was too much to gain in weight reduction, performance and efficiency — for us, the decision was clear." And now, so is the path forward. CW

+ LEARN MORE

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

ABOUT THE AUTHOR

CW senior editor Ginger Gardiner has an engineering/materials background and more than 20 years of experience in the composites industry.
ginger@compositesworld.com

Composites recycling: Gaining traction

Recycling of carbon fiber, glass fiber and — *at last* — resins, is growing as new players enter the space.

By Sara Black / Senior Editor

» A key question — What happens to manufacturing waste and end-of-life parts? — was silently swept under the rug in the composites industry for years as companies resigned themselves to paying for landfill disposal while metals suppliers touted recyclability to industry. But at least three marketplace realities have converged to drive the growth of composites material recycling, particularly the reclamation of carbon fiber:

- First, the European Union's end-of-life-vehicle (ELV) directive requires that 85%, by weight, of the materials used in a car or light truck must be reusable or recyclable.
- Second, carbon fiber's high manufacturing cost and high performance, even in chopped form, make it an attractive recycling target, which is creating market pull for recycled fiber products, most notably, from automotive.

Waste reclamation: Key source for recycled fiber

Composites recycling is gaining momentum as more players become involved, and might be approaching commercial volumes as demand from part manufacturers and consumers continues to grow. The carbon fiber shown here was reclaimed from waste, using pyrolysis to burn off the resin.

Source | ELG CF

■ Automotive industry: A ready market for recycled carbon fiber

Recycled carbon fiber is already in use, for example, as a filler in polyurethane (PU) rear and front bumpers on the new Mercedes *AMG GTC* roadster. Milled fiber for the bumpers is supplied by CarboNXT, the partner company to CFK Valley Recycling (Wischhafen, Germany), part of the Karl Meyer Group.

Source | CFK Valley

- Finally, the newest generations of consumers were raised on environmental awareness, actively support recycling activities and closed-loop manufacturing, and seek out goods with recycled content.

Although *CW*'s coverage of composites recycling (see Learn More, p. 55) dates back over a decade, informal statistics still show that only ~2% of composites-related companies are active recyclers. That said, three years since our most recent feature on the subject, there is demonstrably greater interest and activity, and commercial applications of recycled fiber are growing.

The technologies: Different approaches

One reason aluminum and steel remain formidable competitors to composites is their suppliers' long track records in recycling, which has helped reduce their overall material production costs, says Ed Pilpel, senior technical advisor at PolyOne Advanced Composites (Englewood, CO, US) and the current recycling committee chairman at the American Composites Manufacturers Assn. (ACMA, Arlington, VA, US). "But it took those industries 30-50 years to achieve their current success rate at recycling, which for aluminum is upward of 80%. The composites industry is much younger, and we have years to go," he admits, "but we've got to jump into the deep end of the pool and get going." »

■ Pyrolyzed reclaimed fibers reportedly retain virgin carbon fibers's key performance levels

A test coupon of PArCF30 thermoplastic composites filled with CarboNXT carbon fibers, reclaimed via pyrolysis, is displayed by a CFK Valley Recycling technician. Fiber properties, post-pyrolysis, are said to be virtually unchanged from virgin data. Source | CFK Valley

Recycling cornerstone: Milled fiber

Milled carbon fiber — shown here is milled fiber from ELG CF (Coseley, West Midlands, UK) — was one of the earliest arrivals in the growing recycled fiber product pantheon. It is used in thermoplastic compounding for injection molding, or as a resin filler, as demonstrated in the Mercedes roadster bumpers application (top image, p. 47). Source | ELG CF

Those who *have* jumped in are employing several recycling strategies, separately or in combination. Most initial efforts have focused on reclamation and reuse of high-quality carbon fiber material waste streams, typically from aerospace manufacturing, because they are relatively easy to work with *and* yield high-quality carbon fibers with performance properties virtually undiminished, albeit in chopped form (continuous fiber can also be recovered, discussed below). Waste sources include off-spec material, cutting/trimming/kitting scraps (dry and prepreg) and bobbin ends, including thermoset and thermoplastic materials.

Current commercial methods for eliminating the resin from the carbon fibers are *pyrolysis* (thermal treatment) and *solvolysis* (chemical treatment). Although pyrolysis requires thermal energy to burn off the resin, and can cause fibers to char, the energy of pyrolysis represents only a fraction of the embodied energy of virgin carbon fiber. Some sources say solvolysis requires even more energy than thermal treatment, but it enables recovery of fiber *and* resin. In both processes, the recovered fibers transfer well to nonwoven mats or thermoplastic pellets for injection molding, and are a natural fit for automotive part applications.

More difficult is recycling of end-of-life (EOL) cured parts to complete a true "closed-loop" situation, where materials are recovered from scrapped products and reused in new iterations of those products. Pyrolysis and solvolysis can be applied to cured parts, as can mechanical crushing, typically used for fiberglass parts; the resulting crushed glass/resin material is either reused as a resin filler, burned for energy (waste to energy plants) or co-processed in cement kilns.

Alternatively, two companies offer recyclable *resin* products that can be un-crosslinked in a chemical solution that leaves the original fiber reinforcements intact (more on that below) for closed loop recycling in some sporting goods applications. And, a number of materials suppliers are investigating in-house, closed-loop recycling of scrap and parts, avoiding a recycling middleman.

But, says Frazer Barnes, managing director at ELG Carbon Fibre Ltd. (ELG CF, Coseley, West Midlands, UK), a subsidiary of German metals recycler ELG Haniel (Duisburg, Germany), "So far, closed loop arrangements are scarce: We're working with *one* closed-loop customer on a development project, where their recovered carbon fiber will go back to them for reuse."

Thermal treatment leads

"Three years ago, it was a real push to get these materials out into the market. Now, there's more 'pull' and we're getting more inquiries on how to use recycled carbon. We are now designing products and developing them to meet specific customer requirements," says Barnes. ELG CF processes more than 2,000 MT of waste material per year in its patented pyrolysis process, including manufacturing waste and cured parts.

All incoming waste is sorted, cataloged and classified, based on fiber type and source, and the fiber provenance data stays with the recovered fiber during processing and recovery. Mechanical testing data on recycled carbon products is freely available, notes Barnes, to encourage greater adoption of recycled fiber, which it offers at a cost about 40% less than virgin fiber: "In an equivalent product form, there is no performance difference between recycled vs. virgin fiber." In addition to its chopped and milled products for thermoplastic compounding, ELG CF offers nonwoven mats, ranging from 100 to 500 g/m^2, as well as hybrid commingled mats that combine chopped carbon fibers and thermoplastic fibers (polypropylene, polyamide, polyphenylsulfone, and polyether terephthalate).

The company is currently involved in providing recycled carbon fiber in thermoplastic pellet form for a production automotive semi-structural part being produced by Tier 1 supplier Sanko Gosei (Skelmersdale, UK), with compounds provided by Albis (Knutsford, UK). The project's objective is to demonstrate the feasibility of using recycled fibers in production automotive applications, which could eventually lead to production of nearly a million parts per year. More automotive projects for ELG CF are in early phases, including a sports car chassis.

The company also was recently awarded a grant from the UK's Rail Safety and Standards Board (RSSB) to explore the use of recycled carbon for future rail-car primary structure. ELG CF also is working with the University of Nottingham and University of Bristol on "realignment" techniques that will eventually align short

■ **Reclaimed long-fiber reinforcement**

ELG also offers reclaimed carbon fiber in its Carbiso CT+ long-fiber (what it calls "oversized") chopped tow format, for incorporation into thermoplastic pellets for injection molding processes and for use in discontinuously reinforced thermoset molding processes as well. The fibers come in nominal (±1 mm) 6-mm and 12-mm lengths. Source | ELG CF

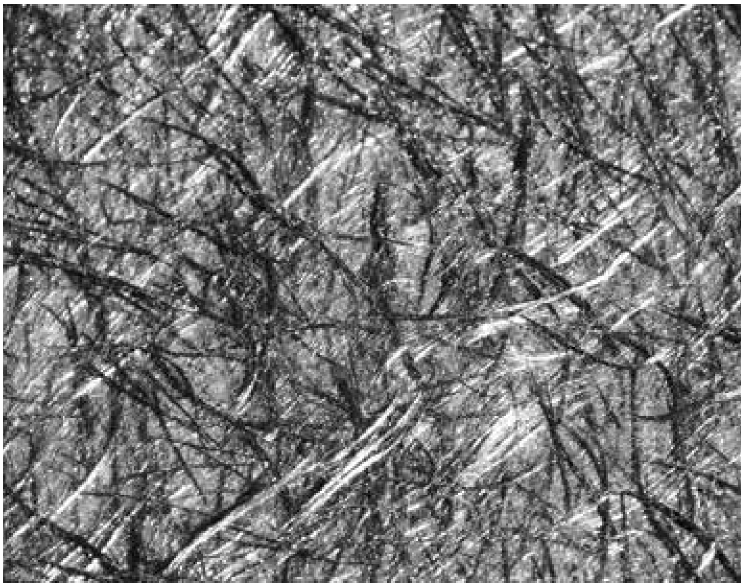
chopped fibers to give better material properties. Barnes says ELG CF might also begin using other recycling processes going forward: "We are not tied to any one technology. Pyrolysis is certainly effective, but 20% of our staff is involved in research and development. We are open to new ways to process, including solvolysis, and it may depend on different incoming materials in future."

In the US, Carbon Conversions (Lake City, SC, US) employs pyrolysis and can process "the entire composites waste stream," claims Keith Graham, Carbon Conversions' VP of business development. That includes continuous tow from various markets; intermediates, such as dry fiber waste (from fabrics, trimming, braiding), and "wet" uncured prepreg and pultrusion waste; and end-of-life parts from commercial aerospace, recreational and industrial sources. "We've built a robust business to take any industry's waste stream and convert it into any one of our many products," adds Graham. Hexcel (Stamford, CT, US) recently purchased a minority stake in the company.

Carbon Conversions' products include two distinct families. The first comprises *chopped-seeded* recycled carbon fibers (that is, fibers that have been treated with a proprietary sizing to increase their bulk density for better handling and processing), primarily used in injection molding applications. Fiber lengths offered range from 6.5-25 mm, all with known pedigrees as to fiber source and type, either high-strength or intermediate-modulus. Carbon Conversions uses a proprietary sizing for compatibility with many common thermoplastic resin systems. "We can provide a recycled milled fiber upon request," he adds. The second product family is nonwoven mat, made from recycled carbon fibers. The mats are offered as recycled carbon fiber only (for RTM, VARTM and prepreg processes) and hybrid, commingled constructions that incorporate thermoplastic fibers for compression molding processes. Nonwoven weights range from 100-500 g/m^2. Carbon Conversions also has patented and trademarked 3-DEP materials made in the Co-DEP wet-laid slurry process, for custom recycled chopped carbon fiber preforms, in weights up to 1,400 g/m^2 (see Learn More). The company has successfully demonstrated automotive parts, including a floorboard part for an automotive OEM. Graham says the company also is working with customers on closed-loop programs: "We worked with Oracle Team USA to recycle their racing yachts and recover the carbon fiber for use in tooling for their newest vessel. We have other customers interested in closed-loop arrangements, and it will give them a distinct advantage in the market as we continue to collaborate on recycling and product development together." Graham notes that Carbon Conversions will push the envelope to advance composites recycling: "We're all in this together, and we need to produce repeatable, consistent quality materials to grow this industry."

CFK Valley Recycling (Wischhafen, Germany), part of the Karl Meyer Group, is Europe's largest composites recycler that uses pyrolysis, and takes in waste streams from automotive, aerospace and end-of-life sporting goods, says Tim Rademacker, a managing director at the company: "Due to the increasing use of wind turbine blades made with carbon fiber, the quantity of waste from the wind industry has risen significantly."

With a 1,000-MT per annum yield of recycled fibers, CFK Valley Recycling's partner company within Karl Meyer AG, CarboNXT (Wischhafen, Germany), distributes the recovered fiber as chopped and milled products as well as wet-laid veils and air-laid nonwoven mats. Says Rademacker, "We identify incoming waste streams, and depending on customer demand, CarboNXT can produce customized recycled semi-finished products, with three different proprietary techniques for resizing the fibers." Although CarboNXT's customer list is proprietary, Rademacker reports that milled recycled carbon fiber is used as a filler in polyurethane (PU) rear and front bumpers on the new Mercedes *AMG GTC* roadster. "The ever-growing consumption of carbon fibers and »



Shedding recycled product limitations

As methods and processes improve, product diversity increases. Carbon Conversions (Lake City, SC, US), for example, can offer chopped, seeded recycled carbon fiber for injection molding applications, and nonwoven recycled carbon mats, available in commingled constructions. Further, it also produces custom recycled carbon fiber preforms, manufactured in its Co-DEP wet-laid slurry process. Source | Carbon Conversions

the resulting greater quantity of composites waste will inevitably lead to a higher demand for recycling technology, and innovative applications for the recovered fiber materials," he adds.

Pilpel describes the ACMA's ongoing collaboration with IACMI (Institute for Advanced Composites Manufacturing Innovation, Knoxville, TN, US) to bring a new thermal recycling solution to market: The trademarked Thermolyzer technology, from CHZ Technologies (a subsidiary of Aliquippa Holdings LLC, Austintown, OH, US), is a waste-to-energy reactor system, developed and originally envisioned in Germany to recycle discarded nylon carpeting. Thermolyzer processes shredded cured-part waste — end-of-life wind turbine blades, for example — and recovers all by-products by means of multiple reactors.

For example, says Pilpel, if copper-clad printed circuit boards were processed, the copper could be recovered, as well as the fibers: "This technology creates a clean-fuel gas product from the resin residue that meets natural gas specifications, and it generates no harmful emissions, thanks to inline scrubbers." With a long list of composites industry and wind energy partners, including Owens Corning (OC, Toledo, OH, US), ACMA and IACMI are evaluating a pilot process in Germany as a first phase, to prove the system and determine scalability, says OC's Dave Hartman.

"More work remains to be done, but it's a very promising technology," adds Pilpel.

Wet chemistry methods growing

Adherent Technologies Inc. (ATI, Albuquerque, NM, US) started its recycling business at least 20 years ago (see Learn More). Company president Dr. Ron Allred and Dr. Jan-Michael Gosau, engineering and environmental project manager, chose a wet chemistry process they call *chemolysis*, also referred to as tertiary treatment, that uses a liquid transfer fluid and catalyst combined with low heat and pressure to recycle end-of-life parts and recover both carbon fibers as well as resin, without generating airborne emissions. The recovered resin can be reused as fuel or as process chemicals in other industries. Allred adds, "We are recycling discarded commercial pressure tanks, for example, on our pilot line that yield 50-mm-long fibers with greater than 90% of virgin properties." Allred and Gosau point to the company's proprietary sizing technology, a key component of the recycling process, that makes the fibers usable again in composites processes. ATI has developed sizings not only for epoxy and thermoplastics (for injection molding pellets) but also for vinyl ester and bismaleimide (BMI) resins: "Our sizings provide superior mechanical properties," says Allred. He says that ATI is working with the University of New Mexico and European groups to develop a method to align recovered fibers and create nonwoven fabrics for the market: "It's a longer-term goal."

ATI has recently formed a partnership with investment group DLC Capital (Melbourne, VC, Australia), owned by Damian Cessario, to commercialize the recycling technology. DLC Capital and ATI have collaborated for years and have now formed a composites company, V Carbon (London, UK), which will reclaim carbon fiber and then use the fibers to manufacture parts within the group. V Carbon provides an integrated composites solution, spanning design and modeling, engineering, manufacturing and recycling, with the ATI process providing recycled fibers for customer projects. "This wet-chemistry process is the most elegant

Aerospace waste to sports & recreation utility

Recycled aerospace-grade prepreg is employed by CRTC (Port Angeles, WA, US) to make pickleball paddles with a balsa wood core for customer PickleballCentral.Com. Pickleball is a fast-growing, fast-paced net game that combines elements of tennis, ping-pong and badminton.

Source (main photo) | USAPA / Photographers | Tom Gottfried

Source (inset) | CRTC

solution of any on the market," contends Cessario, "because the resin is recycled as well as the fiber. We're offering a holistic composite solution."

Explains Allred, "ATI and V Carbon will be operating under the umbrella of the V Carbon Group, within which ATI will be the R&D entity." Cessario adds that plans are in the works for recycling plants in the UK, Europe and additional US locations.

A new entrant to the recycling community is Vartega (Golden, CO, US), headed by Andrew Maxey, an engineer whose interest in carbon fiber came from cycling: "We're the new kids on the block, but things are accelerating and the opportunities for recycling are growing." Vartega currently has a pilot-scale, proprietary and patent-pending low-energy solvolysis process, which treats uncured prepreg and tow-preg scrap, from sources including Alchemy Bicycle Co. (Denver, CO, US). The company is developing a path whereby Vartega would eventually provide its process technology to licensees, who would lease modular equipment for in-house, closed-loop recycling on a regional basis, because, says Maxey, "It's expensive to ship waste!"

For now, Vartega is working with Technical Fibre Products (TFP, Schenectady, NY, US), which converts the recovered fibers (some of them continuous, from towpreg process waste), all with known pedigree and source, into nonwoven mat and veil products. Maxey says Vartega mills and chops fibers internally and works with other partners to compound the material into pellets and 3D printing filament. Vartega is also part of ongoing research on techniques for fiber alignment in, for example, extruded thermoplastic sheet. "We're now processing enough material to supply developmental programs — for example, automotive programs to validate that the process and the material is viable," says Maxey. The company has released testing data on its recovered fiber (see Learn More), where the tensile strength and modulus of recovered fiber are comparable to virgin fiber controls.

"The fiber retains 100% of its properties with our process," Maxey contends. "This type of testing information is vital to help the composites industry get recycled fiber into automotive programs." Vartega also is working with sizing company Michelman (Cincinnati, OH, US) to develop sizings for recycled fibers to improve adhesion at the fiber/resin interface in thermoplastic composites.

Recyclable resins, reuse of material

"We're an atypical company," states CEO Bob Larsen of Composite Recycling Technology Center (CRTC, Port Angeles, WA, US). "We're a nonprofit, and our mission is to inspire, grow and lead the recycling community." Located in a region of concentrated composites manufacturing, in proximity to Boeing and many Boeing Tier companies, Larsen says CRTC wants to drive economic redevelopment and help reduce Port Angeles' unemployment, while modeling wise use of resources. CRTC combines recycled carbon fiber product development with production processes for high-volume, low-cost production. "Lack of consumer demand is often cited as a major factor holding back the development of the recycled composites industry," observes Larsen. "We are overcoming that barrier by bringing high-performance recycled carbon fiber products to consumer and industrial markets at heretofore unattainable prices." The company is co-located with Peninsula College and that school's Composite »

Fuel salvaged from former landfill waste

The American Composites Manufacturers Assn. (ACMA) is working with IACMI to develop the Thermolyzer waste-to-energy technology from CHZ Technologies (Austintown, OH, US) for composites recycling. The reactor system recovers multiple waste by-products and creates a clean fuel gas product that meets natural gas specifications. Source | CHZ Technologies

Work Force Training program, to train future employees for planned growth.

The company purchases "near first-quality" uncured aerospace prepreg scrap at a nominal rate from partner companies, including Toray Composites (America) Inc. (Tacoma, WA, US), and transforms it to make new, nonaerospace products. It has no plans to recycle cured composite parts: "We're taking advantage of the chemistry that's already there," says Larsen. "We're avoiding the need to add energy and cost to the material — carbon fiber already has more than twice the embodied energy of aluminum!"

CRTC has found success with its first commercial product, recycled carbon fiber pickleball paddles used in the popular court game. They are made using two plies of T800 carbon/epoxy prepreg, in a 0/90° layup over a balsa wood core, and oven-cured. The paddles have been certified by the USA Pickleball Assn. (Surprise, AZ, US) and are distributed by Pickleball Central.Com (Kent, WA, US). As an IACMI member, CRTC has already set up numerous collaborative research projects with universities and other recycling companies, including ELG CF, with whom it is working on applications of recycled carbon fiber material forms.

To support its manufacturing efforts, CRTC has moved into a purpose-built new facility, equipped with freezers for prepreg storage, presses, ovens, molds and more, says Larsen. "With our ELG partnership, we're a one-stop solution for scrap carbon fiber," he contends. "We have three or four new products coming later this year and are preparing for rapid growth."

Procotex (Dottignies, Belgium, a subsidiary of Dolintex NV) also recycles only unprocessed fiber waste — primarily, weaving and cutting scraps, waste from carbon fiber producers and, for now, only dry fibers. At its inception in 1965, Procotex was a flax fiber processor, but in time began to recycle both natural and synthetic fibers. The company entered the technical fiber space in 2011, when it acquired Apply Carbon SA (Lacuidic, France), an established specialist in the milling and precision cutting of not only carbon but also aramid, basalt and glass fibers used in composites.

Procotex sales director Bruno Douchy says the company recycles more than 1,000 MT of carbon fiber waste per annum, to produce milled and chopped carbon. To address the issue of dust emitted from milled carbon, Procotex has developed a new milled carbon fiber in granulate form, which allows better dosing/dispersal into the extruder, without conductive dust, says Douchy. Cut carbon fibers range from 30 μm to 120 mm in length, with fiber quality comparable to virgin fiber. New products include oversized, precision-chopped or random-cut carbon fibers, offered with sizings compatible with a number of matrices, with fibers designed to stay in bundle form for better dosing and dispersal. Says Douchy, "Recycled carbon fibers are attractive to the automotive industry, because good properties can be achieved at a much lower price. A challenge for auto industry projects is maintaining stable supply and quality. For this reason, we keep on hand a large stock of unprocessed material."

In addition to its technical fibers, says Douchy, Procotex processes 20,000 MT of recycled natural fibers, such as flax, plus synthetic fibers, including aramid and polypropylene — much of the latter from the carpet industry. "We're involved in the automotive, geotextile and concrete markets, and many more," states Douchy. "We're one of the biggest players, with real industrial project experience in fiber recycling."

Adesso Advanced Materials (Wuhu, China; Cambridge, UK and Princeton, NJ, US) and Connora Technologies (Hayward, CA, US) are approaching recycling from the flip side: Through a strategic partnership, they have developed recyclable thermoset *resins* that, post cure, can be readily degraded and removed from the reinforcement, leaving fibers intact for reuse. Bo Liang, Adesso's chairman and CEO, says its trademarked Cleavamine hardener and Recycloset resin enable the crosslinks in the cured part to be "cleaved" by a mild acid solution, such as vinegar. The recovered resin is neutralized and the thermoplastic precipitate can be reused as a toughening agent in adhesives or molding compounds, explains Liang: "This is a programmable, recyclable material by design." Testing reportedly shows that composite coupons made with this recyclable resin and hardener are comparable in performance to conventional carbon/epoxy.

Adesso is currently involved in several major programs, including recyclable printed circuit boards (PCBs) for Shengyi Technology; a production carbon fiber bicycle by Pardus (a Taishan Sports brand, San Mateo, CA, US); automotive parts for Wuhu-based Chery Automobile Co. Ltd., in partnership »

■ **Removable, recyclable matrices enable easier reclamation**

Resins also can be recycled and reused, which allows recovery of the reinforcements in original form and condition. Here, Adesso Advanced Materials' (Wuhu, China) Recycloset epoxy resin with Cleavamine hardener is predesigned for recycling-friendly removal. In the photo at bottom, the matrix on the bottom third of the PCB, as designed, has been degraded and removed after immersion in a mild acid, leaving the printed circuit board (PCB) glass layers intact and undamaged. Source | Adesso Advanced Materials

with ELG CF; and research on recyclable wind blades, in cooperation with the University of Southern California. Adds Liang, "We're currently teaming with a large US chemical company with global reach and the manufacturing capacity to make this technology available worldwide."

In a similar vein, Connora Technologies' trademarked Recyclamine product is a hardener for epoxy resins that likewise enables polymer crosslinks in cured composites to be broken by an acid, leaving a thermoplastic epoxy residue. The reinforcing fibers originally used in the composite part can be recovered without chopping or shredding, in their original form and architecture, without damage. *CW* has written about Recyclamine's use in a high-pressure resin transfer molding (HP-RTM) process (see Learn More) in cooperation with Fraunhofer Project Center for Composites Research (FPC, London, ON, Canada) and Fraunhofer ICT (Pfinztal, Germany). The study showed that, after recycling, the properties of recovered reinforcements were the same as virgin carbon fiber.

Applications are on the way. The company is continuing work on HP-RTM for the automotive industry via a Phase II SBIR project. More recently, Connora Technologies announced partnerships with Shred Optics (a company of Anomaly Action Sports USA, New Boston, NH, US), Future Fins (Huntington Beach, CA, US) and snowboard makers including Burton Snowboards (Burlington, VT, US), Niche Snowboards (Salt Lake City, UT, US) and The CAPiTA Mothership (Gail, Austria) to turn snowboard manufacturing waste into action sports accessories, says Connora CEO Dr. Rey Banatao. "Through our Recyclamine resin technology, we can recover all of the snowboard waste that typically goes to landfill," he says. "In addition to reclaiming the plastic and fiber reinforcement components, the epoxy resin is transformed into a reusable thermoplastic that is injection moldable, to go back into the sporting goods industry, and reduce waste normally sent to landfill." To reach industrial scale and cost Connora partnered recently with global epoxy producer and GL-certified wind turbine industry supplier, Aditya Birla Chemicals Ltd. (Lummpini, Bangkok, Thailand), which is now manufacturing Recyclamine at metric-tonne scale.

Many more composites recycling efforts, for lack of space, couldn't be covered here. The Japan Carbon Fiber Manufacturers Assn. (JCMA) has operated a pilot plant in Ohmuta City, Fukuoka Prefecture, since 2009, and continues R&D efforts on recycling technology. The Korea Institute of Science and Technology's (KIST, Seoul, South Korea) Carbon Convergence Materials Research Center has reportedly developed a wet-chemistry method for carbon fiber recovery that is 60% less expensive than pyrolysis. And Karborek (Martignano, Italy), which uses a patented combined pyrolysis and oxygen upgrading process, to avoid creating char on the fibers, is still providing Karbo Chopped and Karbo Felt nonwovens.

Recycling efforts have been implemented by individual suppliers as well. Toho Tenax Co. Ltd.'s (Tokyo, Japan) German subsidiary Toho Tenax Europe GmbH (Wuppertal, Germany), for example, recently introduced Tenax-E COMPOUND rPEEK CF30, a reinforced material that combines waste materials generated during processing of its Tenax ThermoPlastics, and recycled semicrystalline PEEK polymer, which contains 30% carbon fiber by weight and offers high performance for injection molding applications. Others, including Continental Structural Plastics (part of Teijin, Auburn Hills, MI, US), have in-house recycling operations at varying scales. And machinery firm Cannon SpA (Peschiera Borromeo, Italy) co-funded a European project called CRESIM (Carbon Recycling by Epoxy Special IMpregnation) and has developed a method for wet compression molding of CFRP parts using recycled carbon fibers.

Developing a business case

Composites recycling efforts are a puzzle right now, with lots of pieces that include technology, government and industry groups, standards and education," says Pilpel. "You have to start with a basic business case." For example, a company's simplest step is to convert its waste to energy at the plant site, avoiding the cost of landfill disposal and recouping a small portion of the original material cost. Greater return on material cost can be gained if waste can be converted to new, useable forms for sale, or returned internally to a company's process: "We need to find the hidden applications for recycled material," he adds, pointing to the success of used auto tire recycling in the US, where uses of shredded tire waste were eventually found, to keep tires out of landfills.

Clearly, if automotive manufacturers do adopt carbon fiber in production vehicles in a big way, supply challenges will follow. High-value recycled carbon fibers can help bridge the supply gap, at a lower price point. ACMA's Recycling Committee is working with ISRI (Institute of Scrap Recycling Industries, Washington, DC, US) as well as IACMI to develop a recycling infrastructure with reliable logistics, and to develop standards for recycled fibers. The looming question is the far greater quantity of glass fiber parts that could, and should, be recycled — at this point, however, the lower value of glass makes it more difficult to address, says Pilpel.

"There's no silver bullet, because composites are complicated structures. But we're on the road to understanding this and getting the industry talking logically. It's an exciting time, because a recycling infrastructure is growing," says Vartega's Maxey. Adds ELG CF's Barnes, "The situation is getting better — by 2019, I think composites recyclers will start to see real volumes." CW

LEARN MORE

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

Previous *CW* articles on this subject can be viewed online:

From 2007, "Carbon fiber: Life Beyond the Landfill" | short.compositesworld.com/3aXXjjLR

From 2014, "Recycled carbon fiber update: Closing the CFRP lifecycle loop" | short.compositesworld.com/RCFUpdate

From the *CW* Blog, "Recyclable epoxy proven in HP-RTM" | short.compositesworld.com/connoraRTM

From the *CW* Blog, "Vartega shows positive results of recycled carbon fiber testing" | short.compositesworld.com/VartegarCF

See the Thermolyzer video online | www.youtube.com/watch?v=b-_HLsZAxal&feature=youtu.be

The UK Composites recycling report is available online | short.compositesworld.com/UKRecycRpt

ABOUT THE AUTHOR

Sara Black is a *CW* senior editor and has served on the *CW* staff for 19 years.
sara@compositesworld.com

Thermoplastic composite panels deliver affordable housing solutions

Modular construction concept takes composite housing another step forward, offering a wide range of comparably priced housing solutions to builders of all types.

By Ginger Gardiner / Senior Editor

» In the 21st Century, one of the more compelling human stories is the growing need for resources to house Earth's expanding population, and the growing awareness that those resources are finite and, in many cases, increasingly scarce. One case in which that contrast is acute is residential housing. The United Nations foresees a deepening global housing crisis — more than 440 *million* urban households will be in need of *affordable* accommodation by 2025. But conservationists warn that the sustainability of Earth's forests, the source of the lumber to build those accommodations, is at serious risk. This conflict has done much to pique interest in fast-build construction technologies based on fiber-reinforced composites. As the new century's second decade nears its end, composite manufacturers' efforts in the housing arena are picking up speed. *CW* reported, for example, on the recent international growth of MVC Plásticos' (São José dos Pinhais, Brazil) locally grown MVC Wall System in 2016 (see Learn More, p. 62). But many such solutions must enter the market if the construction industry is to make inroads into residential construction and homebuilders are to appreciate the value that lightweight, energy-efficient composite technologies can offer.

Continuous fiber-reinforced *thermoplastic* composite panel technologies conceived seven years ago by Axia Materials (Hwaseong, South Korea) have already seen use in numerous projects. Among them are uses as diverse as US military barracks in Kuwait, vacation cabins in Europe, affordable homes in Asia, Africa and Central America, and, currently, bids for multi-family refugee and student housing in Scandinavia. Used together with an in-house developed, software-based housing design system, Axia's composite panel concept is, today, anticipating the future of residential homebuilding.

Thermoplastic composite panels

Axia Materials began in 2000 as PolymersNet Co. Ltd., a developer and supplier of thermoplastic engineered polymers for injection

Short on build time, not on quality

The 45m² Gable House demonstrator was completed in only seven days, using LitePan composite SIP with LiteTex thermoplastic composite skins and the Pixel Haus modular construction system.

Source (all images) | Axia Materials

molding. Using novel, in-house polymerization technologies, the company formed partnerships with well-known engineering plastics firms worldwide. In 2004, it focused on high-flow polymers and *in situ* polymerization, changing its name to Axia Materials in 2007. At that time, it also established a subsidiary in Kirchheim, Germany, for raw material development.

In 2010, the company began prototyping its LiteTex continuous fiber-reinforced thermoplastic production line for thermoformable sheet stock. "We produce continuous rolls, containing up to 400m of 3m-wide sheet, made using our proprietary powdered resin matrix materials," says Justin Jin, CEO and president of Axia Materials. The einforcement may be carbon, glass, aramid or any other industrial fiber, while the matrix is one of six resins that Axia has commercialized (Table 1, p. 61). "We use solid monomer to avoid volatile organic compound (VOC) emissions," Jin adds.

The solid monomer, formulated for high flow, avoids not only VOC issues but also other problems common to materials already processed into high-viscosity polymers. For example, to maintain pressure on viscous melted polymers, sheet width must often be limited and the manufacturing method is typically a batch process. But Jin notes that LiteTex is made in a continuous process at speeds of 2-4 m/min, "determined by the *in situ* polymerization rate of each monomer. Our lines do not use high-pressure machines and typically stay below 260°C." Rolls of reinforcement are fed into the machinery. The monomer is added in power form, then melts, *in situ* polymerizes and consolidates it with the reinforcement. The melted monomer's waterlike viscosity enables *micro*-impregnation of filaments within the fiber bundles, achieving a high degree of resin-to-fiber distribution. The consolidated sheet receives a UV protection film in line, and then rolled, labeled and inventoried. »

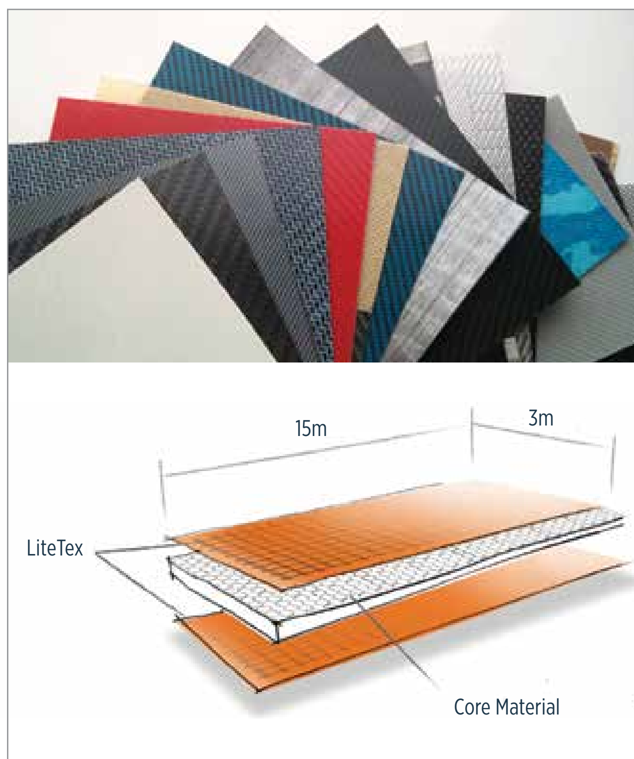


FIG. 1 Versatile materials and generous panel span

LiteTex continuous fiber-reinforced thermoplastic composite is produced using a variety of reinforcements and matrix resins (top). LitePan composite structural insulation panels (SIP) are available in labor-reducing long spans (up to 3m by 15m) thanks to LiteTex faceskins, produced up to 3m wide and in continuous lengths, which are laminated onto lightweight, insulative core materials (bottom).

1 CAD files for this Pixel Haus kit were used to program CNC robots, which rout out window and door openings.

2 Panels were readied to be flat-packed into a standard shipping container for transport to the construction site.

3 Panel floor was attached to the prepared concrete slab, and two panels forming one gabled end-wall were erected first, attached to each other and the floor, using a proprietary adhesive and composite profiles.

4 Adjacent panels were then bonded to each previous panel, glued along edges and to the floor, moving around the perimeter of the house until the walls were constructed.

By 2014, two LiteTex lines were refined and running, but now the LiteTex panels weren't used only for thermoforming. Axia Materials added a LitePan laminated composite structural insulation panels (SIP) production line, in which LiteTex skins are laminated onto both sides of a core material (Fig. 1, p. 57) to form what would become its residential housing panel stock.

The panels can be varied according to application and need. The core can be insulation foam — expanded polystyrene (EPS), extruded polystyrene (XPS), polyurethane (PU) or PET — or one of the more recently developed structural insulation cores made with rubber, ceramic or polymer honeycomb materials. Panels up to 3m by 15m are produced using a proprietary adhesive and a vacuum or hydraulic press. Production time varies between 20 and 120 minutes, depending on the process. Panels are then checked to ensure a smooth, flat, high-quality surface. They are then trimmed and routed to create window and door openings and finished for use as walls, roofs and floors in permanent or deployable buildings.

Eclectic and varied applications

From the beginning, Axia has emphasized breadth of application. Case in point? An early LitePan destination was at the Eiffel Tower. LiteTex thermoplastic skins laminated to PU foam, then to marble facing, were used in 2014 to reduce the weight of hundreds of Tower stairs. "The 20-mm-thick marble steps were too heavy," says Jin. "We were able to reduce this to 5-mm-thick marble facings bonded to very strong yet lightweight panels, featuring LiteTex skins made from glass fiber woven roving and our proprietary mEP resin."

In 2015, Axia customer Technology and Supply Management LLC (TaSM, Fairfax, VA, US) used LiteTex glass fiber/mEP skins for the interior and exterior faceskins of the composite panels

5 Two panels were then attached to form the roof.

7 By day four, windows and door installations were completed, as were interior plumbing and wiring, and a zinc roof system was in progress.

6 On day two, window and door were installations had begun and the floor heating system was installed.

8 By day seven, the 45m² house was complete, including interior paint, wood flooring, exterior stucco and paint, lighting and plumbing fixtures, Google Nest IoT system, ventilation and final finishes.

it supplied for the US military's Kuwait Energy Efficient Project (KEEP) at Camp Buehring, Kuwait. The relocatable kit developed by TaSM enabled the construction of 75 two-story and 25 one-story shelters, fabricated by connecting the SIP walls, roofs and floors, without any additional structural framing. Even when outside temperatures hit 115°F/46°C, the buildings maintain 78°F/26°C inside, without air conditioning, thanks to the R-25 panels, with an insulation rating of 0.23 w/m²K. The buildings also feature roof-mounted solar panels. Their energy efficiency and comparatively low weight will save the military hundreds of thousands of dollars in fuel and energy costs.

Pixel Haus: Housing simplified

As Axia Materials worked with TaSM and its other customers, it recognized the need for a set of pre-engineered, standard designs, using panels pre-tested to meet industry building and fire regulations. Thus, the Pixel Haus system was developed for a variety of temporary, emergency and permanent accommodations using LiteSpan SIP. There are currently several Pixel Haus design categories:

- Four standard "tiny house" designs (e.g., 6m width with lengths from 5-10m)
- Four standard designs for "regular" homes (e.g., one 6m by 14m story, two 4.5m by 14m stories)
- Three sizes of emergency/disaster/mobile shelters (18, 27 or 36m²)
- Temporary housing (36, 58 or 65m²) sized slightly larger than a shipping container, which can be built in one day for use as a field office, temporary hospital, school building or any other application where mass accommodation is needed in a short period.

"The building sector contributes up to 30% of greenhouse gas »

FIG. 2 LitePan adaptable to conventional finishing materials

Pixel Haus modular construction uses a LitePan composite SIP with 1.2 cm by 1.2 cm thick wood furring strips attached to one side which support the fireproof layers, e.g., sheetrock, gypsum or magnesium oxide (MGO) board.

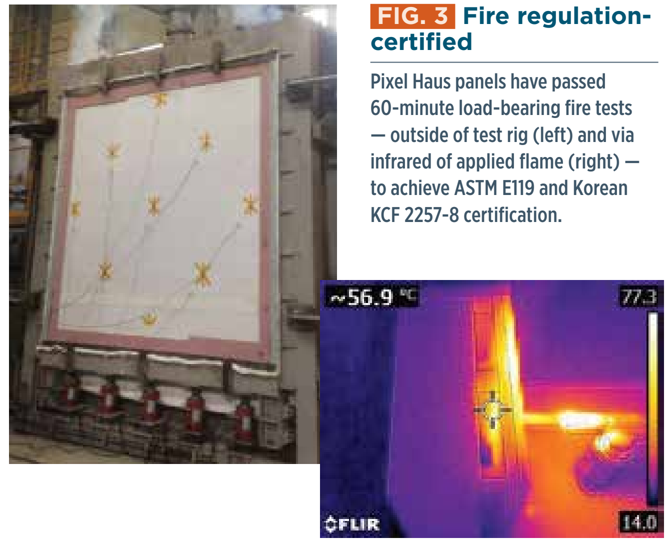


FIG. 3 Fire regulation-certified

Pixel Haus panels have passed 60-minute load-bearing fire tests — outside of test rig (left) and via infrared of applied flame (right) — to achieve ASTM E119 and Korean KCF 2257-8 certification.

and consumes 40% of energy worldwide," says Jin. He claims the Pixel Haus building system requires only 15% of the energy vs. steel, yet is 4-10 times stronger, plus offers a longer lifecycle. "I would describe Pixel Haus as 'Energy House' because it minimizes energy use from the manufacturing of materials, through to delivery, construction, building management/operation, demolition and recycling," says Jin. "All of the processes emit minimum CO_2 yet achieve maximum energy efficient housing, plus all the materials used for Pixel Haus can be 100% recycled," he adds.

"Each Pixel Haus design is based on easy-to-build modules," Jin explains, "so construction takes only 12% of the time compared to typical building methods. We can connect all of the panels for a single module with eight people in three hours." Further, he notes, this process does not require building experts, thus enabling do-it-yourself (DIY) construction. "We believe this DIY process is the only way to supply large numbers of houses in short time periods."

> Pixel Haus design is based on easy-to-build modules, cutting typical residential construction time by 88%.

The panels that comprise Pixel Haus modules consist of a LitePan SIP with 1.2 cm by 1.2 cm thick wood furring strips attached to one side, which support the fireproof layers (e.g., sheetrock, gypsum or magnesium oxide (MGO) board). The air gap between LitePan and the fireproof layer also hides electric cabling and increases insulation (Fig. 2, above). To pass one-hour load bearing fire tests, two fireproof layers are screwed into the furring strips. The number, thickness and type of fireproof layers are highly dependent on each site's building code. Jin notes that Pixel Haus designs use insulated panels rated up to R-50 with no thermal bridging. Each house is also surface-sealed, waterproof and airtight.

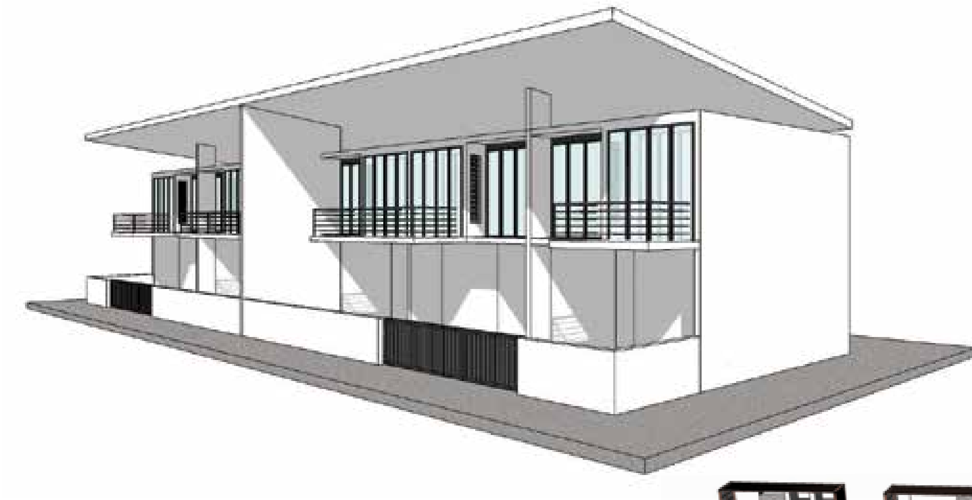
Pixel Haus panel-to-panel structural connections can be selected from various methods, including adhesively bonded composite profiles or engineered plastic fastener systems. "The engineered plastic fasteners have been jointly developed with a German company," says Jin, and provide more than 1,600N (about 160 kg) of pullout strength while maintaining a watertight seal. Axia also is working on a proprietary prepreg connection method. "The key technology of the panel-to-panel connection is to achieve load transfer, so that you exploit the composite panels' high tensile strength," Jin explains. "Axia Materials has developed various proprietary connecting methods, which have already passed building regulations."

Gable House demonstration

In a demonstration project called Gable House, completed in Hwaseong, Korea, in October 2016 and pictured here on pp. 56-57, a 45m² house was built in seven days.

The two-story house, comprising a 32m² first floor and 13m² second floor, was constructed from 14 LitePan units with 150-mm thickness and R-27 insulation. After lamination, the LitePan panels were transferred to an automated cell where CAD files for this Pixel Haus kit directed CNC robots to rout each panel's dimensions (e.g,, end panels were cut diagonally to enable support for its gabled roof), as well as cutouts for window and door openings (Step 1, p. 58). All panel edges were tightly sealed to avoid damage or water absorption during delivery and construction. Panels were then flat-packed into a single container and transported to the construction site (Step 2).

Onsite, a concrete pad was prepared for construction. (Note: Although Gable House was a demonstration of construction method and speed and, therefore, plumbing steps were bypassed, plumbing connections ordinarily would be installed in the Pixel Haus concrete pad before panel construction began.) Pixel Haus panels then were unloaded.



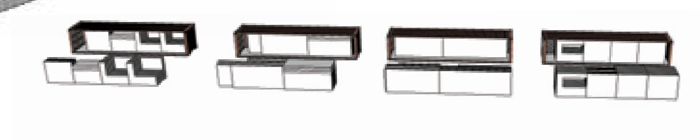


FIG. 4 Affordable, fast-build housing

Pixel Haus refugee and student housing offers affordability and speed in transport of materials — four containers for each 547.5m^2 module — and construction of high-quality, energy-efficient housing.

The bottom floor panel was anchored into the concrete foundation with mechanical fasteners. Two panels were formed into one gabled end-wall, using the adhesive and composite profile structural connection. Then the assembled end-wall was erected (Step 3). Adjacent panels were then bonded to each previously erected panel, glued along edges and also to the floor, moving around the perimeter of the house until the walls were in place (Step 4). This process was completed in only three hours. Then two panels were adhesvely bonded over the top of the walls to form the gabled roof (Step 5, p. 59).

On the second day, wall, floor and roof connection zones were triple-sealed, windows and doors were installed and the inner floor heating (an electric-powered hot-water system using vacuum copper pipe) was installed (Step 6). On day three, interior plumbing and electrical wiring were completed and the zinc roof system was laid directly over the LitePan roof panels (Step 7). Note that additional waterproofing was unnecessary, which saved time and cost compared to conventional building technology. A layer of sheetrock was applied to all walls and roof panels, providing 1-hr load-bearing fire resistance. The roof was finished on day 4, concrete was applied on top of the floor heating system and the interior walls/ceiling and exterior walls were prepared for paint and plaster, respectively. On day five, the outer-wall stucco and interior paint was applied, and wood flooring was installed. Painting was finished inside and out on day six. Day seven installations included lighting and plumbing fixtures, Google Nest Internet of Thing (IoT) control system, ventilation and other final finishes (Step 8).

Certification, cost and future projects

Jin is quick to point out that Pixel Haus is far beyond the demonstration stage. "Many Pixel Haus projects have now been completed," he empahisizes, "including hospitals in Africa, affordable homes in Central America, passive energy homes in Korea and emergency homes in New Zealand." The Pixel Haus panels have passed 60-minute load-bearing fire tests to achieve ASTM E119, European REI 60 and Korean KCF 2257-8 certification (Fig. 3, p. 60). "Now we are proceeding with certification per the *International Building Code* (*IBC*), which will include testing for mechanical properties, fire rates and fastening," says Jin. "We are already approved for construction around the world, including in North America," he adds. "Having *IBC* certification just reinforces the reliability of our data and construction approach."

The Pixel Haus concept is being further developed in cooperation with the Aachen Center for Lightweight Technology (AZL, Aachen, Germany), including pursuit of Zero Net Energy (ZNE) certification. ZNE buildings, as defined by the New Buildings Institute (NBI, Washington DC, US), are ultra-efficient constructions that consume only as much energy as they produce from clean, renewable resources. ZNE construction is a fast-growing trend, with the US Green Building Council (USGBC, Washington DC, US) reporting a 74% increase in ZNE-certified buildings in 2017 and continued growth expected. "We are developing »

Table 1	Axia Materials matrix resins used in LiteTex products
m-EP	monomer epoxy/polyester
PA6	polyamide 6
PA12	polyamide 12
CBT	cyclic butylene terephthalate
Polyketone	-
TPU	Thermoplastic polyurethane

TABLE 1 LiteTex matrix resins

Axia combines carbon, glass, aramid or other industrial fiber with one of six matrix resins that Axia has commercialized.

'click-in' solar roof panels using LitePan modular roof systems to further reduce installation and maintenance costs," says Jin. "We are also using small wind turbines for power as well as to generate air current, forcing airflow through the space between the solar panels and the roof."

Significantly, Jin claims Pixel Haus cost is comparable to or less than that of conventional construction, due to reduced labor and time. For example, a fully-equipped 65m^2 house starts at US$30,000 and can be built in seven days. "Our hardware and materials cost more," he concedes, "but our approach requires much less time and labor and our transportation costs are lower, due to flat-pack ability."

He points out that its transportability makes the Pixel Haus concept well-suited for disaster and emergency housing. Indeed, a submitted bid proposal for refugee housing in Scandinavia calls for each 548m^2 Pixel Haus module — comprising four one-bedroom/one-bathroom units connected by a central hallway — to be built from 96 panels that can be transported via four 12m freight containers (Fig. 4, p. 61).

Finally, Jin is excited about the concept of do-it-yourself (DIY) housing. "Within the next 12 months, we will launch a next-generation Pixel Haus that helps normal people build their own homes without needing support from building experts," he reveals. "Now under development by a global team, this next generation of Pixel Haus will be 'drag-and-drop' designed on the web and will exploit virtual reality technology to help people imagine their house before construction." As is done for professional homebuilders, do-it-yourselfers will see precision-cut thermoplastic composite panels delivered as flat packs directly to their building sites.

"We are actively working on developing game-changing solutions to meet a wide variety of housing needs around the world," says Jin. "Our goal is to bring the most energy efficient and eco-friendly house solutions with the best composite material for the best performance but in a smart way that delivers on affordability." CW

LEARN MORE

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

Read more about thermal bridging and composites as thermal breaks online | short.compositesworld.com/ThermBrk

ABOUT THE AUTHOR

CW senior editor Ginger Gardiner has an engineering/materials background and more than 20 years of experience in the composites industry.
ginger@compositesworld.com

Composites Events

Aug. 20-25, 2017 — Xi'an, China
ICCM21 – 21st International Conference on Composite Materials
iccm21.org

Aug. 22-24, 2017 — Detroit, MI, US
6th Global Automotive Lightweight Materials Congress 2017
global-automotive-lightweight-materials-detroit.com

Sept. 5-7, 2017 — Sheffield, UK
ACIC 2017 – 8th International Conference on Advanced Composites in Construction
acic-conference.com

Sept. 6-8, 2017 — Novi, MI, US
SPE Automotive Composites Conference and Exhibition (ACCE)
speautomotive.com/acce-conference

CW **Sept. 11-14, 2017 — Orlando, FL, US**
CAMX (Composites and Advanced Materials Expo) 2017
thecamx.org

Sept. 12-15, 2017 — Husum, Germany
HUSUM Wind 2017
husumwind.com/husumwind/en

Sept. 13-15, 2017 — Nagoya, Aichi, Japan
ICOLSE – 2017 International Conference on Lightning and Static Electricity
icolse2017.org

Sept. 18-20, 2017 — Toulouse, France
SpeedNews 18th Annual Aviation Industry Suppliers Conference in Toulouse
speednews.com/aviation-industry-suppliers-conference-in-toulouse

Sept. 19-21, 2017 — Tampa, FL, US
IBEX 2017
ibexshow.com/show-info

Sept. 19-21, 2017 — Stuttgart, Germany
Composites Europe 2017
composites-europe.com

Sept. 19-23, 2017 — Vancouver, BC, Canada
39th IABSE Symposium: Vancouver 2017
iabse.org

Sept. 26-28, 2017 — Birmingham, UK
TCT Show 2017
tctshow.com

Oct. 2-4, 2017 — New Orleans, LA, US
2017 Polyurethane Technical Conference
polyurethane.americanchemistry.com/2017-Polyurethanes-Technical-Conference.html

Oct. 4-5, 2017 — Los Angeles, CA, US
SpeedNews 22nd Annual Business & General Aviation Industry Suppliers Conference
speednews.com/business-and-general-aviation-industry-suppliers-conference

Oct. 5-7, 2017 — Istanbul, Turkey
TURK Kompozit 2017 Composites Summit Turkey
www.turk-kompozit.org/en/home

Oct. 10-12, 2017 — Knoxville, TN, US
Additive Manufacturing Conference 2017
additiveconference.com

Oct. 17-19, 2017 — Wichita, KS, US
ASIDIC 2017: Aerospace Structural Impact Dynamics International Conference
asidiconference.org

Oct. 23-25, 2017 — West Lafayette, IN, US
32nd Annual American Society for Composites Technical Conference
cdmhub.org/groups/asc2017

Nov. 1-3, 2017 — Seoul, Republic of Korea
JEC Asia 2017
jeccomposites.com/events/jec-asia-2017

Nov. 8-10, 2017 — Boston, MA, US
Greenbuild International Conference and Expo
greenbuildexpo.com

Nov. 14-16, 2017 — Stuttgart, Germany
SAMPE Conference 17 Stuttgart
sampe-europe.org/conferences/conference-2017-stuttgart

Nov. 15-16, 2017 — Madrid, Spain
Composite Spain
compositespain.com/en/default.html

CW **Nov. 28-30, 2017 — Charleston, SC, US**
CompositesWorld's Carbon Fiber 2017
carbonfiberevent.com

Source | Bike Ahead

AUTOMATED CUTTER ENHANCES BICYCLE PRODUCTION

Precision and reliability keyed startup's success.

› Although many well-known bicycle manufacturers have long since moved their production to the Far East, start-up company Bike Ahead (Würzburg, Germany) has successfully bucked that trend. Armed with a degree in plastics engineering and a passion for biking, company founder and leader Christian Gemperlein developed, in 2010, a six-spoke carbon wheel as part of his studies. With the help of a private investor, he started Bike Ahead two years later. Now he and his staff of 17 build not only wheels but carbon fiber bicycle frames, sold through distributors worldwide, plus finished bikes in short runs. What's more, they have moved well beyond the biking world into automotive, machine design and construction as well as medical technologies on a contract basis.

Gemperlein believes his company has a competitive advantage: "From idea to development and all the way through the production process, we produce *in-house*. This helps in customer-driven projects, especially in prototyping for applications that go well beyond bicycling." Most of Bike Ahead's turnover, however, comes from building bicycles in small series.

Gemperlein knew that part production would require carbon fiber prepreg, and he realized that this high-cost material required precise fiber orientation, especially for the very light areal weight materials the company uses. Manual cutting, he says, was out of the question. For that reason, he chose early on to invest in a **Zünd Systemtechnik AG** (Altstätten, Switzerland) G3 L-2500 digital flatbed cutting machine. "The G3 cutter was our most important start-up investment besides the autoclave."

The intuitive user-interface and workflow software that comes with the Zünd Cut Center (ZCC) reduced training time for operators and has increased familiarity with the equipment. The software's open interface design makes the Zünd G3 very easy to integrate into his existing production workflow, says Gemperlein. While the machine speed is welcome, he adds, "production speed was *not* our primary concern. We wanted the precision and reliability the Zünd G3 cutter could offer."

State-of-the-art nesting functionalities ensure optimal ply placement even for parts with highly complex contours. This reduces setup time and waste and optimizes yield. Plus, the automated cutting frees up operators for other tasks. "The machine is so reliable, we can let it run by itself without any qualms." CW

MANUFACTURING SUPPLIERS

RECRUITMENT/ HELP WANTED

TESTING

ADVERTISING INDEX

ADVERTISING INDEX

SHOWCASE

RTM-based redesign advances safety for one-of-a-kind wind tunnel

Glass fiber and honeycomb spacers between compressor blades get upgraded to a higher factor of safety with less weight using solid carbon fiber and RTM.

By Ginger Gardiner / Senior Editor

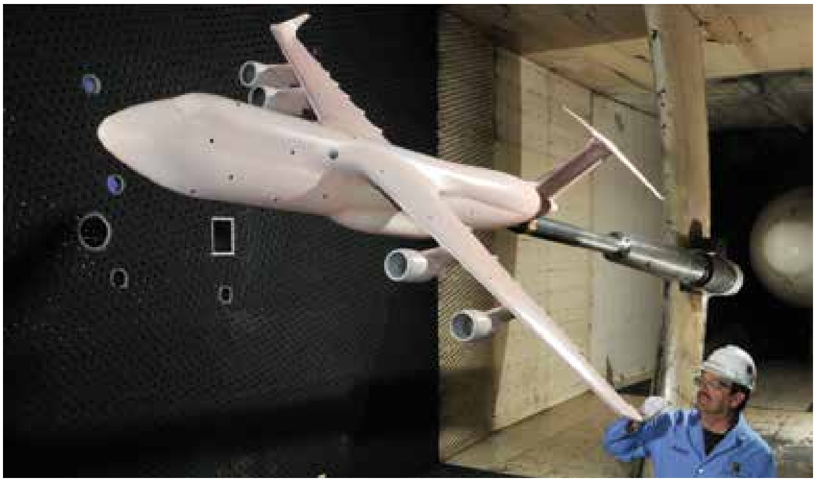


FIG. 1 A top wind tunnel for a half-century

The 16T wind tunnel, used in almost every major DoD and US spaceflight vehicle program for 55 years, was fitted with the new spacers, which are bolted onto the hub of its compressor. The compressor's nosecone nacelle can be seen at far right above the technician. Source | AEDC

» The Arnold Engineering Development Complex (AEDC, Arnold Air Force Base, TN, US) is the world's largest, most advanced collection of flight simulation test facilities. Many of its 55 wind tunnels have capabilities unmatched elsewhere. The "transonic" 5m by 12m long test section for tunnel 16T, one of three tunnels in the AEDC's Propulsion Wind Tunnel Facility, is one of these exceptional assets — a workhorse that can test models at air speeds from Mach 0.05 to 1.60, while simulating unit Reynolds numbers from 0.03 to 7.3 million/ft and replicating altitude conditions from sea level to 23 km (Fig. 1).

Chris Gernaat, structural analysis engineer for 16T, says it has supported almost every major US Department of Defense (DoD) and space flight vehicle program in the past 55 years. "We're currently doing work for the US Air Force, NASA and commercial space companies, among others."

Gernaat was a technical team member on the project to replace the tunnel's previous glass fiber/epoxy and Nomex honeycomb-cored spacers with a new generation of composite structures. Positioned between the blades of 16T's 600-rpm, 9.1m-diameter, three-stage compressor, the spacers hold the blades in place in the absence of centrifugal force while at rest and during compressor ramp up and ramp down. They prevent rotor blades from impacting adjacent stator blades, which could cause disastrous failure (Fig. 2, p. 70). Despite the previous spacers' 35 years of service, their safety factor of 2 (load carrying capacity of two times the ultimate in-service load) left much to be desired in terms of risk mitigation. "Our main goal was to increase the factor of safety," he says.

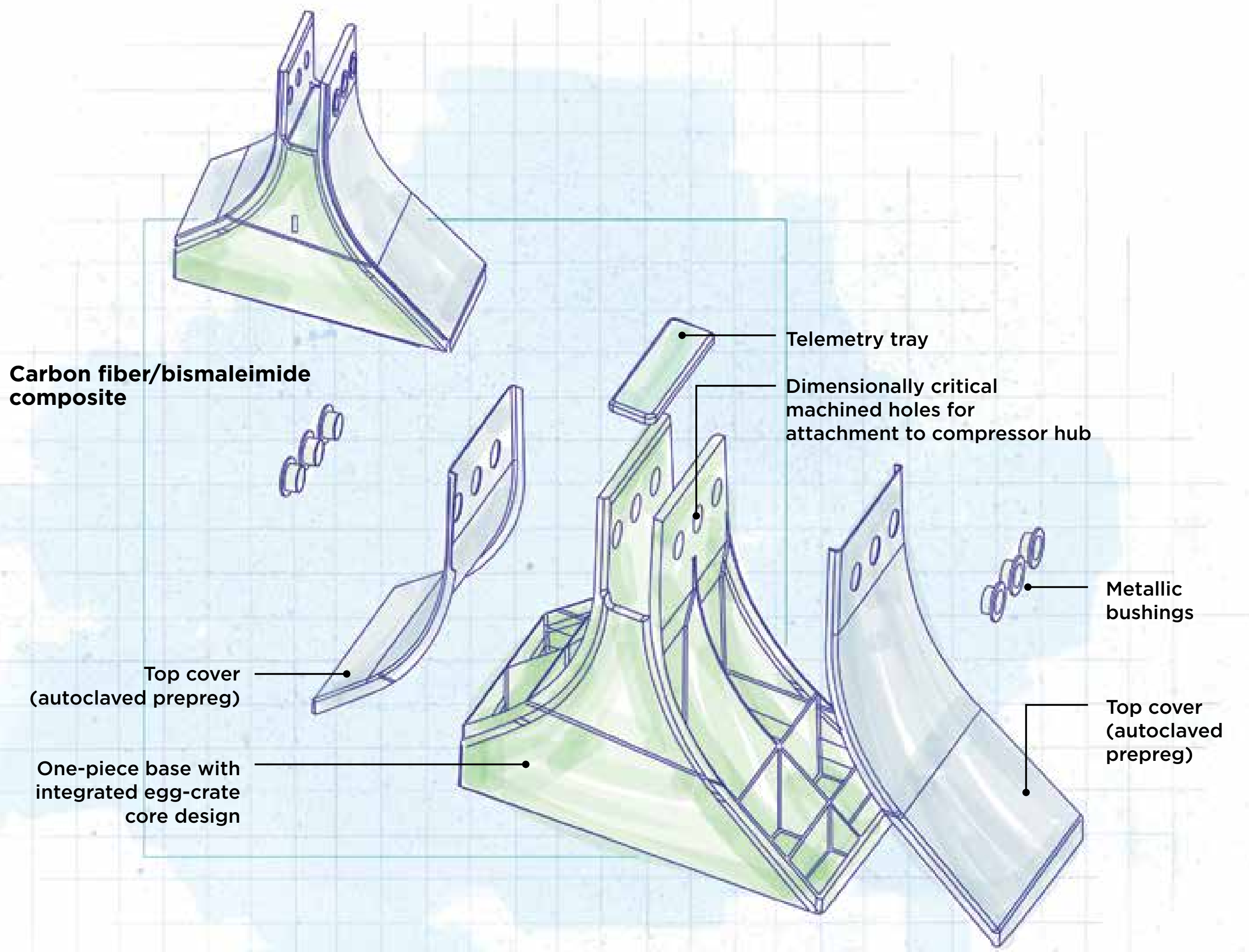
Developing a bid-winning design

When the project was offered worldwide, Matrix Composites (Rockledge, FL, US) turned in the winning bid. "I can't say it was any one thing that won the contract for us, beyond meeting the technical objectives at an attractive cost," says Matrix president Dave Nesbitt, whose background includes parts production for NASA's Space Shuttle and US military and commercial aerospace companies. "But a lot of it had to do with our RTM experience." He notes the company uses a range of processes, "but our closed molding capability is what sets us apart."

Notably, the bid solicitation *didn't* specify a manufacturing process. "We were given the design envelope and critical attachment points as well as operating requirements," Nesbitt recalls. The spacers feature a complex shape and would be subject to high loads in a high-temperature environment, thanks to the friction of compressed air and the compressor's rotational speed. "The spinning parts are rotating with a 1,000G load, so balance in the compressor is crucial," he points out, "which translates into a need for exceptional part-to-part repeatability." Although this is where RTM excels, its selection wasn't a given, but became clear only after the structural design was explored.

Nesbitt says the shape's complexity was the big challenge initially. "Our technical team brainstormed half a dozen conceptual designs, staying open to process, geometry and assembly options," he explains. "We then did a trade evaluation, rating the designs on weight reduction, tooling cost, producability, production cost, etc., and finally selected the best-rated option."

Using Dassault Systèmes (Waltham, MA, US) CATIA software for solid modeling and NEi Nastran (AutoDesk, San Rafael, CA,



DESIGN RESULTS | **Matrix Composites RTM'd Spacer for 16T Wind Tunnel**

- An improvement in the spacer's factor of safety from 2 to 5, plus increased durability through monolithic construction, by replacing ingression-prone honeycomb.
- An increase in the legacy spacer's in-service temperature capability of 66°C to a much safer continuous operating temperature range of greater than 149°C.
- An egg-crate design in the base of the 610-mm long by 356-mm wide by 560-mm high spacer that contributes to a weight reduction of 62%, from 21 kg to only 8 kg.

Illustration / Karl Reque

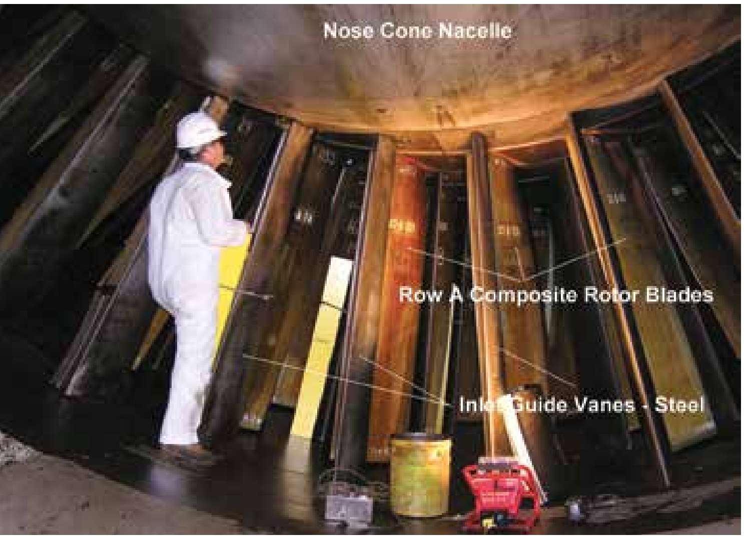
US) for structural analysis, the team determined that monolithic composite laminates with an egg-crate reinforcement grid in the base would achieve a safety factor of 5. The laminate transitions from 2.5 mm thick at the egg-crate partitions up to 16.3 mm in the plate where holes were machined for attachment to the compressor hub (Fig. 3, p. 70). Each 610-mm-long by 356-mm-wide by 560-mm-high spacer body would be produced as an integrated, single-piece unit, using RTM.

Materials selection

The trade study led to 5250-4 bismaleimide (BMI) resin from Solvay Aerospace Materials (Tempe, AZ, US) and IM7 carbon fiber from Hexcel (Stamford, CT, US). "This is the same material system qualified on multiple fighter jet programs supported by Matrix," Nesbitt points out, "so it had a significant database, which was very important."

"We did have to do some supplementary allowables testing at elevated temperature," Nesbitt acknowledges. "The established database had ambient temperature, CTD [cold temperature dry] and ETW [elevated temperature wet] data, but that temperature wasn't representative of the actual operating environment, so we performed additional testing."

For the fabric, Matrix selected a 4-harness satin, woven by BGF (Greensboro, NC, US) and tackified by Solvay. It provides 0° and 90° fiber orientations but is more pliable than plain or twill weaves and more easily conforms to complex shapes. »



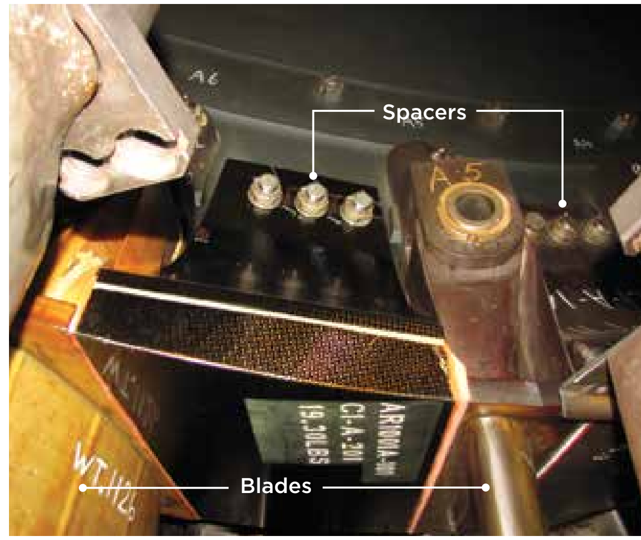


FIG. 2 **Avoiding potential compressor failure**

Spacers prevent the wind tunnel compressor's rotor blades from impacting the adjacent stator blades (the first row of stator blades are labeled here as inlet guide vanes), which would cause disastrous failure. The spacers (see photo at right) are bolted onto the compressor hub, positioned in between the rotor blades. Source | AEDC

Topsides, tooling and tolerances

To enhance durability, the initially open spacer body design was fully enclosed. Matrix designed the curved right and left covers that form each spacer's "top" surfaces as well as the central telemetry tray (see drawing, p. 69). These would be fabricated using the same fiber and resin as the RTM'd base, but in prepreg format with 40% resin content. After hand layup and autoclave cure, the covers and tray would be bonded to the base structure.

Tools and fixtures — made mostly from steel and hard-coat aluminum — were designed in-house but manufactured by subcontractors. "In order to keep the cantilevered blades from hitting the spacers and each other, we had to calculate the tolerance on the suction side of the blade vs. the pressure side — these tolerances were different due to the different loads," observes Matrix engineering manager Ryan Wood. He explains that each spacer is bolted to the compressor hub and each sits between individual 52-kg blades. "There is a 5,000-lb [2,268-kg] side load on the spacer from the abutting blade. We had to model the spacer structure with this side load in order to predict the torsional deflection and make sure we maintained both blade suction and pressure side tolerances." Analyzing loads in this complex dynamic environment required a time-consuming effort.

A three-stage compressor, finally, has three rows of blades and spacers in graduated sizes. Therefore, the spacers required three unique sets of multi-piece molds. To reproduce the egg-crate structure and overall geometry and meet the tolerance requirements for each row, without bridging in the corners, each set required as many as 70 pieces of tooling. Further, a separate tool set was required for the covers.

FIG. 3 **Spacers with a superior safety factor**

The redesigned composite spacers (front, left) for the 16T wind tunnel feature monolithic laminates, both in the single-piece RTM base with its integrated egg-crate reinforcement grid (visible in the shelves at right and illustrated on p.69) and in the autoclave-cured prepreg top covers (shelved at top left). Holes are machined at the top for bolting spacers to the 16T compressor hub. Source | Matrix Composites

Molding, bonding and machining

When tooling was complete, production commenced. "The spacer body was made using our standard, high-pressure RTM process," says Nesbitt. "Standard" in this case is RTM equipment that Matrix Composites designed and produced in house, which achieves >300 psi in the mold and was used to manufacture more

FIG. 4 **Part complexity with cycling simplicity**

These two views of a high-temperature composite structure produced by Matrix Composites for another project (an aircraft engine) shows the complexity and flawless surfaces possible in the single-piece moldings produced via Matrix Composites' RTM process.

Source | Matrix Composites

than 6,000 fracture-durable components for the F-22 *Raptor* aircraft program. RTM cycle time for the bases and autoclave cure for the covers was roughly nine hours, including ramp-up and cool-down. A postcure for all parts, to enable the spacers to operate at temperatures greater than 149°C on a continual basis, was of similar duration.

Each postcured piece was inspected. "This is pretty standard in the aerospace industry," says Wood. Matrix subcontracted nondestructive ultrasonic A-scan inspection to Arcadia Aerospace Industries (Punta Gorda, FL, US), now part of Applus+ Laboratories (Barcelona, Spain).

LEARN MORE

Read this article online | short.compositesworld.com/T16Spacer

After inspection, covers and telemetry trays were bonded to the spacer bases with Henkel's (Rocky Hill, CT, US) Hysol EA 9394 epoxy structural adhesive. "Of course, we first did a dry-fit inspection," says Wood. A FARO Arm (Faro Technologies, Lake Mary, FL, US) coordinate measuring machine was employed to ensure piece dimensions were exact prior to bonding. "We used a purpose-built bond fixture to apply pressure to the bondlines," he adds. The adhesive cured at room temperature overnight, after which the part was removed from the fixture and postcured at 66°C.

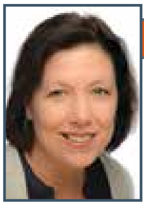
After bonding came machining. "There are six holes that allow attachment to the compressor hub," says Nesbitt. "This is the most dimensionally critical area of the assembly," he adds, explaining that during installation, there must be a slip-fit of the bolts through these machined holes. Machining was designed to account not just for the metallic bushings but also for the adhesive bondline thickness used to bond them in, while the bond fixture Matrix designed maintained axial alignment of the bushings within the holes.

RTM as an enabler

In all, Matrix Composites delivered more than 200 spacers, with the safety factor of 5 and a 62% weight savings. "Even though we didn't specify it, that decrease in weight has been a good benefit for us," says Gernaat. "The technicians have to pick the spacers up over their heads to install them, so an 18-lb [8-kg] spacer vs. the previous 47-lb [21-kg] version has been much easier to handle."

Although the legacy and updated designs were both bonded assemblies, the lack of core material in the RTM'd spacer also is an improvement. "The honeycomb core tended to soak up oil," he says, which deteriorated the parts and increased their weight, causing balance issues. "We've been running these spacers for more than 18 months, and the composite spacer structure has performed well."

"I don't think it would have been possible to create the egg-crate structure without RTM," Nesbitt contends. He asserts that with other composite processes,the necessary part-to-part repeatability and laminate quality would have been a challenge (Fig. 4, above). "We have often found RTM to be an enabling technology," he sums up, "and the 16T Tunnel spacer program is just one example. CW



ABOUT THE AUTHOR

CW senior editor Ginger Gardiner has an engineering/materials background and more than 20 years of experience in the composites industry.
ginger@compositesworld.com