CW COMPOSITESWORLD
compositesworld.com

HIGH-PERFORMANCE Composites

NOVEMBER 2014 / Vol. 22 / No. 6

- FACC AG: Austria's aerocomposites hub
- Spread-tow CF enables global solar flight
- Composites in regional commercial aircraft
- Automotive: SPE ACCE 2014 Report

FEATURES

COLUMNS

DEPARTMENTS

NOVEMBER 2014

volume: twenty-two
number: six

FOCUS ON DESIGN

ON THE COVER

Among the many structures FACC AG (Reid im Innkreis, Austria) now builds for major aircraft OEMs, this translating sleeve for the Boeing 787 is unique: It's the first of its kind to feature a double-degree acoustic surface and an undulated (chevron) engine nozzle design. Take a walk with *HPC* through several of this growing global aerocomposites firm's manufacturing facilities, beginning on p. 38.

Source: FACC AG

CW COMPOSITESWORLD

HIGH-PERFORMANCE Composites

Publisher	**Richard G. Kline, Jr.** / rkline2@gardnerweb.com
Graphic Designer	**Susan Kraus** / skraus@gardnerweb.com
Marketing Manager	**Kimberly A. Hoodin** / kim@compositesworld.com

Midwestern U.S. & International Sales Office
Associate Publisher **Ryan Delahanty** / rdelahanty@compositesworld.com

Eastern U.S. Sales Office
District Manager **Barbara Businger** / barb@compositesworld.com

Mountain, Southwest & Western U.S. Sales Office
District Manager **Rick Brandt** / rbrandt@gardnerweb.com

European Sales Office
European Manager **Eddie Kania** / ekania@btopenworld.com

GARDNER Business Media, Inc.

6915 Valley Avenue
Cincinnati, OH 45244-3029
P 513-527-8800 / Fax 513-527-8801
gardnerweb.com

PO Box 992,
Morrison, CO 80465
P 719-242-3330 / Fax 513-527-8801
compositesworld.com

Richard G. Kline, CBC	President
Melissa Kline Skavlem	COO
Richard G. Kline, Jr.	Group Publisher
Tom Beard	Senior V.P., Content
Steve Kline, Jr.	Director of Market Intelligence
Ernest C. Brubaker	Treasurer
William Caldwell	Advertising Manager
Ross Jacobs	Circulation Director
Jason Fisher	Director of Information Services
Kate Hand	Senior Managing Editor
Jeff Norgord	Creative Director
Rhonda Weaver	Creative Department Manager
Dave Necessary	Senior Marketing Manager
Allison Kline Miller	Director of Events

ALSO PUBLISHER OF

- Composites Technology
- Moldmaking Technology
- Products Finishing
- Plastics Technology / PT Handbook
- Automotive Design & Production
- Modern Machine Shop
- IMTS Directory
- Products Finishing Directory
- Production Machining
- NPE Official Show Directory

High-Performance Composites (ISSN 1081-9223) is published bimonthly (January, March, May, July, September and November); copyright ©2014 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 *High-Performance Composites* 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.

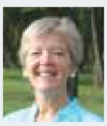
MEMBERSHIPS:

EDITORIAL OFFICES

CompositesWorld / PO Box 992 / Morrison, CO 80465
p: 719.242.3330 / f: 513.527.8801 / www.compositesworld.com

Jeff Sloan / Editor-in-Chief
jeff@compositesworld.com / 719.242.3330

Mike Musselman / Managing Editor
mike@compositesworld.com



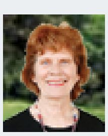
Sara Black / Technical Editor
sara@compositesworld.com

Ginger Gardiner / Senior Editor
ggardiner@compositesworld.com

Lilli Sherman / Senior Editor
lsherman@compositesworld.com

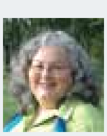
CONTRIBUTING WRITERS

Dale Brosius
dale@compositesworld.com

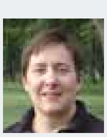


Donna Dawson
donna@compositesworld.com

Michael R. LeGault
mlegault@compositesworld.com



Peggy Malnati
peggy@compositesworld.com



Karen Wood
karen@compositesworld.com

FROM THE EDITOR

jeff@compositesworld.com

You have in your possession the very last issue of *High-Performance Composites* magazine that will ever be published. That, however, is not bad news. It's *good* news. Let me explain.

HPC, as you may know, is one of two magazines we have published over more than 20 years for designers, fabricators and other professionals in the composites industry. *HPC* has focused primarily on the use of continuous carbon fiber and other advanced fiber-reinforced polymers in the aerospace industry and other high-performance applications. Sister publication, *Composites Technology* (*CT*), has focused primarily on the use of polymers reinforced with more economical fibers — mostly glass and plant-derived — in continuous and discontinuous forms in automotive, marine, industrial, consumer and similar applications. Each magazine has been published bi-monthly in alternating months.

I noted here a few months ago that for most of their history, publishing two magazines, one for the "advanced" composites professional and the other for those involved in "industrial" composites, made sense and was very manageable. Over the past few years, however, as the composites industry has evolved to expand fiber and resin integration across multiple and diverse end-markets and applications, the line that separated *HPC* and *CT* has gotten increasingly fuzzy. Finally, that fuzziness has forced us into a new business and editorial paradigm.

And that's the good news: Starting January 2015, *HPC* and *CT* will be merged to create one new monthly publication, called *CompositesWorld* (*CW*). As the merger implies, *CW's* editorial content will focus on use of all fibers and resins in all end-markets and applications throughout the world. In short, we are growing and changing with the industry we serve.

What does this mean to you, the reader? On that subject, the news is even better. The same great content you've come to know and trust remains, but now it will come to you every month. In addition, familiar features — Inside Manufacturing, Focus on Design, Work in Progress, Plant Tours and Market Outlooks — remain as well. And *CW* will continue to focus on aerospace and other high-performance applications that have always been the hallmark of *HPC*. But in addition, you will now enjoy our coverage of composite materials and processes employed in end-markets for which there seldom was room in *HPC*, including the wind energy, marine, automotive, architecture, corrosion, sporting goods and consumer sectors.

The new magazine has acquired a new name because we want to emphasize its role as your window into the whole world of composites innovation. And that gave us just the excuse we needed to design a new logo (below) and a new look — for that, you will have to wait until the inaugural issue of *CW* arrives in your mailbox in January.

It is not without a tinge of regret that we say good-bye to a 20-year friend with the discontinuation of *HPC*, but we are excited about the launch of *CompositesWorld*, and we're confident that you will find its expanded focus and global perspective a key component of your continuing education program in the ever-expanding and ever-evolving composites industry.

CW
CompositesWorld

Thanks for loyally reading *HPC*, enjoy reading *CW* and, as always, let me know how we're doing and how we can serve your composites information needs most effectively.

Jeff Sloan


Tom Onsrud, CEO
ARE YOU
STRUGGLING
TO KEEP UP WITH
PRODUCTION
DEMANDS?
Thank you for coming to see us during the CAMX show in Orlando. If we missed you, give us a call, and let one of our industry-smart representatives show you why C.R. Onsrud should be the next machine you add to your production facility.
C.R. ONSRUD
5 AXIS
HYBRID MILL
5 AXIS
C.R. ONSRUD
C.R.ONSRUD
www.cronsrud.com
A Family With a Century of Cutting Edge Innovation.
704.508.7000

COMPOSITES: PERSPECTIVES & PROVOCATIONS

THE DEMOCRATIZATION OF CARBON FIBER

Dale Brosius is the head of his own consulting company, which serves clients in the composites industry worldwide. Services include strategic planning, market analysis, assistance in mergers and acquisitons activities and technical support. His career has included a number of positions at Dow Chemical, Fiberite, Cytec and Quickstep, and for three years he served as the general chair of the Society of Plastics Engineers' annual Automotive Composites Conference and Exhibition (ACCE). Brosius has a BS in chemical engineering from Texas A&M University and an MBA. Since 2000, he has been a regular contributing writer for *Composites Technology* and *High-Performance Composites*.

Back in the summer of 2002, when I was writing feature articles for *HPC* and sister magazine *Composites Technology* (*CT*), I attended the annual editorial meeting, where the staff gathered to brainstorm ideas for themes and stories for the following year's issues of both magazines. I proposed a feature story on the increased use of carbon fiber in automobiles, which then meant high-end sports cars, and a debate ensued as to which magazine should carry the feature.

I pushed that the story should be in *CT*, because that is where we generally covered automotive stories. Some of the staff thought it should run in *HPC*, because *CT* was focused primarily on fiberglass-based applications and technologies — "boats and bathtubs" — and anything featuring carbon fiber should be in *HPC*. Ultimately, I prevailed in the debate, and the August 2003 feature turned out to be one of the most popular stories to ever run in *CT*. Since then, a number of such "crossover" application stories have made their way into that publication.

In recent years, the major dividing line has been "aerospace" vs. "industrial" when determining the fit for the two magazines. For me, as I am looking at ideas for this column, I need to decide where the topic fits best and whether it is appropriate for *HPC*. With the recent announcement that both magazines are going to be combined into a single monthly publication called *CompositesWorld*, it obviates the need for such decisions. I'm glad to see that happen.

A few days back, I was looking at a recently constructed table of comparative properties for carbon fibers used in aerospace applications, and it struck me that they all looked as familiar to me today as they did 20 years ago! I combed my memory banks (which are usually pretty good) for when was the last time a major carbon fiber was introduced for use in aerospace — meaning, one that actually got qualified and saw serious commercial sales? For reference, I pulled out an extensive guide to available fibers that we used at Fiberite back in 1993, and sure enough, all the familiar fibers, like Toray T800 and M60J, Hexcel IM-7, Toho Tenax HTS and IMS and Cytec T650 are listed.

> The battle for carbon fiber's industrial market will be won by suppliers with the lowest costs and greatest capacities.

T800 is the predominant structural fiber on the Boeing 787, IM-7 the major fiber on the F-35, and IMS and IM7 the principal fibers used on the Airbus A350 XWB. Yes, there have been slight "tweaks" to some of these fibers, and the ownership of the manufacturing sites has shifted a bit since 1993, but unless I have overlooked something, it appears the aerospace carbon fiber market stagnated two decades ago when it came to pursuing new fibers and remains closed to all but the "big four" suppliers.

Is this because the current product portfolios offered meet all the needs? Or is it because qualifying a fiber for a new application is prohibitively expensive? Today's tensile strengths are only a fraction of what is theoretically possible, but the main design drivers in aerospace design are not tensile strength and stiffness, but compression and shear strength, where the major advancements need to be made. I presume if someone comes up with a fiber/resin combination that doubles compression strength, it would draw a lot of attention, but this is not an easy problem to solve. There has been a lot of development in prepreg resins, mainly for vacuum-bag-only processing, yet in almost every case, prepregs developed for out-of-autoclave cure use the same group of fibers employed in autoclave prepregs, presumably to make the direct comparison of properties easier and reduce qualification time and cost.

In the industrial carbon fiber market, by contrast, the last past two decades have seen the entry of new fiber producers and the introduction of new fibers by established suppliers. The new fibers have been targeted to automotive, wind energy, pressure vessel and electrical/electronics applications. Many of the new players are located in previously unlikely places: China, South Korea, Turkey and, soon, Saudi Arabia. These suppliers have no aspiration to chase the aerospace market, and it's easy to see why: Barriers to entry are much lower in the industrial markets.

Industrial demand already exceeds that in the aerospace sector, and all signs point to continued rapid expansion in consumption. There's a "land rush" going on and the battle will be won by suppliers with the lowest costs and greatest capacities. As industrial markets seek lower carbon fiber prices, aerospace companies seek higher-rate, lower-cost manufacturing techniques. Although "aerospace" and "industrial" will retain some distinctions that separate them, due to inherent differences in structural dynamics, it is clear that a composite part no longer has to fly skyward to be called "high-performance." ■

TESTING TECH

THE PICTURE-FRAME SHEAR TEST METHOD

Dr. Donald F. Adams is the president of Wyoming Test Fixtures Inc. (Salt Lake City, Utah). He holds a BS and an MS in mechanical engineering and a Ph.D in theoretical and applied mechanics. Following a total of 12 years with Northrop Aircraft Corp., the Aeronutronic Div. of Ford Motor Co. and the RAND Corp., he joined the University of Wyoming, directing its Composite Materials Research Group for 27 years before retiring from that post in 1999. Dr. Adams continues to write, teach and serve with numerous industry groups, including the test methods committees of ASTM and the *Composite Materials Handbook 17*.

The picture frame shear test method achieved some popularity in the early days of composite materials development when few other shear test methods existed. But as the two- and three-rail shear test methods, and later the Iosipescu shear test, were introduced for characterizing basic shear properties, picture frame shear testing became less popular for three reasons: It used a relatively large specimen; test preparation required that a number of holes be drilled in the specimen; and the method required a complex fixture. Despite these disadvantages, the picture frame shear test continued to be an attractive option for composite laminate panel testing because the method accommodates large specimens.

A fixture similar to that shown in Fig. 1 has long been in use. As noted above, a series of holes are drilled in each of the panel's four edges. The required number of holes depends upon panel strength and thickness. The hole *pattern* matches that of the four pairs of fixture rails. Bolts are then used to clamp the panel edges between the rails. The rail surfaces that come into contact with the specimen may be coated with tungsten carbide particles, or otherwise roughened, to increase their gripping effectiveness. The four corners of the fixture are pinned, allowing the pairs of rails to rotate relative to each other. During the test, the panel is subjected to shear by applying a pulling force to diagonally opposed corners of the fixture's frame.

When the method is used to test relatively low-strength composite panels, it might be possible to simplify both the specimen and the fixture. An example of a simple fixture is shown in Fig. 2. No bolts are used, so drilling is unnecessary. The pairs of rails are joined using C-clamps, with the panel sandwiched between them. Alternatively, clamps can be integrated into the fixture rails. Here, too, the rail surfaces may be coated with tungsten carbide particles or roughened to enhance gripping.

Despite its long history, the picture frame test has not yet been the subject of an ASTM International (W. Conshohocken, Pa.) published standard. But today, as designers turn increasingly to composite sandwich panels in many applications, picture frame shear testing is attracting renewed attention. In response, a draft standard is now being developed by ASTM Subcommittee D30-09 on Sandwich Construction. It will use a test fixture similar to that in Fig. 1, but with a single row of fasteners along each edge.

Beyond sandwich panel testing, an even greater motivation for picture frame fixture development is its utility in determining the shear properties of *dry reinforcement fabrics* and uncured fabric prepregs. The purpose is to determine the material's *drapeability* during layup procedures. The material must smoothly conform to the mold's three-dimensional surface without wrinkling. The fabric achieves this primarily by the rotation of the fiber bundles relative to each other at their crossover points, which is a *shear* process. The practical limit of this shear deformation is reached when the fiber bundles rotate so far that they begin to interfere with each other, defining

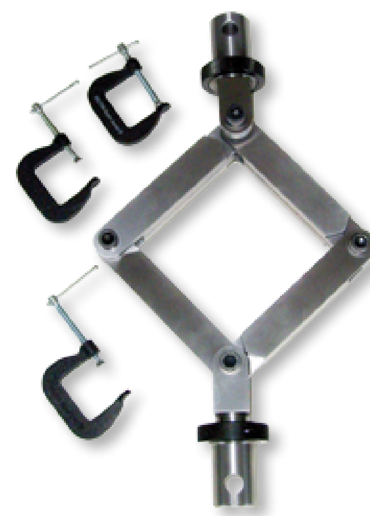


Fig. 2 Simple Picture Frame Shear Test fixture.

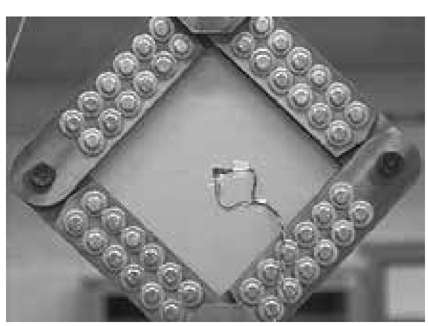


Fig. 1 Typical Picture Frame Shear Test fixture used for testing solid laminates.

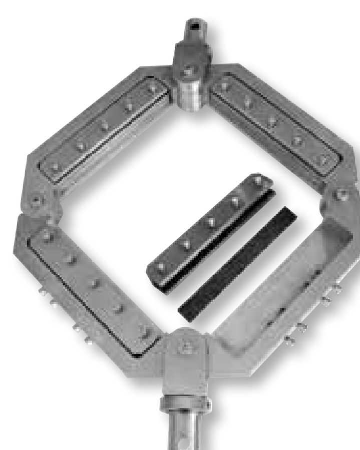


Fig. 3 Picture Frame Shear Test fixture with strand-straightening mechanism.

Source: (All photos) Don Adams

the *lock angle* of the fabric. Thus, shear is the appropriate simulation mode, and a picture frame shear test is a suitable method for applying the shear force.

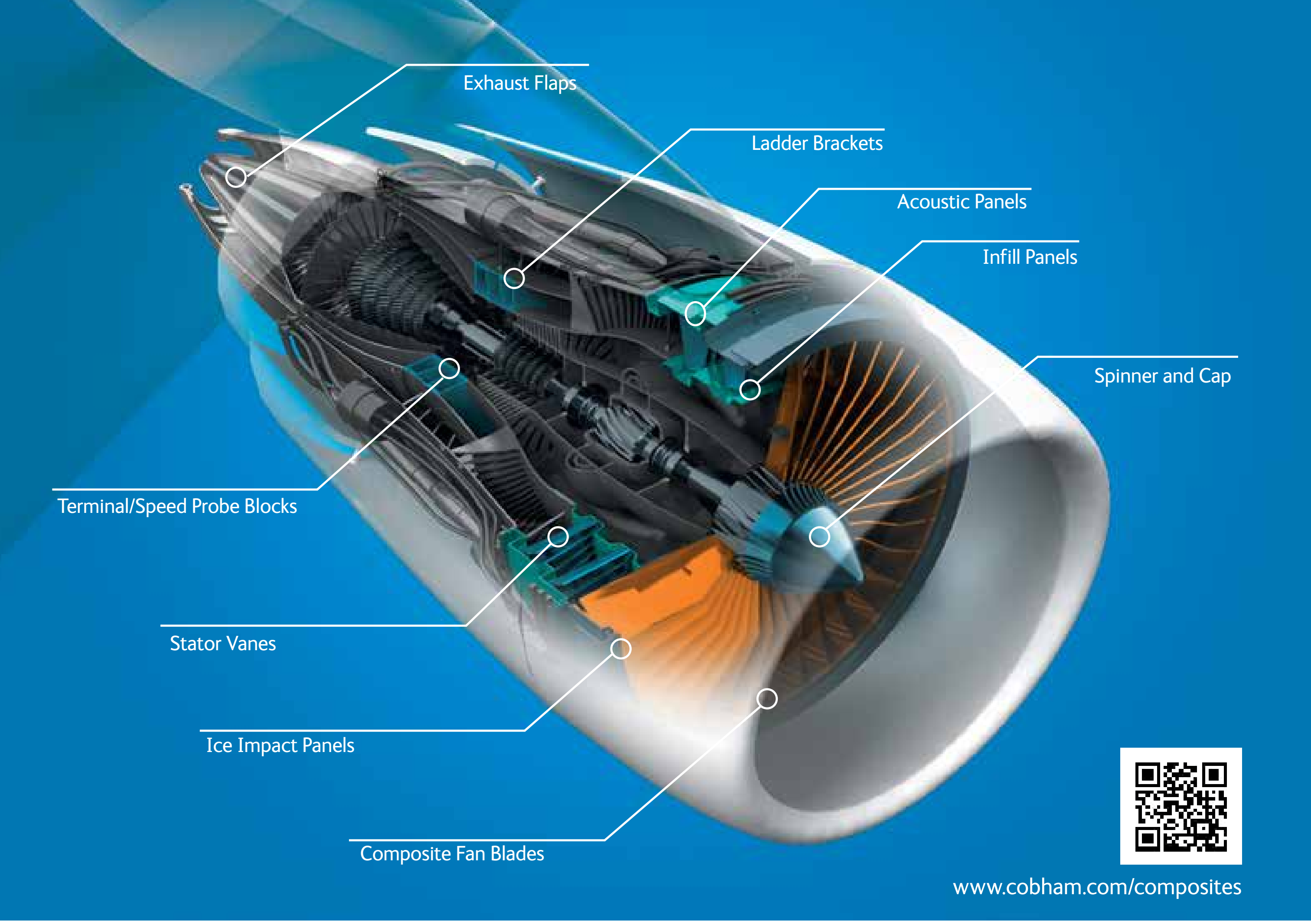
There are alternative methods for determining drapeability. The specimen can be subjected to opposing in-plane forces at, and parallel to, two opposite edges, much like the loading of the two-rail shear test method for solid composite laminates (ASTM D 4255). However, this so-called Direct Shear Force Loading induces tensile stresses throughout the dry fabric or prepreg, in addition to nonuniform shear stresses. Because it is difficult to *separate* the contributions made to fabric deformation by the shear and tensile stresses, the accuracy of this test's result is questionable.

Another technique, favorable for its simplicity, is the Bias Extension method. The fabric is oriented at ±45° and subjected to a simple in-plane tensile loading (that is, a biased loading), much like that applied in the ASTM D 3518 in-plane shear test for composite materials. No fixture is required — just tensile grips. To generate a central zone of shear stress, a specimen at least twice as long as its width must be used, so that none of the fiber bundles in the specimen's central region are held in the grips at either end. But because the quantity of interest is the *shear* force required to cause a given shear deformation (i.e., fiber bundle rotation), this test, too, is problematic. Even the fiber bundles in the central region carry *some* tensile load due to sliding friction between bundles. Again, separating the force required to create the shear rotations from the sliding friction forces of the fiber bundles is difficult so the result could be unreliable.

Given the above, the picture frame method is preferred for determining drapeability. But one practical challenge, especially with dry fabrics, is properly gripping the specimen. In theory, all of the fabric strands should be gripped and loaded uniformly because there is minimal force transfer between strands to aid in load redistribution — force transfer is high when testing a composite laminate. Ideally, the strands should be equally straight before the test begins. Practically, this can be achieved to a degree as the load is applied: those strands that are straightest and, thus, carry a greater portion of the load, slip in the grips, redistributing the load. Unfortunately, the loads required to shear the dry or prepregged fabric are not high, so the tensile loads carried by these strands will distort the test result. Some improvement in load uniformity can be achieved by applying multiple preliminary loadings prior to that for which deformation measurements are made.

The fixture in Fig. 3 exemplifies one attempt to straighten fibers prior to testing. The fabric or prepreg is carefully aligned and lightly clamped between the rails (coated with 36-grit tungsten carbide), and then the clamps are moved outward, using the adjustment screws on the fixture's four sides. Because the specimen is lightly clamped and the displacements are in the strand directions, tight strands slip and slack strands straighten. When acceptable alignment is achieved, the clamping screws are fully tightened.

Although it doesn't straighten fibers, another grip design has rail pairs with mating *wavy* surfaces perpendicular to the strand direction, forcing the clamped strand end down into the troughs to create a more torturous pullout path. ■



Advanced Composite Solutions

When Reliability and Durability Matter

For over 25 years Cobham has earned its customers' trust by providing reliable and durable composite products. Cobham's technical leadership in the use of advanced composites and its unequaled track record in innovative design solutions have made Cobham one of the foremost designers and manufacturers of complex composite components and structures in the US and Europe.

Strategic Company Focus

- High Temp Aircraft Engine Components
- Aircraft Engine Structures and Components

For sales inquiries or more information, please contact:

Cobham Composite Products - San Diego, CA, USA T: 001 (858) 824 8958
Cobham Advanced Composites Ltd - Shepshed and Leicestershire, UK T: 0044 (1509) 504 541

Manufacturing Process Capabilities

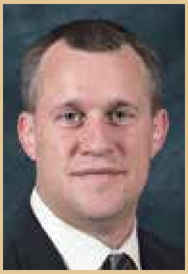
- Multi-Axis Compression Molding
- Resin Transfer Molding (RTM)
- Bladder Molding
- Hand lay-up/autoclave cure
- Mechanical and Electrical Assembly and Integration
- Design and Modeling
- Tooling Design and Fabrication
- High Volume Production

The most important thing we build is trust

COBHAM

BY THE NUMBERS

COMPOSITES BUSINESS INDEX 50.2 – INDUSTRY FLAT SINCE JULY



Steve Kline is the director of market intelligence for Gardner Business Media Inc. (Cincinnati, Ohio), the parent company and publisher of *High-Performance Composites*. Kline holds a BS in civil engineering from Vanderbilt University and an MBA from the University of Cincinnati.

In August, our Composites Business Index (CBI) read 49.9, indicating the industry was essentially flat after 10 consecutive months of growth. Nonetheless, the Index was higher than it was one year earlier. In fact, the month-over-month rate of change had grown since September 2013, and the annual rate of change had accelerated for seven months.

Also, there were some positives in the subindices. New orders increased for the ninth month in a row, and production expanded for the eighth straight month. Although backlogs contracted for a third month, the rate was slower and its index was 17.4 percent higher than one year earlier and had shown accelerated growth every month in 2014 — a very strong sign that capacity utilization and capital equipment investment will grow through 2015. Employment grew, but at its slowest rate since June 2013. Exports had contracted sharply for two months, falling to their lowest level since the index began (December 2011). Supplier deliveries had lengthened at a moderately increasing rate since October 2013.

Material prices continued to increase, near peak levels reached since January 2012. Prices received were up for the fifth straight month — the longest stretch of increases since summer 2012. Future business expectations were at their lowest level since September 2013.

Mid-size facilities (20 to 249 employees) continued to expand. Those with less than 19 employees had contracted four of the previous six months. Facilities with more than 250 employees contracted for the first time since October 2013.

Regionally the West and Northeast, expanded. The North Central – West contracted after expanding in July. Both the North Central – East and the Southeast had contracted for two straight months.

Future capital spending plans contracted for a second month. The annual rate of growth slid to its second slowest rate since November 2013.

September's CBI of 50.2 indicated a slight overall expansion, but the industry remained flat for a fourth month. The rate of change was a mere 2.4 percent, the slowest month-over-month growth since August 2013. For the first time in 2014, the annual rate of growth decelerated.

New orders grew for the tenth consecutive month, at a rate virtually unchanged for three months. Production expanded for a ninth month. The rate of expansion, had slowed since June, but ticked up slightly. Backlogs contracted for a fourth month, but its index was 2.5 percent higher than one year earlier. Significant growth in the annual rate of change was another strong sign that capacity utilization and capital equipment investment will increase through 2015. Employment growth accelerated noticeably compared to the previous two months. For a second month, exports contracted at their fastest rate in CBI history. Supplier deliveries lengthened again, and had done so at an accelerating rate since June.

Material prices continued to increase, but growth had slowed since May and September saw the slowest rate of 2014. Prices received had increased for six straight months — their longest sustained stretch since summer 2012. Prices received were at their highest since June 2012. After falling significantly for two months, future business expectations rebounded sharply.

Larger facilities continued to see exceptional growth at an accelerating rate. Mid-size plants contracted for the first time since December 2013, and the rate was the fastest since December 2012. Plants with less than 20 employees contracted for the third month in a row.

For a second month, only two regions expanded. The West was the best performer again. The only other region to grow was the Southeast, for the first time since May. Contraction was relatively moderate in the Northeast, and North Central – East accelerated as it had during the two preceding months.

Future capital spending plans contracted for a third month, but the rate had slowed each month. Although the annual rate of change went up, it did so at its slowest rate in the past year. ■

THE COMPOSITES BUSINESS INDEX

Subindices	September	August	Change	Direction	Rate	Trend
New Orders	52.5	52.3	0.2	Growing	Faster	10
Production	53.3	53.0	0.3	Growing	Faster	9
Backlog	44.6	46.6	-2.0	Contracting	Faster	4
Employment	53.3	50.8	2.5	Growing	Faster	19
Exports	41.8	42.5	-0.7	Contracting	Faster	3
Supplier Deliveries	55.6	54.5	1.1	Lengthening	More	34
Material Prices	64.3	65.8	-1.5	Increasing	Less	34
Prices Received	55.0	51.1	3.9	Increasing	More	6
Future Business Expectations	73.1	66.7	6.4	Improving	More	34
Composites Business Index	50.2	49.9	0.3	Growing	From Contracting	1

NEWS

NASA announces two winners in "space taxi" competition

Spacex and Boeing proceed to next stage, Sierra Nevada mounts protest

NASA reported on Sept. 16 that it has selected The Boeing Co. (Houston, Texas) and SpaceX (Hawthorne, Calif.) to develop spacecraft to transport U.S. crews to and from the International Space Station (ISS). Boeing was the big winner, awarded $4.2 billion to develop its *CST-100* spacecraft (pictured here, near right). SpaceX was awarded a smaller amount, $2.6 billion, to develop its *Crew Dragon* spacecraft. Sierra Nevada Corp. (SNC, Sparks, Nev.) and its Space Shuttle-like crew ship (far right), the *Dream Chaser*, was eliminated.

The U.S. has not had a spacecraft of its own available to transport U.S. crews to the ISS since the Space Shuttle fleet was retired in July 2011. Since then, NASA has relied on Russian-built craft to ferry its astronauts for space station duty. NASA administrator Charlie Bolden says, "Thanks to the leadership of President Obama, the hard work of our NASA and industry teams, and support from Congress, today we are one step closer to launching our astronauts from U.S. soil in American spacecraft and ending the nation's sole reliance on Russia by 2017. Turning over low-Earth orbit transportation to private industry will also allow NASA to focus on an even more ambitious mission — sending humans to Mars."


Source: The Bowing Co.


Source: Sierra Nevada

These Commercial Crew Transportation Capability (CCtCap) contracts are designed to complete the NASA certification for human space transportation systems capable of carrying people into orbit. The contracts with Boeing and SpaceX include at least one crewed flight test per company with at least one NASA astronaut aboard to verify that the fully integrated rocket and spacecraft system can launch, maneuver in orbit and dock to the space station and confirm that systems perform as expected. If and when each company's test program is completed successfully, it will conduct at least two to as many as six crewed missions to the space station. These spacecraft also will serve as a lifeboat for astronauts aboard the station.

NASA's Commercial Crew Program will implement this capability as a public/private partnership. The U.S. missions to the ISS will allow the station's current crew of six to grow, enabling its members to conduct more research aboard the unique microgravity laboratory aboard the ISS. The companies will own and operate the crew transportation systems and be able to sell human space transportation services to other customers in addition to NASA, thereby reducing the costs for all customers.

In the wake of NASA's announcement, Sierra Nevada laid off 90 employees at its Denver, Colo.-area facility, and announced on Sept. 26 that it has filed a formal legal challenge to the decision. Sierra Nevada noted in its press release that it had never before filed a legal challenge to a government contract award, but believes there are serious questions about, and evidence of inconsistencies in, the source selection process. The company also indicated it is continuing its efforts on a number of commercial and international partnerships with other space agencies and organizations. A company spokesperson also confirmed that a decision has been made to continue the development of the *Dream Chaser* through to flight readiness.

Correction

In our "Farnborough 2014 Airshow Report" published in the September 2014 issue of *HPC* (p. 46), the caption for the photo on that page stated that the Irkut (Moscow, Russia) *MS-21* stabilizer skin on display at the show (and pictured in the photo) was fabricated with materials supplied by Cytec Industries (Woodland Park, N.J.). This is incorrect. Alexander Pashenkin, Irkut's chief technologist, alerted *HPC* to the fact that material was, instead, HexPly M21 carbon fiber prepreg, supplied by Hexcel (Stamford, Conn.). *HPC* regrets the error.


OMAX® JetMachining® Centers provide premium high-precision abrasive waterjet cutting.
THE POWER OF ABRASION.

Toray, Hexcel announce European carbon fiber production expansions

The worldwide demand for PAN-based carbon fibers expanded in 2013, exceeding 40,000 metric tonnes (88.184 million lb), and is expected to continue to grow at a rate in excess of 15 percent per year. Two of the world's most prolific carbon fiber producers have made significant announcements about new production facilities that will impact positively the supply of carbon fiber.

Toray Industries Inc. (Tokyo, Japan) announced on Sept. 29 that it and subsidiary Toray Carbon Fibers Europe SA (CFE, Abidos, France) held a ceremony on Sept. 26 to mark the completion of its new polyacrylonitrile (PAN) precursor plant at CFE's Lacq, France, facility. The event was attended by about 230 guests, led by Japan's Ambassador to France, Yoichi Suzuki, and officials from French government agencies and municipalities as well as those representing the carbon fiber industry.

The new precursor plant is part of the Toray Group's investment plan announced in March 2012, with the goal of expanding carbon fiber production capacity at its four global production sites in Japan, the U.S., France and South Korea. The new CFE plant is the third precursor production base added to the Group's holdings, following previous openings of facilities in Japan and the U.S.

The move enables CFE to move on to an integrated production regime, switching to precursor produced at its own plant instead of relying the on material imported from Japan. Local production of precursor is expected to boost the location's cost-competitiveness. CFE also will supply precursor to other Toray Group production bases, including Toray Advanced Material Korea Inc., contributing to the group-wide business expansion.

Hexcel Corp. (Stamford, Conn.), for its part, announced on Sept. 30 that it will expand its carbon fiber production capacity through the addition of new precursor and carbon fiber lines in Roussillon, France. The $250 million (USD) investment will also include associated quality-control laboratories and offices.

The new French plant will occupy a 37-acre site at the Osiris Chemicals Industry Platform in Roussillon, which is close to Hexcel's weaving and prepreg manufacturing facilities near Lyon. Carbon fiber from the new plant will be supplied to Hexcel customers, including Airbus (Toulouse, France) for the A350 XWB and Safran (Paris, France) for the CFM LEAP engine. Construction of the new plant will begin by mid-2015 and it is expected to employ 120 people when fully operational in early 2018.

Hexcel says the new facility is part of the company's ongoing worldwide investment to create a diversified and robust global supply chain to support aerospace customers' growing demand for carbon fiber composites. In recent years, Hexcel has increased its precursor and carbon fiber capacities through targeted expansions at several existing facilities. Notably, Hexcel is investing in ongoing precursor and carbon fiber expansions in the U.S. and is currently installing its resin mixing and filming technology – first developed in Europe – in the U.S. as well. The new facility in France is the next step in support of European customers.

Bicycle manufacturer Bianchi (Milan, Italy) was recently recognized for its updated *Infinito CV* carbon composite model, named "Bike of the Year" by bicycling Web site www.road.cc. The *Infinito* CV was ridden by cyclist Lars Boom to victory in Stage 5 of the 2014 Tour de France, a segment known for its teeth-chattering cobblestones.

A key element of the *Infinito* model is an integrated vibration-cancelling product called COUNTERVAIL (a globally registered trademark) developed and produced by Materials Sciences Corp. (Horsham, Pa.). The latter has provided design, analysis, engineering and testing services to the advanced composites industry since 1970, and has worked with the U.S. Army, Navy and Air Force. NASA and the Defense Advanced Research Projects Agency (DARPA), as well as notable industry players, such as McDonnell Douglas (now Boeing) Phantom Works.

Materials Sciences' commercial COUNTERVAIL product combines traditional vibration-damping layer concepts with a patented fiber preform to offer reportedly "unparalleled" vibration reduction in composite structures. The preform's woven fiber pattern maximizes the vibrational energy dissipation achieved by an integrated viscoelastic damping layer. Damping performance has been shown to be at least 200 percent better than similar constructions using traditional viscoelastic methods. Reportedly, layups can be tailored to balance the vibration-damping coefficient with stiffness and strength, and even drapeability. Very high damping is possible with carbon fiber, and good damping is achievable with glass, at a lower cost. The company says COUNTERVAIL is unique because it is integrated into the structure without adding parasitic weight.

When a bike tire passes over a cobblestone, the initial shock impulse excites the structure and causes it to resonate at certain frequencies. COUNTERVAIL is able to damp that resonance very quickly, and does so much better than rubber damping material employed by other bicycle manufacturers, says Materials Sciences.

Beyond bicycle frames, COUNTERVAIL technology offers the potential for thinner, lighter aircraft interior panels that offer airlines the benefit of reduced transmission of engine and airflow noise into the aircraft cabin. Similarly it can mitigate repeated and severe shock loads experienced by marine vessels as the result of high-speed wave impacts.






Face-To-Face, NPE2012

Boeing flight tests CMC engine nozzle

The Boeing Co. (Chicago, Ill.) reported on Sept. 5 that it has successfully flight tested an innovative jet engine nozzle made of a ceramic matrix composite (CMC). Designed to reduce noise, weight and reduce fuel use, the CMC nozzle was taken through a series of tests aboard Boeing's *ecoDemonstrator* 787 Flight Test Airplane. The regime included community noise testing, during which

Source: The Boeing Co.

the plane was flown over a large acoustic array in Moses Lake, Wash. Boeing engineers have been working on the technology during the past five years, says Mitch Petervary, the technology's principal investigator. Seeing all their hard work come to fruition, he noted, was gratifying. "This program began years ago with small samples in labs, and now we have flight-tested the largest oxide CMC structure in the world, and it performed at a very high level," Petervary says. "Our innovative team has worked so hard to get to this point. Seeing our technology in the sky is remarkable and is a testament to what we can achieve." This flight demonstration is part of the five-year U.S. Federal Aviation Admin. (FAA) Continuous Lower Energy, Emissions and Noise (CLEEN) program. Boeing is one of five industry contractors participating in CLEEN, an open, competitively bid, cost-sharing program focused on speeding development of new technologies that improve airplane fuel efficiency and decrease volatile emissions and noise.

"The FAA CLEEN Program is very excited to see Boeing's ceramic matrix composite exhaust nozzle fly," says Arthur Orton, FAA CLEEN program engineer. "The flight test of the CMC nozzle is a major milestone for this technology. Innovative technologies such as this are needed to help meet FAA's NextGen environmental goals, and represents excellent progress for the CLEEN Program." Modern engines have higher operating temperatures to achieve improved fuel efficiency and reduce emissions. However, these

(*continued on p.* 22)

(continued from p. 21)

hotter temperatures are pushing the capabilities of currently used metallic components. According to its proponents, CMC technology is not only lighter than current metallic components but also can last longer at higher temperatures. Moreover, special CMC designs are amenable to having acoustic treatments built into them that help make engines quieter, lighter and more efficient. The technology also could enable new, dramatically different engine designs in the future.

The *ecoDemonstrator* test plane is employed by researchers in Boeing's development and test program of the same name, which focuses on improving environmental performance by bringing new technologies, materials and methods to implementation faster than ever before.

NEWS BRIEF

Effective October 2014, **Delsen Testing Laboratories** was officially renamed **Element Materials Technology Los Angeles LLC** (Glendale, Calif.). Element is a global network of laboratories with experts who specialize in materials testing, product qualification testing and failure analysis for the aerospace, oil & gas, transportation and industrial sectors. Its team of 1,540 scientists, engineers and technicians work in 44 facilities located throughout the U.S. and Europe.

DARPA solicits ideas for new concepts in armored vehicles

For the past 100 years, efforts to provide better ballistic and explosive-device protection for ground-based armored fighting vehicles and their occupants has focused on increased armor. The ability of weapons systems to penetrate armor, however, has advanced faster than armor's ability to withstand assault. As a result, achieving even incremental improvements in crew survivability has required significant increases in both vehicle mass and cost.


Source: DARPA

Increasingly heavy, and therefore, less mobile, these more expensive armored vehicles unfortunately hinder efforts to rapidly deploy and then maneuver manned vehicles in what are often challenging environments. Moreover, larger vehicles are limited to established roadways and require more logistical support. They are also more expensive to design, develop, field and replace. The U.S. military is now seeking innovative and disruptive solutions to ensure the operational viability of

(*continued on p.* 24)

(*continued from p.* 23)

the next generation of armored fighting vehicles. Toward that end, the U.S. Defense Advanced Research Projects Agency (DARPA, Arlington Va.) has created the Ground X-Vehicle Technology (GXV-T) program to disrupt the current trends in mechanized warfare. GXV-T seeks to investigate revolutionary ground-vehicle technologies that would simultaneously improve vehicle mobility and survivability through new approaches, including detection avoidance and evasion of engagement and targeted hits.

GXV-T's technical goals include the following improvements relative to today's armored fighting vehicles, goals that certainly seem consistent with composite materials: reduce vehicle size and weight by 50 percent, reduce the size of the onboard crew needed to operate the vehicle by 50 percent, increase vehicle speed by 100 percent, gain off-road access to 95 percent of the terrain in deployment zones, and reduce signatures that enable adversaries to detect and engage the vehicles.

"GXV-T's goal is not just to improve or replace one particular vehicle, it's about breaking the 'more armor' paradigm and revolutionizing protection for all armored fighting vehicles," says Kevin Massey, DARPA program manager. "Inspired by how X-plane programs have improved aircraft capabilities over the past 60 years, we plan to pursue groundbreaking fundamental research and development to help make future armored fighting vehicles significantly more mobile, effective, safe and affordable."

GXV-T development will run for 24 months after initial contract awards, which are expected on or before April 2015.

SPE ACCE 2014 REPORT

Source: SPE ACCE

Automotive composites still on the horizon — are they getting closer?

Nearly 850 attendees gathered to assess the state of composite materials in automotive platforms at the Society of Plastics Engineers' Automotive Composites Conference and Exhibition (ACCE), held at the Diamond Banquet and Conference Center at the Suburban Collection Showplace venue in Novi, Mich., from Sept. 9 -11. ACCE welcomed 68 exhibitors (see a sampling of the new products on display at ACCE, beginning on p. 58) and, with the aid of numerous event sponsors, fielded a technical program that comprised more than 80 presentations, roundtable discussions and keynote speeches, covering advances and issues in the areas of thermoset composites, thermoplastic composites, nanocomposites, virtual prototyping/testing and sustainability as well as business trends and technology solutions for autocomposites applications.


Source: SPE ACCE

Tracing technological links

In his keynote address at ACCE, Dr. Jan Anders Månson, professor and VP at the École Polytechnique Fédérale de Lausanne (Lausanne, Switzerland), examined the links between composites used in sporting goods and those now earning a place in high-performance automotive applications.

In the past, the ACCE's executive panel discussion has been a "reality check" for composites advocates. This year was no exception. Moderated by Jay Baron, president and CEO of the nonprofit Center for Automotive Research (CAR, Ann Arbor, Mich.), the panel included Dr. Paul Krajewski, global manager and technical fellow for vehicle mass integration and strategy at General Motors (Detroit, Mich.); Tom Pilette, VP, product and process development, at automotive systems supplier Magna International (Troy, Mich. and Aurora, Ontario, Canada); Harry Singh, executive program manager at design firm EDAG (Fulda, Germany); Martin Starkey, director, Gurit Automotive (Newport, Isle of Wight, U.K.); and Dr. Peter Friedman, manager of manufacturing research, Ford Motor Co. (Dearborn, Mich.). Reluctant to embrace composite materials *per se*, panelists instead preferred to discuss lightweighting in terms of multimaterial solutions.

General Motors' Krajewski admitted that there are many targets for saving weight, including interiors, wheels and the vehicle frame, but he observed that "the customers only want a solution that *works*, and they don't care about which material is used." He went on to say that whatever material is selected, his team needs to be able to *model* it and predict its performance, and he suggested composites suppliers take their cue from the steel industry, where competitors have worked *together* as a group to collectively develop new, lighter material forms.

EDAG's Singh pointed out that the steel industry has reinvented itself, quoting a cost of only $500 for a *complete* steel

ACCE highlight: The Executive Panel

Moderated by Jay Baron (Center for Automotive Research, Ann Arbor, Mich.), ACCE's always illuminating Executive Panel discussion provided autocomposites advocates a strong "reality check."

car body. Today's steel, he added significantly, is 10 times stronger and better in quality than that of a decade ago. He did admit that, given the new CAFE standards, "*any* material is on the table, due to the activity in many areas." But Ford's Friedman emphasized, "We can't just substitute new materials for old. We try to be material-agnostic, and use any material where it needs to be within a multimaterial vehicle."

Gurit's Starkey pointed out that, given the many forms of resins and reinforcements, composites are "infinitely tailorable for any application," but deciding on the right mix and the right process, given that huge range of possibilities, presents an unusual challenge.

When asked if lighter cars (i.e., those containing a lot of composites) are as safe as steel-bodied cars, panelists answered *yes* while noting that designs need to provide an adequate level of safety, no matter what the material. Magna's Pilette pointed out that with more required safety features, such as backup cameras and self-braking systems, which add weight to the vehicle, the pressure is on to reduce weight in other systems to compensate, yet maintain safety.

As in previous years, the panel concluded that composites make sense for a vehicle when there is a compelling economic business case. The take-away? New, lightweight steel alloys have captured the attention of OEMs and will increase the competitive pressure composites face in the automotive market to a greater degree than many realize.

A wealth of technology

Technical sessions revealed a wealth of new revelations from composites research. A recurring theme was high-rate-capable processing methods for thermoset materials. Koichi Akiyama, group leader for automotive composites material development group of Mitsubishi Rayon Co. (Tokyo, Japan), described ongoing development of his company's prepreg compression molding (PCM) technology, in which carbon fiber prepreg material, preformed in a press-forming process, is molded in a high-speed compression press. Akiyama reports that prepreg cure is in the three- to five-minute range, and work continues to reduce it further. PCM reportedly yields a Class A finish and can be modified for comolding with other materials, such as SMC. Akiyama described the redesign and processing of a carbon fiber decklid for the Nissan *R35 GT-R*, using PCM. On display at the show, the part is 40 percent lighter than the aluminum part it replaced.

Although state-of-the-art epoxy systems can cure in as little as two minutes, high-volume automotive applications require production output of about 1,000 parts per day, which equates to a *one*-minute cure time over two shifts. Roman Hillermeier, transportation technology manager, Momentive Specialty Chemicals Inc. (Columbus, Ohio), presented a method capable of producing carbon fiber-reinforced "crash box" components via RTM at that rate, using its fast-curing EPIKOTE epoxy system and multicavity tooling. (Crash box components attach to the front-end module of the body-in-white, absorbing energy in event of a crash.) The carbon fiber preforms for the parts were continuously braided on a mandrel, cut and then placed directly into a multicavity mold. At nine parts per mold, given an average cure cycle of two to three minutes, the process can produce 1,000 parts in 10 hours — six hours short of two shifts. Hillermeier asserted that a cost objective of €5/kg of saved weight could be achieved by using glass or lower-cost, heavy-tow carbon fiber.

Sebastian Schmidhuber, lead R&D engineer at KraussMaffei Technologies, explained the nuances of several *high-pressure* RTM (HP-RTM) processes. One of the newest, Surface RTM, is capable of producing ready-to-paint carbon fiber exterior parts out of the mold. In this two-step process, a preform is placed in the mold and impregnated with a matrix resin via compression RTM. Next, the mold is opened slightly and polyurethane is introduced into the cavity through a side injector in the mold. The mold is again compressed, creating, after cure, an overmolded Class A surface.

In the area of sheet molding compound (SMC) for body panels, Ashland Inc.'s (Covington, Ky.) Michael Sumner, group leader for SMC, gel coat and marine resin, in the composite polymers Global Technology Organization, described that group's design-of-experiments project to boost the mechanical properties of its 39 percent glass-filled, 1.2 density Class A SMC. Its goal is a minimum 20 percent improvement by replacing the material's unsaturated polyester resin (UPR) with differing amounts of vinyl esters. Researchers found that a 50 percent blend of a particular vinyl ester with a new, low-profile additive and reactive toughener yielded up to a 40 percent improvement of target mechanical properties without a major compromise in surface finish quality.

SMC also was the topic for AOC's (Collierville, Tenn.) Jeff Klipstein, a closed mold technical service specialist, who described his company's new low-density (1.2) SMC that reportedly has properties equivalent to standard SMC at 37 percent lower mass, *and* with a Class A surface. This is tricky, explains Klipstein, because adding more glass enhances mechanical properties but tends to degrade the molded surface quality. The new, low-density formulation of polyester and glass fiber is reportedly competitive with aluminum in terms of cost and weight savings. Work is ongoing to further reduce density while maintaining properties and surface quality.

Thermoplastic autocomposites

Thermoplastic composites were featured in several sessions. One of the challenges for thermoplastics in automotive applications is meeting part stiffness requirements at elevated temperatures — typically 90°C/194°F. DuPont's (Wilmington, Del.) Paul Kane, who leads DuPont's Performance Materials North America advanced development automotive lightweighting solutions team, presented a review of high glass-transition-temperature (high-T_g) polyphthalamides (PPAs) and their use as an overmolding resin with stamped, continuous glass fiber/polyamide inserts. Kane reported that at 90°C/194°F, a 50 percent glass-reinforced PPA with a T_g >100°C/212°F has almost *twice* the modulus of a 50 percent glass-filled PA 6/6. Kane reported results of a study that found crossmember beams compris-

Source: SPE ACCE

Battery-case case study

Keynote speaker Kestutis "Stu" Sonta, senior materials engineer, General Motors Co. (GM, Detroit, Mich.), revealed the novel composite design developments that preceded production of the complex, two-piece battery enclosure now aboard GM's Chevrolet *Spark* (see the photo and caption on p. 29).

Source: SPE ACCE

SPE ACCE Scholarship winner

A winner of one of two SPE ACCE Scholarship Awards, Fatimat Oluwatoyin Bakare was awarded $2,000 in honor of her proposal for "Synthesis of Bio-Based Composites with a Lactic Acid Based Thermoset Resin from Lactic Acid and Allyl Alcohol." Originally from Nigeria, Bakare is working on her Ph.D in materials science/polymer engineering at the University of Borås (Borås, Sweden). Michael Connelly, product manager at Huntsman Polyurethanes (Auburn Hills, Mich.), presented the award.

Battery enclosure sparks innovation

On display at ACCE was the battery enclosure recently developed by A123 Systems (Waltham, Mass.) for General Motors' Chevrolet *Spark* battery electric vehicle. The story behind the enclosure design is the subject of an "Engineering Insights" feature in *HPC's* sister magazine, *Composites Technology*: "Onboard protection: Tough battery enclosure" (*CT* October 2014, p. 70) or visit short.compositesworld.com/SparkBEV.

ing stamped, 1.5-mm/0.06-inch-thick, 66 percent continuous glass sheet and polyamide overmolded with PPA had almost 30 percent higher stiffness at 90°C than the same beams overmolded with PA 6/6, as evaluated by a three-point bending test.

Presently, injection molded, glass fiber-reinforced parts are most commonly manufactured from thermoplastic pellets containing strands of chopped glass fiber. Mark Paddock, sales manager for Arburg Inc. (Lossburg, Germany), provided details of a project entailing long fiber injection molding from continuous glass rovings. The glass roving is paid out into a side feeder, where it is cut into fiber strands in lengths of 15 to 50 mm (about 0.6 to 2 inches). The project used a 275-ton injection molding machine equipped with a specially designed 60-mm/2.36-inch two-stage screw, which carries out both melting of the resin and homogenization and blending of the fibers into the melt. Arburg claims that analysis of a sample airbag housing made from long-fiber granulate showed that only 30 percent of its fibers were longer than 2 mm/0.086 inch. Another housing, made using Arburg's method, showed that 50 percent of its fibers were longer than 2 mm, resulting in far better properties. Development and optimization of the process is ongoing.

A twist on long-fiber technology was the focus for Alexander Roch, a scientific staff member and project director in the polymer engineering department at Fraunhofer Institute for Chemical Technology (Pfinztal, Germany), who discussed the automotive lightweighting potential for injection molded, long glass fiber-reinforced integral *foams* using "breathing mold" technology. Two material systems, PP-LGF and PA6-LGF, were tried, coupled with chemical blowing agents and a physical blowing agent, at both low and high pressure. A gas-loaded melt is injected into a cold mold, forming a solidified skin with a foamed core throughout the mold cavity, regardless of part complexity. The sandwich approach saves material in the neutral-axis area and provides high bending stiffness at low surface weight, which, Roch claims, could work for large parts, such as door panels, spare-wheel wells, seat shells/backrests, underbody assemblies and instrument panel supports. ■

CW LEARN MORE @ www.compositesworld.com

Read an extended version of this show report online at short.gardnerweb.com/SPEACCE14.

Airframers Vie for Shares in Growing Short-Haul Market

OEMs of aircraft with 150 or fewer seats exploit composites' appeal to fuel efficiency-conscious regional air carriers.

BY DONNA DAWSON

Short-haul air travel is big business. In 2014, says the Regional Airline Assn. (RAA, Washington D.C.), regional airlines flew nearly 157 million passengers in aircraft that range from 9- to 90-seat passenger capacity. Of the 614 U.S. airports with regional service in 2013, 431 were served *only* by regional carriers. There are about 13,000 regional flights per day — regional carriers account for 50 *percent* of the U.S. commercial schedule.

Frederic Morais, however, sees the regional aircraft category in broader terms, and therefore, worthy of an even larger share of the flying public's business. The director of marketing for Bombardier (Montreal, Quebec, Canada), Morais contends that, today, the regional market includes any commercial aircraft *with less than* 150 *seats* — up from the sub-100 seat designation used in previous years. The 20- to 99-seat category includes more than 6,000 flying aircraft, but he says the 100- to 149-seat segment adds about 5,000 more. Morais, then, forecasts for his more inclusive 20- to 149-seat category about *13,000* aircraft deliveries in the next 20 years.

"Deliveries in the 60- to 99-seat segment are driven both by emerging markets and up-gauging of smaller 20- to 59-seat aircraft," he points out, adding that today's large number of aging commercial aircraft signals an almost certain growth opportunity. "The 100- to 149-seat segment has a large installed base of old aircraft that must be replaced," he points out, "and we anticipate that market will be stimulated by the arrival of new and optimized aircraft *designs* like the C*Series*." He also projects increased demand for fuel-efficient turboprops.

Industry leaders agree, however, that regionals are miles — and some 9,000 actual aircraft — behind the single-aisle, narrow-body jets exemplified by the Airbus (Toulouse, France) A319 and A320 and The Boeing Co.'s (Chicago, Ill.) 737 and 757 — aircraft with seating capacities that vary widely between 100 and 200 passengers. Although growth of regional air share has not kept pace with narrow-bodies, neither in the number of flights nor the number of aircraft built by these major OEMs (see Fig. 2, p. 31), the regional market nevertheless remains a strong sector, says Michael Miller, VP valuations and consulting for AVITAS Inc., (Chantilly, Va.), a leading advisor to the aviation industry.

Fig. 1 Source: Bombardier, Belfast

A technician inspects a starboard wing for Bombardier's (Montreal, Quebec, Canada) *CSeries* regional jets during final assembly operations in the airframer's wing factory in Belfast, Northern Ireland. The *CSeries* wings are the first on a commercial aircraft to have skins formed from dry carbon fiber rather than prepreg. Wingskin layups are infused via Bombardier's proprietary Resin Transfer Infusion process.

That strength and growth potential has encouraged a growing handful of aircraft OEMs to enter the regional jet market in a big way. In fact, Miller points out, "there may not be enough volume to go around for all the entrants." He suggests that the market may seem "overrun" by startups because aspiring airframers believe their interests are best served by jumping into commercial aerospace with a 70- or 90-seat aircraft rather than building a larger plane that puts them into direct competition with Boeing and Airbus. This appears to be especially true in China, Russia and other developing countries.

Regional composites

The use of composite materials in regional airframes has been steadily increasing in the past few years, largely in response to airlines' concern about the ever-increasing cost of fuel. At CompositesWorld's High-Performance Composites for Aircraft Interiors conference in Seattle (October 2013), Chris Red, president of Composites Forecast and Consulting LLC (Mesa, Ariz.), estimated that a mere 1 lb/0.45 kg of weight savings reduces annual fuel expenses (at \$3/gal) by \$185 to \$360 per year for a regional turboprop and \$175 to \$432 per year for jets, dependent on aircraft size and annual flight hours.

Currently, two OEMs dominate the regional market, Bombardier and Empresa Brasileira de Aeronautica S.A. (Embraer, São José Dos Campos, Brazil). On the strength of that success, each is, in fact, rapidly moving on to produce larger aircraft, even as several competitors ready models for entry into regional airspace.

Bombardier established itself as an aerospace entity in the late 1980s and early 1990s when it acquired two other Canada-based aircraft facilities, De Havilland (Toronto, Ontario) and Canadair (Montreal, Quebec), picked up Learjet (Wichita, Kan.) in the U.S. and then added Short Brothers in Belfast, Northern Ireland. In the de Havilland *Q-Series* turboprop design (Q is for quiet) in the early 1980s, composites were used extensively in cabin components and secondary airframe structure. The plane had its beginnings at de Havilland as the *Dash* 8-100, and was rebranded as the *Q100*.

"Composites were estimated at ~10 percent of the empty weight of the aircraft," says Gavin Campbell, director of design engineering and technology development at Bombardier's Belfast plant. S-2 glass is still used in radomes for Bombardier's latest *Q400* turboprop series because of its transparency to radar, and Kevlar (DuPont, Wilmington, Del.) aramid fiber was and still is used for door panels, load-bearing floor panels and other cabin components. Over time, however, some parts were switched to carbon fiber reinforcement. The *Q400 NextGen* floor panel, for example, is a carbon fiber/honeycomb sandwich construction (see Fig 3, p. 32). The *Q400* also makes use of damage-tolerant Kevlar in its wing leading edges, horizontal and vertical stabilizer leading edges, and dorsal fin — applications that were pioneered in the 1980s.

The Belfast operation began to incorporate carbon fiber composites in the late 1980s, along with honeycomb stiffening for engine nacelles and control components. Campbell says, "The component that was a landmark for Bombardier in use of carbon fiber composites, certified during the 1990s, was the horizontal stabilizers on its business jet, the Bombardier *Global Express*." Still used on those parts and now considered a conventional process, Belfast's automated tape laying of load-bearing skins with woven fabrics in a varied ply orientation was advanced in its time. Although it's manufactured on a smaller scale, says Cambell, "the stabilizer has all the complexity and all of the load-bearing requirements that a wing might have."

When it re-engineered its 60- to 99-seat *CRJ* line of regional jets, Bombardier moved to carbon composite construction for the flaps and aileron high-lift devices. Using carbon fiber reinforcement on the new *CRJ NexGen* family, Campbell says, "we could tailor the stiffness and strength characteristics to achieve exactly the performance that we were looking for and, at the same time, we could achieve very high strength, reliability and long product life."

For its all-new *CSeries* jetliner, aimed at the 100- to 149-seat sector, Bombardier decided on carbon composite wings and is the first commercial aircraft manufacturer to use *dry* fiber rather than prepreg, for wing structures (see Fig. 1, p. 30 and "Learn More"). Its new wing factory in Belfast uses Bombardier's patented Resin Transfer Infusion (RTI) process (a variant of resin transfer injection).

Fig. 2 Source: AVITAS

Firm order backlog of regional aircraft as of March 2014.

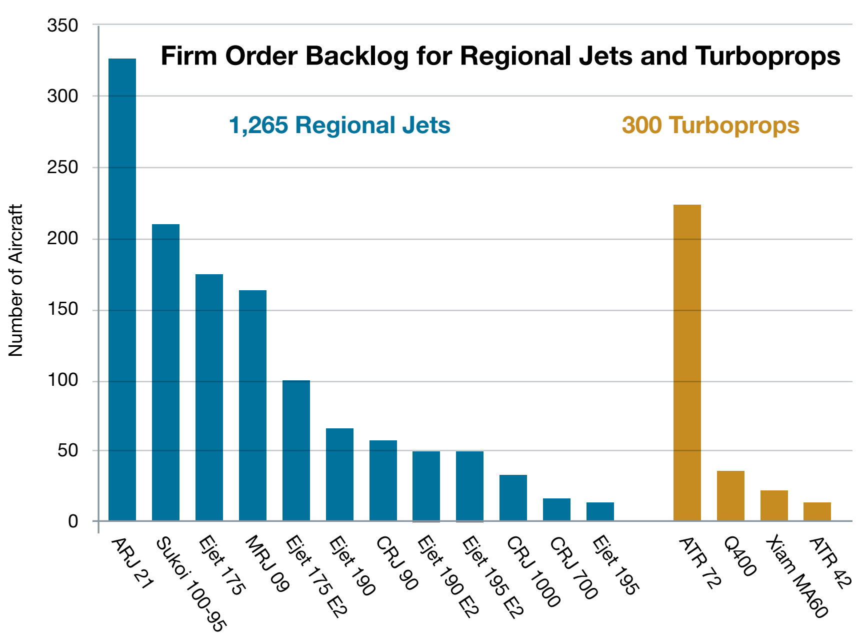


Fig. 3 Source: Bombardier

Bombardier's *Q400 NextGen* turboprop steps up composites use, compared to previous *QSeries* iterations, with aramid fiber-reinforced composites in the leading edges of its wings, stabilizers and dorsal fin, but carbon fiber has replaced aramid in its cabin floor panels.

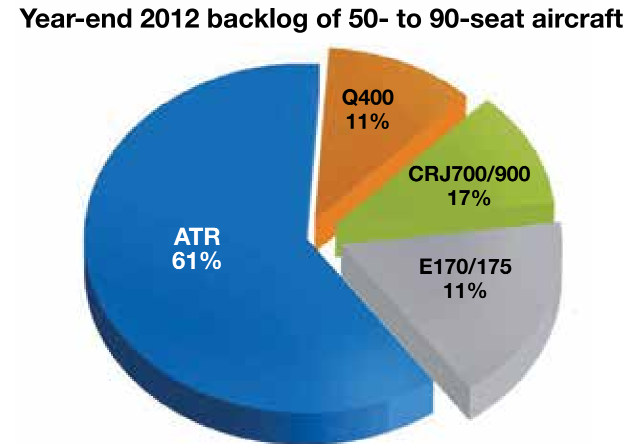


Fig. 4 Source: ATR for SpeedNews

Among regional aircraft in the 50- to 90-seat category, airlines clearly prefer those produced by ATR (Toulouse, France). ATR's current share is greater than that of Bombardier's *CRJ* and *Q400* models and Embraer's *E-jets* combined.

Workers first lay up dry fiber over various sections of hard metal tooling that represent the wing's outer mold line, using laser technology to enable ply placement and fiber orientation. The tooling sections are then assembled and the complete mold assembly and layup (which includes wing stiffeners) is moved into an autoclave fitted with plumbing that enables resin infusion of the closed mold *inside* the pressure vessel. A vacuum is applied, and the wing is cured under closely monitored temperatures and pressure.

Embraer SA's early work in composites for primary structure focused on the vertical fins, horizontal stabilizers and pressure bulkheads in its business aircraft: the *Phenom* 100/300 line and, more recently, its *Legacy* 450/500 platform. Carbon composites were used in control surfaces and to fashion fairings and ancillary structures. By 2012, carbon composites accounted for close to 20 percent of the structural weight in its executive jets. Embraer announced in 2008 and broke ground in late 2011 for what Marco Túlio Pellegrini, then senior VP of operations and the COO of the firm's Executive Jets division, called a "state-of-the-art composites center of excellence" located in Évora, Portugal. The facility, representing an estimated investment of $71.6 million (USD), is dedicated to making com-

Fig. 5 Source: ATR

Composites use in ATR's *ATR72* is illustrated here, and includes the use of glass, aramid and carbon fiber reinforcement. (A similar graphic illustrating composites use on the *ATR42* can be viewed online (see "Learn More").

posite parts via lean manufacturing approaches. The facility features automated capabilities including fiber placement and automated tape laying machines.

The key to Embraer's regional jet aspirations, however, is its *E-jet* family. Its first-generation *E-jets* featured doors and other nonstructural parts made from composite materials. Embraer announced the launch of its new E-*Jets E2* commercial aircraft at the 2013 Paris Air Show. These second-generation jets reportedly will offer airlines a family of "leading-edge regional jets" with a capacity for 70 to 130 seats. Embraer foresees a demand for 6,400 jets of this size in the next 20 years.

The family will comprise the *E175-E2*, *E190-E2*, and *E195-E2* — updated and upgraded versions of its original *E-jet* trio. Although advanced technologies will be applied to engines, wings and avionics, the E-*Jets E2* planes will provide airlines commonality with current *E-Jets*, yet are expected to yield double-digit reductions in fuel consumption, emissions, noise and maintenance costs. According to Embraer, parts made with composite materials will include flight-control components (flaps, ailerons, elevators, rudder, spoilers), landing gear doors, wing-fuselage fairings and radomes. However, Embraer decided not to use composites on the wing primary structure, after trade studies reportedly indicated that aluminum was the most cost-effective, low-risk choice.

FACC AG (Ried im Innkreis, Switzerland) is designing, building and will provide support for the wing spoilers and ailerons for the *E-Jets E2*. FACC estimates that revenue from the contract, said to extend for the lifetime of the program, could exceed $120 million (USD), depending on the sales of the aircraft.

Struck in August of 2013, the contract marked a significant expansion of FACC's relationship with Embraer: Previously limited to the supply of products for aircraft interiors, FACC gained entry into Embraer's aerostructures (take *HPC's* FACC Plant Tour, beginning on p. 38).

Installed in the wing trailing edge, above the flaps, the spoilers number six per aircraft side. The aileron is attached to each wing's trailing edge. Both systems are in design phase and will be tested and manufactured by the FACC Aerostructures division in Austria. The engineering Joint Definition Phase (JDP) began in June 2013. Delivery of the first parts is expected in first quarter 2015.

These moveable flight-control surfaces will incorporate "innovative connecting elements" and the fundamental spoiler and aileron functions will be integrated into one ready-for-delivery unit. According to FACC, the result will be a vital element in Embraer's effort to give these next-generation aircraft an aerodynamically advanced wing, reduce fuel burn and limit emissions.

In June of this year, Embraer announced that it had concluded the preliminary design review, and thus the Joint Definition Phase (JDP), as well as the wind tunnel tests, on the *E190-E2* jet. The next step in its development is the critical design review, when the product's maturity will be validated, opening the way for prototype production. Scheduled to begin revenue service in 2019, the *E195-E2* entered its Joint Definition Phase in May this year. Concurrently, Embraer concluded concept studies for the E175-E2, which is expected to enter service in 2020, and commenced the preliminary studies as well as the aerodynamic wind tunnel tests. The E175-E2 will have wings and engines that are optimized for the aircraft's size, distinctly different from the configuration that was adopted for the other models.

Although Embraer and Bombardier dominate this segment, they are no longer alone in regional air space. The following OEMs are vying for market share:

ATR, an Alenia Aermacchi SpA (Venegono Superiore, Italy) and Airbus Group joint venture based in Toulouse, is rapidly gaining market share in the 50- to 70-seat range with its regional turboprops and claimed 61 percent of the sub-90 seat market at the end of 2012 (Figs. 4 and 5, p. 32). Filippo Bagnato, ATR CEO, foresees growth in the regional market due mainly to the development of new regional networks in Southeast Asia and Latin America. Growth will be augmented as aging turboprop fleets are replaced in Europe and the U.S. "We estimate a global demand for some 3,300 turboprops within the next two decades," Bagnato says.

ATR began using composites in the 1980s for wing flaps, ailerons and some fairing panels on its original *ATR42*, and designed and produced a full composite outer wingbox for its 1980s-version of the *ATR72*. Typically, the company uses Kevlar aramid fibers for secondary

structures, rather than fiberglass, and still uses Kevlar for *ATR42* and *ATR72* fuselage fairings, tail cones, trailing edge panels and other airframe elements.

With the entry of the *ATR72* into service in 1988, the company began using carbon composites for the outer wingbox. "Until a few years ago, this part was one of the largest composite parts on a commercial aircraft," Bagnato says. Today, ATR reduces weight on its latest *ATR72* model by using carbon composites to build the primary structural outer wingbox skin, spars and internal ribs, and vertical and horizontal stabilizers, as well as secondary elements, including the nacelle fairing, engine cowl and flight controls (wing flaps and aileron, and empennage rudder and elevator.)

In Japan, **Mitsubishi Aircraft Corp.** (Nagoya) and parent company Mitsubishi Heavy Industries Ltd. (MHI, Tokyo) are winging into regional air with that country's first commercial passenger jet, the *Mitsubishi Regional Jet* (*MRJ*, see Fig. 6, this page). The *MRJ* family, thus far, boasts two models: the *MRJ90* and the *MRJ70*, designed to accommodate 90 and 70 passenger seats, respectively.

Fig. 6 Source: Mitsubishi Aircraft Corp.

Mitsubishi Aircraft Corp. (Nagoya, Japan) introduced its *MRJ* to capture a share of the regional carrier market. Carbon composites are featured in both structural and nonstructural elements (inset shows an *MRJ* on the wing/fuselage assembly line).

Long a manufacturer of composite structures and parts for other aircraft — most notably, Boeing's 787 — MHI determined to enter the field with a high-end jet featuring a composite empennage and new-generation, fuel-efficient engines, built by Pratt & Whitney (Hartford, Conn.). Parts for the MRJ are manufactured primarily at MHI's Oye plant in Nagoya, and its nearby Tobishima plant, and assembled at MHI's Komaki South Plant.

Hideto Kurosawa, head of public and customer relations for Mitsubishi Aircraft's Corporate Communications Group, expects growth in the overall market due to the steady increase in general passenger traffic across the spectrum of aircraft sizes. Replacement of smaller aircraft and upgauging to larger aircraft are considered strong factors in the expected growth.

Overall, the *MRJ* will be approximately 10 percent composite materials. Glass fiber-reinforced composites will be employed in nonstructural areas, including the belly fairing, nose cone and flap hinge fairings. "The use of fiberglass com-

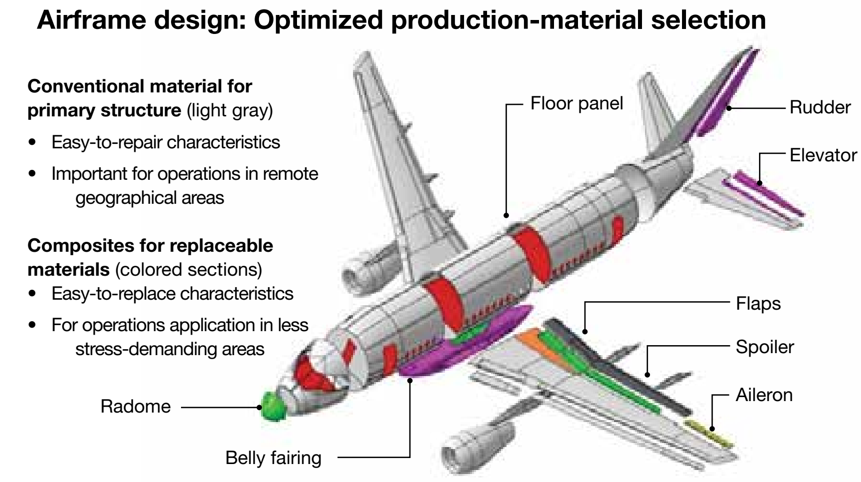


Fig. 7 Source: Superjet International

Startup Superjet International (Venice, Italy), a joint venture of Alenia Aeronautica (Rome, Italy) and Moscow, Russia-based Sukhoi Holding Co., makes relatively limited use of composites on its Superjet *SSJ100* (above) and has no plans to extend their use to primary structure.

posites on the *MRJ* follows true-and-tried practices on aircraft that are currently flying," says Kurosawa, who expects their use to continue in future generations of aircraft. "Fiberglass composites are a proven material in terms of durability and applicability in the areas noted."

The *MRJ* will integrate carbon composites into control surfaces, such as flaps, spoilers, ailerons, rudder and elevators, as well as vertical and horizontal stabilizer boxes. "Carbon composites are known for weight and strength benefits and *MRJ* is using them for these benefits," Kurosawa notes. "Moreover the use of carbon composites in both structural and nonstructural areas leverages greater maintenance advantages, such as lower weight and corrosion resistance — factors that drive maintenance pluses."

Superjet International is a regional jet startup with ambitious plans. Established in 2008, the Venice, Italy-based airframer is a joint venture of majority shareholder Alenia Aeronautica (Rome, Italy, 51 percent) and Sukhoi Holding Co. (49 percent), a Moscow, Russia-based civilian and military aviation company that emerged from the collapse of the U.S.S.R. Superjet produced 25 of its 98-seat *SSJ100* aircraft in 2013; 26 were in service by April 2014. John Buckley, Superjet's VP of business development, based in Washington D.C., says, "We are adding aircraft every month." A total of 40 were forecast for this year and 50 are expected to follow in 2015.

Targeting worldwide service capability, the company is establishing maintenance and repair operations (MROs) in support of the aircraft by partnering with existing MROs in Europe, the Americas, Africa and Asia.

Notably, Superjet has limited the use of composite materials on its jets to what it considers "replaceable parts," and does not expect to build composite primary structure (see Fig. 7, p. 36). "The extensive use of composites increases manufacturing cost," Buckley contends. "In the case of large transport aircraft, the cost of composite technology seems to be worth the weight savings — for example, in the B787 some 25,000 lb (11,340 kg) of weight savings was achieved, but at significant cost," he maintains. "In manufacturing the *SSJ*, Sukhoi wanted to have a known construction material, both from a cost perspective and certification risk, which we consider is not balanced by weight savings in aircraft having less than 150 seats."

Desirable diversity

New entries in the regional aircraft market, no doubt, will make for stiffer competition among the participating OEMs, but that's a welcome development for regional air carriers. AVITAS' Miller points out that the deployment pattern — that is, how the aircraft are actually used in terms of miles traveled per flight — will be considerably short of the planes' ultimate ranges. Moreover, the airlines' passenger seating requirements will vary greatly, depending on the route and region. "One size does not fit all," he sums up, so a broad range of airplanes with a variety of seat densities is a necessity.

In North America, another factor that will affect regional aircraft deployment is a contractual arrangement between airlines and the Air Line Pilots' Assn. International, which limits the number of regional jets that can be flown by a given airline. The largest pilots' union in the world, it represents *50,000* pilots employed at 33 U.S. and Canadian airlines. This "gives the pilots a big chip in the game overall with respect to how many of the regional airplanes can be used," Miller notes. Further, pilots must be specifically trained and qualified to fly regional aircraft. Consequently, RAA chairman Brad Holt says many RAA member airlines were forced to park aircraft and cut services in 2014 because "there simply aren't enough qualified pilots to fly these airplanes."

Challenges notwithstanding, composites use will expand in the commercial aircraft market, and integration into regional airframes is expected to keep pace. Although incursion of composites into both the regional and jumbo jet categories (less-than-150 seats and more than 300 seats, respectively) has lagged behind the trend set by OEMs in the mid-size, twin-aisle class — no regional aircraft manufacturer has yet tackled a composite fuselage — composites use in primary structure is no longer off-limits in *any* commercial transport segment. Composite wings, tail structures and other control surfaces are well established in regional aircraft, and composites use in second-generation programs is unlikely to go anywhere else but up. ■

CW LEARN MORE @ www.compositesworld.com

Read this article with additional graphic illustrations online at http://short.compositesworld.com/ShortHaul.

(Read more about dry-fiber ATL technology in "Resin-infused *MS-21* wings and wingbox," *HPC* January 2014 (p. 29) or visit short.compositesworld.com/MS-21wings.

FACC AG: AEROCOMPOSITES POWERHOUSE

BY GINGER GARDINER

This pragmatic Austria-based innovator is pursuing lofty goals in an aerocomposites future full of opportunity.

Source: FACC

Aerospace headquarters in Austria

FACC AG's Plants 1 (Ried im Innkreis) and 4, in neighboring Ort im Innkreis, are just two of five facilities in Austria, including a new R&D/Technology Center and adjacent Composite Lab (see Fig. 4). They are augmented by joint ventures in Russia, China and the U.A.E.

When it received Frost & Sullivan's Global Market Share Leadership Award in 2012, FACC AG (Ried im Innkreis, Austria) already had a 30-year history in composites and had become a Tier 1 supplier to Airbus, Boeing, Bombardier, Dassault and Embraer. Yet it remains relatively unknown in the composites industry.

This hardly seems possible for a company that holds contracts for parts on every major commercial airframe now in production. FACC employs more than 3,000 people (more than 700 are engineers) and maintains four fabrication facilities, totaling 60,300m²/649,000 ft², in Austria alone. But it also has forged joint ventures in Russia, China and Abu Dhabi, U.A.E., and has customer support/engineering operations in China, Germany, India, Russia, Canada and the U.S.

The company has focused on three product portfolios: Interiors, Aerostructures and Engines & Nacelles. Considering innovation one of its core capabilities — e.g., the now-standard door hinge with integrated damper for interior stowbins and the industry's first composite wingbox components produced in a one-shot, out-of-autoclave (OOA) process — FACC is poised to expand into primary structures and recently guided *HPC* through several of its Austrian facilities, offering the following glimpse into its global operation. (Take a walk through FACC history in "FACC timeline: Engineer-centric evolution," on p. 41.)

Emphasis on innovation

HPC was accompanied by CEO Walter Stephan and aerostructures product

Emphasis on engineering innovations

FACC builds translating sleeves for the Airbus A350 and Boeing's 787. On the latter, FACC pioneered this double-degree acoustic surface and undulated (chevron) engine nozzle design.

Focus on aircraft Interiors

AN FACC forté, the aircraft interior was an early beneficiary of several of the company's innovations. FACC recently installed this new, optimized A320 interiors assembly line.

development director Hermann Filsegger. Asked to account for FACC's obvious success, they were quick to point out the company's focus on finding ways to cut weight, reduce fasteners and part count, simplify installation and reduce costs.

A case in point involves spoilers for the Airbus A330/A340, previously assembled from several precured carbon fiber-reinforced polymer (CFRP) parts bonded to an aluminum main fitting. However, the difference in coefficient of thermal expansion (CTE) between the CFRP and aluminum was an issue. "We saved 15 percent weight vs. the original design by using RTM [resin transfer molding] and CFRP," said Filsegger. "We had no more CTE issues nor need to purchase expensive forged metal fittings." Since then, FACC has developed the design further for the A350 XWB (see Fig. 1, below, and Fig. 2, p. 40). Filsegger noted, "The RTM fitting has flown on the A330 for years without any problem."

The resin is Cytec (Woodland Park, N.J.) 977-20 toughened epoxy. And it was Cytec, in fact, which suggested FACC involvement in the Irkut (Moscow, Russia) *MS-21* wingbox program (see "Learn More"). "The customers knew they wanted to proceed with an OOA composite concept for the wing but were looking for a partner with expertise in the technology," Filsegger recalled, contending that FACC's tooling concept was "smarter" than its competitors', both for the infusion process and final assembly. (FACC's infusion process — a proprietary and patented system — is described in "FACC: Aerospace infusion pioneer," on p. 40.) Why? "Because we calculated the thermal expansion and laminate warpages so that the resulting parts are true to dimension," he explained, adding, "Not just expansion and shrinkage, which is expected, but more importantly, we could manage the remaining springback in final assembly."

This, on a 1-inch/25.4-mm thick spar at the root, would make it impossible to bend the part into its necessary shape. "And even if you did," said Filsegger, "you would introduce an uncontrolled preload on the fasteners, which is not permissible. Our tools could handle springback effects easily, allowing the skin to fit perfectly to the ribs and spars. And it was right the first time." According to Filsegger and Stephan, this was possible because FACC had considered all of the risks during infusion and final assembly from the start. "For us, it was a standard technical risk assessment, but it is key to developing innovations so that you can deliver what is promised."

When asked if FACC foresees building OOA wings in the future, Stephan explained that OEMs will likely retain (and in Boeing's case reclaim) control of the wing. So what future primary structure is the target? "We have developed our expertise so that OOA vertical or horizontal stabilizers will be readily achievable."

Winglets, spoilers, bypass ducts

The tour commenced in Plant 1, which houses FACC's corporate headquarters as well as production of aerostructures and some engine and nacelle components. Tour highlights in the 21,000m²/226,000-ft² facility included winglet, spoiler and engine bypass duct operations.

A global leader in the development and production of winglets, FACC

Fig. 1

FACC replaced the costly forged aluminum main fitting in A330/A340 and now A350 spoilers with RTM CFRP, cutting CTE issues and 30 percent weight. Now via its DAEDALUS Project, FACC infuses dry preforms for the shell, ribs and fittings with resin using its MARI process, further reducing manufacturing steps and weight (see "FACC: Aerospace infusion pioneer," p. 40).

Fig. 2

Preforms for the A350 XWB spoiler center hinge fitting are shown here, prior to resin transfer molding.

delivered its first set of Aviation Partners Boeing's (APB, Seattle, Wash.) trademarked Blended Winglets for the Boeing 737 N*ext Generation* (i.e., -600/-700/-800/-900 series) in 2002. It then worked with APB to retrofit them to Boeing 757 aircraft. In 2010, FACC delivered the 3,000th shipset of Blended Winglets and was named single-source supplier for the product lifetime.

It collaborated again on APB's next design, the Split Scimitar Winglet (see Fig. 4), performing stress analysis, manufacturing development and production tool design and fabrication. The name describes use of both a split winglet design and high-performance scimitar-shaped tips, which, combined, cut aircraft fuel consumption by about 2 percent. FACC prototyped the winglets in only three months.

In 2013, FACC worked with Airbus to develop new winglets for the A350 XWB, which measure 2.3m/7.5-ft wide at the base and 2m/7-ft high. FACC was responsible for the development, qualification, production tooling design and fabrication, as well as testing, series production and assembly of the individual components into a ready-to-install system for delivery to the Airbus final assembly line (FAL) in Toulouse, France. This program was the first in which tests on full-scale parts of this size — wingtips with attached winglets are 6m/20-ft long — were carried out at FACC's Composite Lab and Test Center (see Fig. 4, p. 41). The complete winglet system was subjected to static and dynamic testing for resilience, fatigue and endurance, up to mechanical failure, and was in the final stages of completion during *HPC's* tour.

SIDE STORY

FACC: Aerospace infusion pioneer

Although it's "new" to aerospace, liquid resin infusion has been the focus of R&D at FACC (Ried im Innkreis) since 2001. "The issue," said FACC's aerostructures product development director Hermann Filsegger, "is in getting 100 percent wetout with no voids in a large part with this much complexity." That's not, by any means, an easy task. The skins FACC developed for Moscow, Russia-based Irkut's *MS-21* wingbox, for example, are more than 1 inch/25.4 mm thick at the roots, with stringers on top. On such a critical component, Filsegger pointed out, "It is not acceptable to go back and do 'emergency' processes to remediate dry spots."

The difficulties encountered in the infusion of large parts prompted FACC to develop its patented process, called membrane-assisted resin infusion (MARI). Filsegger contends that it does not infringe on the Vacuum Assisted Process (VAP) patent because the membrane is not applied directly to the part surface (see "Learn More," p. 45).

"It is still in the breathing path but easier to apply and enables a very robust process that takes care of the consistency problems while delivering 100 percent impregnation." When asked about the cost of producing primary structures in this way, Filsegger explained that the dry fiber lay down is much faster than hand layup and even automated prepreg layup, due to the lack of tack. "This integrated wing panel has just a slightly curved surface," he noted. "So laying these fabrics is like rolling out carpet. The noncrimp fabric basically prefabricates your laminate, configuring five plies into one layer." (See Fig. 3, below.)

Fig. 3

In the run-up to fabrication of prototype OOA wingbox components for the Irkut *MS-21*, FACC found dry fiber layup using NCF and infusion via its large-format MARI technology much faster than prepreg and potentially faster than ATL with system optimization and new NDT developments.

The company continues to refine its proprietary MARI process with an eye toward production of primary structures. Can OOA liquid infusion molding compete with ATL prepreg in production manufacturing? Filsegger said yes, assuming some necessary innovations in NDT. "But we still need to work on the right fiber materials for permeability and also better flow resins with a short cure time."

He pointed out that the entire system must be developed together — fiber, resin, process and inspection — and much work remains in optimization. Well-developed processing technology notwithstanding, such work also demands a commitment in time and perseverance. "Our thermoplastic copolymer is woven into the fabric, making up 8 percent of the laminate without any clustering or filtering of the toughener," he said, by way of example. "We did many tests, trying four to five resins and then 10 to 15 different combinations of parameters to see what worked and how to minimize variability, realizing that permeability is the largest cause of unreliability in infusion."

"Only one resin worked," he added, naming Cytec's (Woodland Park, N.J.) 977-20 toughened epoxy resin system.

Elsewhere in Plant 1, myriad automated cutting machines raced through meters of carbon fabric and prepreg in several large glass-encased kitting rooms. Behind these were massive cleanrooms where skins, stiffeners and other structures are hand-layed onto arrays of production tools. These tools are loaded into various autoclaves and ovens in the facility, after which parts are transferred to dedicated assembly areas.

Walking through the area for Split Scimitar Winglet assembly, 8 to 10 fixtures supported winglets in various stages of completion. The structure featured CFRP skins with bolted stringers and numerous brackets for lights and glazing to be attached later (see Fig. 5, p. 42). FACC also paints the winglets with each airline's livery in an adjoining paintshop, complete with multiple spray booths and a large open area reserved for final detailing.

Source: FACC
Source: HPC/Photo: Ginger Gardiner

Fig. 4

FACC's new Composite Test Lab enabled in-house, full-scale qualification testing of the new 6m/20-ft long Airbus A350 winglet.

Moving on through one of the spoiler fabrication areas, racks of completed spoilers shared space with parts in progress on mobile fixtures. Filsegger pointed out the RTM fitting for the A350 XWB spoiler — a massive and, visually, impeccable layup of carbon composite, with no detectable voids or distortion.

An adjoining area featured large CNC-machining bays as well as automat-

SIDE STORY

FACC timeline: Engineer-centric evolution

FACC (Ried im Innkreis, Austria) has always been an engineering-based company. Its CEO, Walter Stephan, started out as head of R&D at ski manufacturer Fischer GmbH (Ried im Innkreis, Austria). When the company faced having to lay off half of its 100 R&D engineers in 1981, Stephan suggested, instead, that the company should design parts for other industries. That same year, his group won a worldwide competition to develop the Airbus A310 crossbeam floor support (floor strut) using carbon fiber/epoxy prepreg. "We completed development in six months," Stephan recalled, "which was impressive because the structure included 75 parts and had 35 different configurations due to changes in loads, depending on the location in the fuselage."

In 1986, FACC became a separate division, with 27 employees and annual revenue of $1.5 million USD (€1.2 million). That same year, it won a contract from Rohr Inc. (now United Technologies Corp., Hartford, Conn.) to make doorframes for the McDonnell Douglas (St. Louis, Mo.) *MD-80* commercial passenger jet. The following year, FACC Plant 1 was built, and the company was awarded the composite flap hinge fairings and sidewall panels contract (previously aluminum) for the McDonnell Douglas *MD-11*.

When it was spun off as an independent company in 1989, FACC AG had grown to 102 employees and $7.5 million USD (€6 million) in annual revenue and had begun production of overhead luggage bins and ceiling panels for the Airbus (Toulouse, France) A320/A321 single-aisle family. Its first complete passenger cabin was for the *MD-95*, which was renamed the B717 after The Boeing Co. (Chicago, Ill.) acquired McDonnell Douglas in 1996.

FACC's engine and nacelle structures business began in 1994 with the engine nozzle for the CFM56-5C engine on the Airbus A340-200/300 family and expanded in 1996 to fan cowls for the CFM-56 5A and 5B. Stephan recounted, "That was a carbon fiber sandwich construction that we won because the previous supplier could not meet production targets."

In 1999, Plant 2 was built in nearby Ort im Innkreis. This campus now hosts production Plants 2 and 3 (totaling 18,300 m^2/194,000 ft^2) as well as FACC's Technology Center and adjacent Composite Lab and Test Center (Plant 5), added in 2012 and capable of airworthiness certification testing for large aerostructures. This facility centralizes R&D and houses 500 engineers from FACC's three product divisions. FACC already has committed to $67.6 million (€54 million) in R&D as part of the extensive investment outlined in its Vision 2020 strategy. The 21,000m^2/226,000-ft^2 Plant 4, which now houses engine cowl and nacelle manufacturing was added in nearby Reichersberg in 2007.

In 2009, Xi'an Aircraft Industry (Group) Co. Ltd. (XAC, Xi'an, China), a subsidiary of Aviation Industry Corp. of China (AVIC, Beijing, China), became FACC's majority shareholder. Walter Stephan remained CEO and FACC's Austrian operations expanded. But FACC has since given greater emphasis to its global positioning. In 2011, FACC was awarded the complete interior contract for Commercial Aircraft Co. of China's (COMAC) *C919* single-aisle jetliner. That same year, it announced its joint venture with Aerocomposit, a subsidiary of Moscow-based United Aircraft Corp., to develop and produce composite components for Superjet International's (Venice Italy) *Superjet SSJ100*, the Irkut (Moscow, Russia) *MS-21* and other Russian-made aircraft.

In 2012, FACC commissioned a new 16,000m^2 (172,000-ft^2) production facility in Zhenjiang, China (250 km/155 miles northeast of Shanghai) to gain a foothold in a regional market that is estimated to need more than 4,300 aircraft in the next 20 years. Here, FACC offers not only local production to support aircraft OEMs' offset commitments for aircraft purchases, but also what it terms "powerful synergies," including XAC's experience in producing wing and empennage (vertical tail) structures.

Fig. 5

Plant 1's winglet assembly area featured racks of CFRP spars ready to bolt to CFRP skins as well as a full paintshop where FACC applies each airline's livery. FACC produces winglets for Aviation Partners Boeing, Dassault and Airbus.

ed nondestructive testing (NDT) cells, including two new machines supplied by local machinery company Fill (Gurten, Austria). One was a high-speed, 10-axis, 3-D linear ultrasound system capable of through-transmission and pulse echo interrogation. Designed for high throughput (linear speed up to 1.7 m/s) and high accuracy (±0.2 mm), two electronically coupled, numerically controlled modules move the inspection heads along a 3-D path generated via interface with standard CAD systems. The second system uses a 7-axis robotic arm to perform pulse-echo ultrasound testing with the same basic speed and accuracy of 3-D inspection. As FACC series production ramps up for a program, Filsegger explained that every part is inspected until statistical quality performance is established over a specified number of parts. After that, defined periodic sampling is considered sufficient.

Before leaving Plant 1, HPC passed through one of the larger open areas within the building, populated by a number of barrel-shaped structures with various-shaped cutouts. Another FACC area of expertise, these were lightweight, sound-absorbing composite outer bypass ducts, which channel the outer (bypass) airflow around the hot core in turbofan engines. FACC worked with Pratt & Whitney to develop the latter's first composite bypass duct in 2002, and has produced more than 1,000 similar parts for Rolls Royce's (London, U.K.) BR700 family of engines since 2001. The Pratt & Whitney structure uses a sandwich construction with carbon fiber/epoxy skins that feature a 2x2 twill prepreg and aluminum honeycomb core. FACC also developed a sound attenuation treatment for the duct's inner skin. In 2013, after only 12 months of development, FACC delivered several variations of a new design for the PurePower PW800 engine aimed at long-range business jets, regional jets and single-aisle jetliners and looks forward to beginning serial production soon.

Interiors now and tomorrow

The tour's next leg took *HPC* to Plants 2 and 3, 10 km/6.2 miles away in Ort im Innkreis. Plant 2 houses interiors production. "There are only three companies who can design, develop and supply a complete aircraft interior," Stephan pointed out. "Diehl [Laupheim, Germany], Boeing Interiors Responsibility Center [North Charleston, S.C., and Everett, Wash.] and us. We make and supply all of the components needed, from cargo to cabin." FACC now owns a 20-plus percent share of the commercial aircraft cabin market. Filsegger credited that to FACC's innovative approach to interiors, which dates back to the first *MD-95*. He recounted an example, "The line of stowage bins, sidewalls and ceiling panels inside the finished cabin had to be precisely level." However, he described the plane's aluminum fuselage sections as "flexible tubes" to which composite interiors were attached using myriad adjustable brackets. Thus, interior unit alignment required painstaking adjustment of hundreds of hard-to-reach threaded tie rods. "We developed a laser-aligned installation, which located a highly effective new type of attachment, independent of the incongruities in the fuselage barrels, which was very fast and efficient."

FACC also pioneered the now-standard hinge used on practically every fixed-shelf stowage bin (overhead compartment) door. "It used to be that this hinge had an air- or spring-loaded actuator that extended back into the bin, but made the corners unusable space," Filsegger recalled. FACC's smaller, more reliable hinge incorporates the actuator into the hingeline, opening up that space.

Plant 2's landscape revealed rack after rack of completed bins and numerous fabrication and assembly areas, each devoted to a different aircraft's components.

Fig. 6

In Plant 2, racks of interior stowbins are assembled from flat honeycomb-cored panels prepotted to receive hardware. FACC continues to push system integration: for example, in-house produced composite ducting (see inset) and, in the future, electric actuation to increase space and loading volume while reducing weight.

Source (both photos): *HPC*
Photo: Ginger Gardiner

Fig. 7

In Plant 3, FACC builds a wide variety of flaps, fairings and flight-control surfaces. Fabrication efforts often involve this massive hot drape forming machine.

The stowbins are all made from flat honeycomb-cored panel stock and curved cored doors, with attachment points prepotted to accommodate hardware. For many of the units, oddly shaped composite duct modules — most made from lightweight glass fabric and phenolic resin — are also prefabricated and then attached during assembly (see Fig. 6, p. 42). After mechanisms and trim are added, finished bins are strapped into specialized containers and shipped to Diehl for rigging of electrical and other systems. FACC continues to increase unitization of the parts it ships. One example is a composite "plug and play" module for the A350 XWB smoke detection panel, designed In cooperation with Siemens SAS (Buc Cedex, France), which reduces part mass and makes it easier and more economical to install than conventional panels.

Although the materials and processes used in stowbins have been standard for decades, Stephan says FACC always looks for new options, but he admits, "crushed core is hard to beat because it is very robust … and it's easy to push out part after part with consistent quality and not a lot of quality control intervention. It is also cheap." When asked if thermoplastic composites hold promise, Stephan was cautious, "The problem is that in order to get the fire, smoke and toxicity [FST] performance, you are forced into materials that are 10 times the cost of current phenolic and honeycomb." Nor does he think thermoplastic composites could increase throughput. "We are already press-forming the phenolic parts with a cycle time as low as 30 minutes for large baggage bin doors," he says. "There is also a limit to the weight savings you can achieve on a sidewall, for example, because noise transmission is governed by mass."

Plant 2 also incorporates a very large core machining area, with two new CNC milling machines used only for honeycomb supplied by Reichenbacher Hamuel (Dörfles-Esbach, Germany) with clamping systems by Inteccs (Dortmund, Germany). Filsegger explained that it is more economical for FACC to mill honeycomb in-house and, as we passed a vast landscape of machined core, he pointed out, "All of this is only for *today's* production."

In Plant 3, a wide variety of flaps, fairings and flight control surfaces are manufactured. Here also, efficiencies from automated tape laying (ATL) and hot drape forming are exploited. The latter applies heat and pressure to flat ATL preforms using a core and flexible forming pad to produce three-dimensional shapes (see Fig. 7, above). One example is ongoing A321 flap production, ➲

Source: HPC/Photo: Ginger Gardiner

Fig. 8

CFRP translating sleeve cowls are hand layed in large cleanrooms. The complex layups are facilitated by laser projection systems.

which uses a cutting-edge automated workcell custom-engineered by Fill.

Large engine parts

In Plant 4, another 21,000m² facility, FACC manufactures a wide array of engine and nacelle components. Filsegger highlighted FACC's large composite translating sleeves, critical components in the cascade thrust reverser systems used in today's commercial jet engines. Sleeve cowls are hand layed (see Fig. 8, this page) in large glass-fronted cleanrooms, the complex layups facilitated by laser projection systems (SL Laser, Traunreut, Germany).

For the Boeing 787, FACC worked with customer UTC Aerospace Systems (UTAS, Charlotte, N.C., previously Goodrich Aerostructures) to develop, engineer and qualify the first sleeve to use a double-degree acoustic surface and undulated (chevron) engine nozzle design, both achieving significant noise reduction. Working again with UTAS, FACC also developed a weight-optimized design for the Airbus A350 XWB. Both programs are now in production.

Plant 4 also houses two large autoclaves (see Fig. 9, p 45) built by Scholz Maschinebau (Coesfeld, Germany). One is 12m/40-ft long by 4.5m/13 ft diameter and the other is 12m long by 6m/20 ft diameter. Each is capable of 250°C/482°F and able to accommodate the sleeve cowls and other massive parts.

After cure, the various sleeve components are assembled, each sleeve is painted and then proceeds through quality assurance (QA). Plant 4 also accommodates an 8 by 4 by 2m (26- by 13- by 7-ft) 5-axis CNC milling machine and multiple laser coordinate measurement machines and ultrasonic inspection units that facilitate QA.

Firmly on the edge

Now a leading Tier 1 aerostructures supplier, FACC's visibility is increasing. The RTM composite annulus filler it developed with Rolls Royce as part of the CleanSky Initiative was recognized with a 2014 JEC Innovation Award. FACC also is in active pursuit of technology that,

Fig. 9

Engine parts in Plant 4 are cured in two massive Scholz autoclaves. Note that the autoclave on the right has the diameter and depth to accommodate several wheeled carts with tools stacked two high.

if successful, will ensure FACC a future share in the spotlight: It's R&D group's desire to cut next-gen jet engine fan blade weight by 40 percent vs. metal predecessors is just one of many examples.

Looking into FACC's future, Stephan claimed that the company's financial targets — including $1 billion USD (€799 million) in total revenue by 2016 — are readily achievable, given the aerocomposites market's 5 percent annual growth rate. Although he acknowledges that "China and Russia are more long-term investments," FACC is nonetheless actively pursing growth in the East and will soon assume a 24 percent share in the KAPO-Kompozit facility (Kazan, Tatarstan). This 33,000m^2/355,000-ft^2 facility will not only produce flaps, elevators, rudder and fairings for Superjet International's (Venice, Italy) *SSJ-100*, but autoclaved prepreg components for Airbus and Boeing aircraft as well. "We are qualifying the Kazan plant now as a new FACC site," says Stephan. "We have already done this with the facility in Abu Dhabi where we have partnered with Mubadala, and are proceeding, likewise, in China."

For some, the risk of expansion into new markets is an obstacle. For FACC, it's an opportunity enabled by its OEM-recognized emphasis on engineering and program management. Stephan contends, "The key to all of our locations is that we ... can not only control the production processes but also protect our customers' intellectual property." He adds that despite its diverse operations and large number of different part programs, "our additional strength is that we have always been solely focused on composites." ■

LEARN MORE @ www.compositesworld.com

Read an expanded verison of this article online at short.compositesworld.com/FACCTour.

Read about Irkut's "Resin-infused *MS-21* wings and wingbox" in *HPC* January 2014 (p. 29) or visit short.compositesworld.com/MS-21wings.

Spread-Tow Technology TAKES OFF

New, ultralight-areal-weight prepreg tapes form the thin-ply laminates that will enable *Solar Impulse 2's* sun-powered flight around the world.

By Donna Dawson

Commercial applications of thin-ply composites made by spreading tows into thin, flat unidirectional tapes has been a composites industry trend for more than a decade. The lure? Spread-tow technology provides composites fabricators a way to fashion reinforcement fabrics almost entirely free of the fiber twist and crimp that stunt fiber performance. The straighter, more uniform fibers in spread-tow tapes optimize a laminate's tensile and compressive strength. The thinner laminates that result afford molders the opportunity to make high-performance components using less material and at reduced cost. In a dramatic example of its promise, the technology will soon take flight — literally — on the *Solar Impulse* 2, an aircraft whose designers hope, in 2015, will become the first to fly around the world powered solely by energy from the sun.

Solar Impulse 2 was developed by the company of the same name, located in Payerne, Switzerland. Solar Impulse chairman Bertrand Piccard, a psychiatrist and aeronaut, made the first non-

Round-the-clock flight around the world

The all-composite airframe of the *Solar Impulse 2* (*Si2*) supports 17,000 solar panels that not only power the craft's four electric prop engines by day, but collect enough additional energy to charge onboard batteries that can power those engines after the sun sets, making *Si2* and its predecessor (*Si1*) the world's only aircraft able to fly nonstop, day and night, on solar power, without a drop of fuel. *Si2* is in preparations now to circumnavigate the globe in 2015.

Source: Solar Impulse/Photo: Ackermann

stop, round-the-world balloon flight and came up with the *Solar Impulse* concept. The venture is led by Piccard, and CEO André Borschberg, whose *curriculum vitae* includes engineering, a graduate degree in management science and experience as a fighter pilot and a professional aircraft and helicopter pilot.

They describe *Solar Impulse* 2, the second generation of the company's first solar-powered aircraft, as "the only airplane of perpetual endurance, able to fly day *and night* on solar power, without a drop of fuel." To make that possible, Solar Impulse enlisted the aid of North Thin Ply Technology (NTPT, Penthalaz, Switzerland). NTPT has successfully developed very thin unidirectional prepregs using spread tow that comprises intermediate-modulus carbon fibers with an areal weight reportedly as low as 18 g/m^2 (0.4 oz/inch^2).

From sails to wings

NTPT's parent company, North Technology Group (Milford, Conn.), made news previously with another spread-tow, thin-ply development, its patented 3Di process, which produces monolithic yacht sails (see "Learn More"). But unlike 3Di, which is designed to produce *flexible* material at the North Technology Group facility in Minden, Nev., that can function like, but perform better than, more conventional sailmaking material, the system developed by North Thin Ply Technology, and registered under the trademark TPT, is "100 percent dedicated to *rigid* composite applications," says NTPT's sales and marketing manager Gilles Rocher. "NTPT offers outstanding composite strength, homogeneity and machinability for rigid commercial applications demanding high performance and low weight."

Solar Impulse 2 (*Si2*) was designed with TPT materials in mind by Solar Impulse in conjunction with its airframe manufacturer, Decision SA — a member, with Multiplast SAS (Vannes, France), of Groupe Carboman SA (Ecublens, Switzerland). Decision constructed the Si2 airframe in its Ecublens facility.

Launched in 1984, Decision focuses on production of innovative composite structures that include not only the *Solar Impulse* airframe but the internal structures of the *Volvo Ocean* 65 high-performance monohull racing yacht. In July 2010, Decision built the prototype model, *Solar Impulse* 1 (*Si1*), the first aircraft in solar aviation history to stay in the air after dark (26 hours of continuous solar-powered flight).

"Construction of *Si2* began in 2011 and lessons learned from the prototype are incorporated into this second airplane," says Bertrand Cardis, Decision's general manager. "Designated HB-SIB, it will have an increased payload, its electrical circuitry will be isolated to enable flights in light rain, and system redundancy will improve reliability. Importantly, its more spacious cockpit will enable the pilot to fully recline during flights lasting up to five days and five nights."

The NTPT materials and process were used to construct the *Solar Impulse 2's* main and rear wing spars and other airframe components.

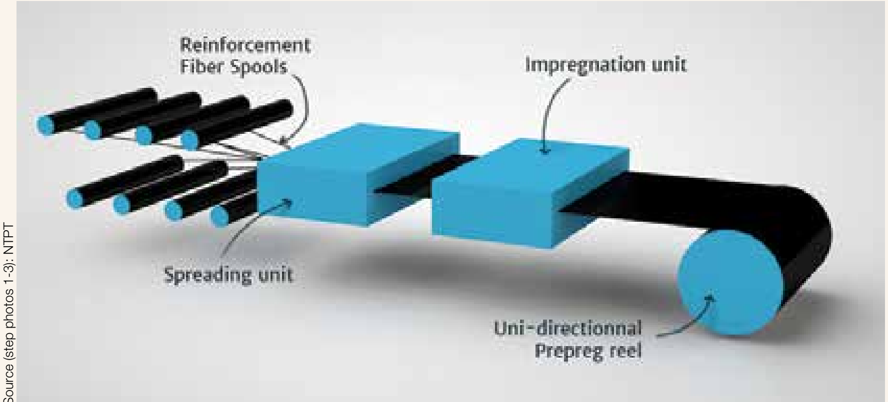
Weight has been decreased "gram by gram" for the *Si2* venture, largely through the use of the NTPT materials and process in the construction of all of the airframe's structural components, which includes the main and rear wing spars, the fuselage and cockpit, the tail structure and the vertical and horizontal stabilizers.

Solar Impulse airframe structure

As the first step in the manufacturing process for the *Si2*, NTPT spread M46J 12K ultrahigh-modulus PAN carbon tow, a 440-GPa fiber supplied by Toray Industries (Tokyo, Japan), using NTPT's proprietary technology. Depending on the carbon fiber, the process can yield tapes with areal weights of 100 g/m^2 (2.3 oz/inch^2), 50 g/m^2 (1.1 oz/inch^2) and as little as 25 g/m^2 (0.6 oz/inch^2) .

Eight spools of M46J 12K tow feed the technology's spreading unit. Rocher points out that NTPT typically spreads a 3- to 4-mm (0.12- to 0.16-inch) tow of 12K to 18 mm/0.71 inch width for a 25-g/m^2 (0.6-oz/inch^2) unidirectional tape. For the *Si2*, however, it produced a 25-g/m^2 unidirectional tape with a width of 300 mm/11.8 inches.

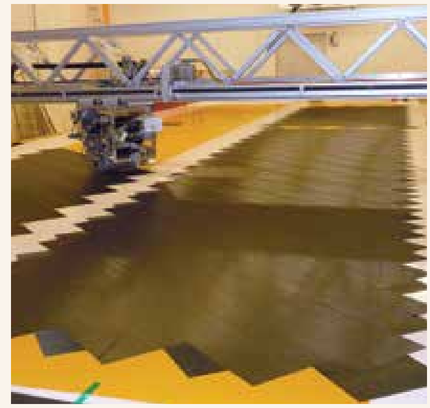
As it came out of the spreading unit, the unidirectional tape was impregnated using NTPT's custom-formulated



Source (step photos 1-3): NTPT

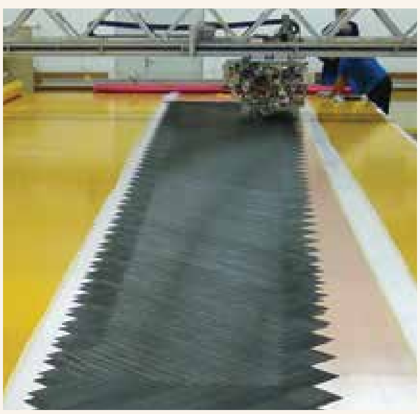
Step 1

Carbon tow is spread into thin tape and resin-impregnated in NTPT's proprietary spreading and impregnation units; the unidirectional prepreg tape is rolled up on a dedicated reel.



Step 2

Reels of prepreg tape are loaded onto NTPT's custom-designed ATL machine, controlled by its own CNC software program.



Step 3

Preforms for the 27m/±45° wingbox skin were layed by the ATL over an epoxy adhesive film on an expanded tool table, as shown here.

Step 4

The *Si2* airframe was constructed in Decision's factory in Ecublens, Switzerland. On the far left is the 30m/100-ft oven, built into one end of the factory.

Source (step photos 4-7): Solar Impulse/Photo: Stephane Gros

Step 5

The wing spar box was layed up as a honeycomb structural sandwich, skinned with TPT 100-g/m,[2] ±45° preforms.

Step 6

One side of the wing spar box is positioned for bonding with the other box sides.

Step 7

Bulkheads are sanded in preparation for bonding them into the wing spar box.

Source (step photo 8): Solar Impulse/Photo: Jean Revillard

Step 8

The wing interior: The white panel at the back of the image is the inside face of the solar panel; the flat black plate on the left is a panel of the wing spar box; and in the foreground are the ribs.

80°C/176°F-cure epoxy system. The result was B-staged and then wound onto reels specially designed for loading directly onto NTPT's automated tape laying (ATL) head. The ATL machine was custom designed and built by NTPT to layup up preforms using its super-thin prepreg materials according to customer-designated fiber orientations and ply schedules.

"The finite element analysis (FEA) and laminate design was developed by the Solar Impulse engineering team," Rocher reports. NTPT, in fact, developed its own software package for FEA and simulation, preform design and ATL monitoring. "That initial design was processed by Decision to create the ultimate design of specific structural components and prepreg preforms for best handling and manufacturability." NTPT then made the ATL CNC manufacturing files from the design provided by Decision.

NTPT developed its own software package for finite element analysis and simulation, preform design and ATL monitoring.

The uni tapes were layed up by NTPT's ATL. The ATL head can be enclosed in plexiglas to allow temperature adjustment for the specific resin prepreg chemistry, typically between 16°C and 23°C (61°F and 73°F). Further, the room that houses the ATL is maintained between 18°C and 23°C (64°F and 73°F). depending on the resin type and tack requirements.

Although the ATL is capable of producing large preforms — up to 3.4m by 12m (11 ft by 39 ft) — the *Si2's* central wing box, alone, is 27m/88.6 ft long. To accommodate the extra long layups, NTPT built a doorway with a fabric closure in the end wall of the ATL room. The fabric could be lifted out of the way, permitting the NTPT team to set up a second layup table that accommodated the 27m length. "For long preforms, we lay down the material onto the 12m ATL table and then we shift what has been laid to the next table and we carry on the laying on the ATL table," Rocher explains. Preforms for the wing, which spans 72m/236 ft, were layed up in similar fashion, but in *three* sections: One at 27m/88.6 ft long, and two others each 22.5m/73.8 ft long.

For the *Si2* preforms, tapes were placed in multiaxial orientations directly onto an epoxy film (also an 80°C cure system). Because the exceptionally thin plies of material would make the *Si2* preforms difficult to handle, each finished preform/epoxy film was placed on siliconized paper and covered by polyethylene film. Then each was vacuum bagged and compressed for debulking at about 0.8 bar. This was done to make the *Si2* preforms easier for Decision's technicians to handle when they arrived at Decision for molding. The consolidated preforms, with protective paper and film, were then rolled up for shipment to Decision.

After layup, prepreg preforms are stored in a discrete room maintained at -18°C/0°F until time for delivery to the customer. (Occasionally a customer will specify dry preform layups, and apply resin during construction of the part. In this case, as the dry fibers are spread, they are bonded onto a polyester scrim that holds the fibers together and subsequently supports the laminate between plies.)

When the prepreg preforms arrived at Decision's facility, they were layed up into the molds for the airframe parts — the fuselage, tail and wing sections, including the wingbox — fabricated by Decision in its Ecublens facility. The epoxy film ensured a better bond to the honeycomb core in the wingbox.

The principal structural element of the wing, the 27m wing spar, was particularly complex: a rectangular box made of four flat plates, each a structural sandwich construction cored with Dupont (Richmond, Va.) Nomex honeycomb. The spar box features bulkheads to reinforce left and right/inner and outer wing spar panels — all constructed from NTPT's preforms. Its central portion features faceskins of TPT preforms comprising four plies of 100-g/m^2 tape in ±45° orientation. The left and right ends of the spars, however, are solid laminates rather than sandwich constructions, made from TPT preforms consisting of four plies of lighter, thinner 25-g/m^2 tape in ±45° orientation. This specified fiber architecture fulfills the torque resistance and bending stiffness requirements, which were the main design criteria for the spar box.

Decision vacuum bagged the parts and cured them out of the autoclave at 80°C/176°F in a 30m/98-ft long, 4.5m/14.8-ft high oven that is built into the Ecublens factory along the length of one wall. The oven is accessible by means of a sliding door that can be tightly sealed during the cure cycle.

Despite a battery package that weighs 633 kg/2,077 lb, the *Solar Impulse 2* has an extraordinarily low empty weight of 2,300 kg/5,071 lb.

After cure of the individual parts, the spar boxes and bulkhead assemblies were bonded together at the joints using prepreg technology from Cytec Industries (Woodland Park, N.J.). The prepreg was used as a doubler at the joints.

Each wing section was postcured before final assembly with mechanical lug fasteners. Then, Decision installed 17,000 solar panels over the cured composite skin across the entire wingspan, the fuselage and even the horizontal and vertical stabilizers. The solar panels convert the sun's radiant energy to electricity that powers the aircraft's four electric motors. During daylight hours the solar cells also recharge the lithium batteries that permit powered flight at night, using electrolytes invented by Solvay (Brussels, Belgium).

The result? An extraordinarily lightweight flying machine that, despite a battery package that weighs 633 kg/2,077 lb and a 72m/236-ft wingspan (as wide or wider than the world's most massive conventional and military transport aircraft), weighs a mere 2,300 kg/5,071 lb.

Si2 made its maiden flight on June 2, 2014, taking off from Payerne Airport, Switzerland, at 5:36 a.m. on a cloudy morning. With test pilot Markus Scherdel at the controls, it flew for two hours and 17 minutes, reaching an altitude of 1670m/5,492 ft before landing. Although global circumnavigation is still ahead, Rocher is convinced that "without TPT lightweight material, *Si2* would not be able to fly around the world."

Looks like a winner

Formed in late 2009, NTPT has soared upward, averaging 50 *percent* annual growth, in part because the company targeted first what it calls the "fast-entry market," of which Solar Impulse is an example, because validation processes take only a few months. But NTPT is now entering aerospace applications where weight savings are critical but the cost of certification is much greater and earning a place on a project can take years. Beyond the aerospace sector, the company anticipates markets for its product in any applications where people are "looking for performance and weight saving," Rocher says.

Decision SA, for its part, has gained invaluable practical expertise in the use of NTPT material, Cardis says. "The *Si2* has been an incredible R&D experience and now Decision SA claims the distinction to be a unique, experienced builder of extremely light composite structures using NTPT products." And NTPT's test results indicate that NTPT's thin-ply laminates not only help manufacturers reduce mass and save money, but also offer superior performance.

NTPT contends that its TPT process produces the world's lightest prepreg tape. "All PAN-based carbon fibers can be spread down to 30 g/m^2 [fiber weight] and intermediate-modulus fibers can be spread to 18 g/m^2 from 12K tows," says Rocher. The lower limit for pitch fibers depends on filament diameter, modulus and strength. For example, NGF YSH70A 780-GPa/10-micron pitch fibers from Nippon Graphite Fiber Corp. (Cyprus, Calif.) can be spread down to 40 g/m^2. Rocher argues that NTPT's process also offers heretofore unavailable processing speed: "Thanks to our fast ATL technology, TPT is a serious option to solve the productivity increase that aircraft OEMs must achieve." Rocher also claims that NTPT's technology enables efficient spreading of *all* types of fibers in untwisted yarns or tows, including not only PAN and pitch carbon, but glass, aramid, quartz, UHMWPE and even metallic fibers. A 14-micron quartz fiber from Saint-Gobain Quartz SaS (Nemours, France), for example, can be spread to form a tape with an areal weight of only 17 g/m^2.

Simply put, NTPT is flying high. ■

CW LEARN MORE @ www.compositesworld.com

Read an enhanced version of this article at short.compositesworld.com/IM-NTPTSi2.

Read more about North Technology Group's unique yacht sailmaking process in a previous Focus on Design feature article, titled "Custom-engineered composite performance yacht sails" (*HPC* March 2012, p. 62) or visit short.compositesworld.com/8kX6ogwR.

Hilton Torrey Pines
La Jolla, California, USA

LEARN!

CompositesWorld's Carbon Fiber 2014 is the Carbon Fiber conference organized by composites industry professionals! Since 1998 the Carbon Fiber conference has successfully been bringing together the industry's leading executives and technologists to explore the expanding role of carbon fiber in the composites industry.

NETWORK!

Nowhere else will you have access to this timely and pertinent information and to the industry's top minds and innovators. As you enjoy the catered networking functions at Carbon Fiber 2014 you will make invaluable contacts with the key executives in the industry.

Pre-Conference Seminar*

Tuesday, December 9, 2014

Composites in Turbofan Aircraft Engines and Nacelles: 2014 - 2023

Presented by:
CHRIS RED, Principal, Composites Forecasts and Consulting, LLC

This seminar provides a comprehensive analysis for understanding the engine market space, current polymeric- and ceramic-matrix composite aeroengine components, and the opportunities that this competitive marketplace presents. Special emphasis will be placed on:

- 2014-2023 Aircraft Production Forecast
- Composite Applications and Trends by Engine Model and OEM
- Jet Engine Production Forecast by Engine Size and Market Segment
- OEM and Tier Suppliers Composite Demand Requirements
- Composite Processing, Manufacturing, and Raw Materials Forecasts

*Separate fee required

REGISTER BY NOVEMBER 11, 2014
AND SAVE $100
ON YOUR CONFERENCE REGISTRATION!
http://short.compositesworld.com/CF2014

CONFIRMED PRESENTATIONS INCLUDE:

Carbon Fiber in 2014 – Lots of Opportunities and Challenges
MIKE CANARIO / Vice President and General Manager – Americas / Hexcel Corporation

Innovating Carbon Fiber Composites: Tackling the Major Challenges for Unlocking New Market Opportunities
ROSS KOZARSKY / Analyst-Advanced Materials / Lux Research Inc.

Using Simulation to Design Lightweight Metallic and Carbon Composite Structures
BRETT CHOUINARD / COO / Altair Engineering

Big Area Additive Manufacturing and Carbon Fiber Composites
RICK NEFF / Manager- Market Development / Cincinnati Inc.

Manufacture of Low-cost Carbon Fiber from Unmodified Textile Acrylic Fiber
LEE MCGETRICK / Director, CF Technology Facility / Oak Ridge National Laboratory

Application of Carbon Fiber Thermoplastic Composites in High Temperature, Low Sag (HTLS) High Voltage Overhead Power Conductors
MICHAEL RUBY / Global Composites Business Manager, Engineered Materials / Celanese
PAUL SPRINGER / Chief Engineer / Southwire Company

Advanced Automation for Large Composite Structures
BARRETT MILENSKI / Research & Development Engineer, Composites Automation and Processing / ATK Aerospace Structures

Composite Cryotank Technologies and Demonstration (CCTD)
JAMES K. SUTTER / NASA Glenn Research Center
JOHN H. VICKERS / NASA Marshall Space Flight Center Manager

Aerospace Complex-Shape Metal Replacement using Xycomp® DLF Thermoplastic Composites
TIM GREENE / Global Product Manager / Greene, Tweed

Recycled Carbon Fiber – Processing and Conversion (uses and potential uses)
ALEX EDGE / Business Development Manager / ELG Carbon Fibre Ltd.

Carbon Fiber Sizing Requirements
ANDY BRINK / Global Technology and Business Development Manager, Fibers and Composites Business Unit / Michelman, Inc.

New Developments in Towpreg Technology
BILL REGAN / VP Engineering & Technology / Zoltek

Design and Fabrication of a Prototype Carbon Composite Radio Telescope for the Square Kilometer Array
GORDON LACY / Mechanical Engineer / NRC Canada

Increased Productivity by RFID-Based Material & Asset Tracking – From the Freezer to the Autoclave and Beyond
AVNER BEN-BASSAT / President & CEO / Plataine Ltd.

Enabling Growth of Carbon Fiber Production while Balancing Product Quality, Economics, and Safety through Computational Fluid Dynamics [CFD] Modeling Analysis
WILLIAM STRY, PETER WITTING, DAVID GELDARD, RENEE BAGWELL / Harper International

AND MANY MORE!
For an up-to-date agenda and abstracts, please visit: http://short.compositesworld.com/CF2014

CALENDAR

Nov. 11-12, 2014 Advanced Engineering UK 2014
Birmingham, U.K. | www.advancedengineeringuk.com/hub

Nov. 11-13, 2014 Feiplar Composites + Feipur 2014
Sao Paulo, Brazil | www.feiplar.com.br/ingles/index.html

Nov. 17-19, 2014 JEC Asia 2014
Singapore | www.jeccomposites.com/events/jec-asia-2014

Dec. 1-2, 2014 5th Wind Turbine Blade Manufacture Conference
Düsseldorf, Germany | http://10times.com/wind-turbine-blade

Dec. 2-4, 2014 CPV (Composite Pressure Vessel) Symposium
Salt Lake City, Utah | www.cpvsymposium.com

CW **Dec. 9-11, 2014** Carbon Fiber 2014
La Jolla, Calif. | www.compositesworld.com/conferences/compositesworld-2014-carbon-fiber-conference

See more events at www.compositesworld.com/events

Dec. 10-12, 2014 India Composites Show 2014
Mumbai, India | www.indiaCompositesShow.com

March 2-4, 2015 SpeedNews 29th Annual Commercial Aviation Industry Suppliers Conference
Beverly Hills, Calif. | http://speednews.com/commercial-aviation-industry-suppliers-conference/registration

March 10-12, 2015 JEC Europe 2015
Paris, France | www.jeccomposites.com

April 20-23, 2015 AeroDef Manufacturing Exposition and Conference
Dallas, Texas | www.aerodefevent.com

April 23-24, 2015 2nd International Symposium on Automated Composites Manufacturing
Montreal, Canada | http://concom.encs.concordia.ca/autocomposites/index.htm

May 4-7, 2015 AUVSI Unmanned Systems 2015
Atlanta, Ga. | www.auvsi.org/events

May 18-21, 2015 SAMPE Baltimore Conference and Exhibition
Baltimore, Md. | www.sampe.org (click "events")

APPLICATIONS

PMI foam core outperforms honeycomb in infused nose landing gear doors

Composite Technology Centre GmbH (CTC, Stade, Germany) specializes in developing cost-effective serial-production composite technologies. A subsidiary of Airbus (Toulouse, France), CTC undertook studies in 2013 to find more productive but less costly methods of fabricating carbon fiber-reinforced polymer (CFRP) sandwich constructions. **Evonik** (Darmstadt, Germany) submitted samples of its new ROHACELL HERO polymethacrylimide (PMI) closed-cell foam to CTC for evaluation as a core-material alternative to traditional honeycomb. The new PMI foam is the fruit of an unusual Evonik effort to develop a new polymethacrylimide (PMI) foam product that can mimic honeycomb core's tendency to show visible laminate damage. Although foam is touted as a means to prevent water-ingress into surface-damaged aircraft parts, PMI foam's greatest asset in other applications — its superior impact resistance compared to honeycomb core products — makes it difficult for aircraft maintenance and repair organizations (MROs) to visually identify damage on aircraft sandwich constructions during part inspections. Evonik's HERO product is specifically formulated to accommodate this need in PMI foam performance properties. (Read more about the HERO formulation in "MRO-friendly PMI foam core" online at short.compositesworld.com/MRO-PMI.)

CTC evaluated three CFRP sandwich construction design options: (1) autoclaved, honeycomb-cored, carbon/epoxy prepreg; (2) autoclaved PMI-cored, carbon/epoxy prepreg; and (3) an out-of-autoclave (OOA) alternative featuring PMI core between faceskins of carbon fiber infused with liquid epoxy resin. Options 2 and 3 required significantly less time and cost than option 1. Option 3 was the best, at 19 percent lower weight and 25 percent lower cost than option 1. Further, it cut 18 hours off production time (a 43 percent savings) because the process eliminated the lengthy core potting step and the two cure cycles typically necessary to integrate the prepreg skins and honeycomb. "These significant savings in time and cost were achieved for a *simple* part," says Remo Hinz, CTC's R&D project leader, "As part complexity increases, the savings in processing time and costs *exponentially increase* in favor of an infused foam core over an autoclaved honeycomb sandwich design."

Preshaped core

The 75-kg/m^3 density PMI foam arrived at CTC GmbH preshaped via CNC machining by Evonik's ROHACELL SHAPES division. The photo shows the shaped foam core during layup between dry carbon fiber fabrics, prior to infusion.

Finished door

This finished nose landing-gear door, designed to replace a forward landing gear door on a *Dornier 728* aircraft, was one of two (left and right side doors) successfully fabricated as technology demonstrators by INVENT GmbH (Braunschweig, Germany).

On the basis of the CTC evaluation, nose landing-gear doors for a Dornier 728 aircraft were successfully fabricated as a technology demonstrator by INVENT GmbH (Braunschweig, Germany). The ROHACELL 71 HERO (75 kg/m^3 density) arrived preshaped, via CNC machining, by Evonik's ROHACELL SHAPES division and was sandwiched between dry carbon fiber fabrics (see photo, above). The layup was infused with **Hexcel's** (Stamford, Conn.) Airbus-qualified RTM 6 epoxy infusion resin.

Evonik reports that the PMI core not only prevents problems seen in honeycomb-cored constructions, such as water ingress, but also eliminates skin debonding due to potting compound deterioration. In addition, the core's greater elongation (9 to 10 percent) and impact resistance makes it viable for exterior aircraft parts.

Impact tests were conducted at 35 Joule impact energy by the **Fraunhofer IWM Institute** (Halle, Germany), according to ASTM D7766/D7766M–11, on specimens cut from the PMI-cored infused laminate and the original honeycomb/prepreg laminate. Nondestructive testing confirmed that damage size and depth in each were comparable.

Professor Axel Herrmann, CTC's managing director, concludes, "ROHACELL HERO is, technically, the better and safer material to specify for sandwich construction, as water ingress issues are eliminated and debonding failure risks are significantly reduced." Evonik, therefore, is working on several structural applications with Airbus, and says that the first Airbus aircraft part specified with its PMI foam will enter service during 2015. ■

Combining curing processes for faster part production

Source: Regoplas USA

Control unit

This control unit, the Regloplas P160M, was developed by Regoplas USA (St. Joseph, Mich.) to heat and cool water, and then circulate that water through a mold plumbed for pressurized-water heating and cooling. In tests, autoclave cure of a part heated and cooled with the Regoplas system used 1/20th of the energy consumed during a conventional autoclave cycle on an identical composite part.

A recent study by researchers from the University of British Columbia, Department of Materials Engineering, and Mitsubishi Heavy Industries, Nagoya Aerospace Systems (Nagoya, Japan), shows that airflow inside an autoclave is rarely uniform, and that heat transfer coefficient measurements made with rod calorimeters vary widely, particularly when comparing regions above and below a test tool. Despite these results, autoclaves are unlikely to be replaced at many companies because of the capital investment they represent. However, **Regloplas USA** (St. Joseph, Mich.) has demonstrated a method for overcoming poor temperature uniformity, says Kip Petrykowski, the company's director of national sales, "*and* reducing autoclave cycle times, through the use of pressurized-water mold temperature controllers."

The approach uses the vessel in concert with molds plumbed for pressurized-water heating. "Heated, pressurized water is proven as the most consistent and most energy-efficient method for heating tools, compared to air, steam, cartridge or oil heating," Petrykowski claims. "And it's been successfully qualified in commercial aircraft airframe part production."

He recently conducted a study comparing conventional autoclave processing vs. water-heated tools inside the

Source: Regoplas USA

System setup

A technician fastens plumbing attachments that will deliver pressurized water to pipes positioned beneath this test panel. The vacuum hose attachment is seen on top of the bagged layup.

autoclave. Petrykowski used a nickel-shell plaque tool, from **Weber Manufacturing Technologies Inc.** (Midland, Ontario, Canada), integrally plumbed for water circulation, and a Regloplas P160M mold temperature controller to circulate hot and cool water. Thin sample parts were made with carbon/epoxy prepreg supplied by **Cytec Aerospace Materials** (Tempe, Ariz.), under a vacuum bag, and the tool setup was monitored via four thermocouples, a power meter and a data logger. Parts were processed inside a **BondTech Corp.** (Somerset, Ky.) vessel at fabricator deBotech Inc. (Mooresville, N.C.). Petrykowski measured the energy consumed for both methods (autoclave alone, and autoclave plus mold controller).

The results were striking: The autoclave alone consumed nearly 90 kW of energy over a 75-minute cure period, about 20 *times* the 4.3 kW of total energy consumed by the autoclave/heated-mold controller on the identical tool/part combination. "The greater energy use is due to heating a larger mass (the autoclave) and the reduced heat transfer value of the air/nitrogen used to heat the autoclave and mold as compared to the integrally plumbed tool with water heating," explains Petrykowski. In addition, temperatures can be ramped up more than three times faster and temperature uniformity is more than 50 percent more precise with the water-heated mold than with the autoclave alone.


Source: Regoplas USA

Adapting the autoclave for pressurized water

This photo, taken inside an autoclave, shows how vacuum ports in the pressure vessel were adapted to plumb the tool.

"The massive cooling capability of the pressurized water system is especially effective when applied to thick composite parts with the potential for exothermic reactions, and for rapid cycle production," he adds. Further, heated-mold parts processed inside the autoclave showed mechanical properties as good as the autoclaved parts made without the Regloplas unit, based on coupon tests of the carbon plaques.

Petrykowski contends that existing vacuum ports on the autoclave can be readily disabled to allow for routing of the water hoses inside to the molds. And, existing metal tools can be retrofitted with plumbing to transition to heated-mold control. Notably, even composite tooling can be integrally plumbed with heating and cooling channels — a current Regloplas customer has done it, and is using the tool in production. ■

NEW PRODUCTS SPE ACCE 2014 PRODUCT SHOWCASE

At the 2014 Society of Plastics Engineers' Automotive Composites Conference and Exhibition (Novi, Mich., Sept. 9 -11), the crowded exhibits area offered a wide array of new technologies designed to appeal to high-production-rate automotive processing. The following is a mere sampling of what was on hand (see our "SPE ACCE 2014 Report" on p. 26).

Acrylic thermoplastic resin for liquid molding

Arkema (King of Prussia, Pa.) highlighted its existing Elium product, reportedly the first liquid thermoplastic (acrylic) resin that provides properties similar to thermoset epoxy resins. The low-viscosity, styrene-free liquid formulation, activated with the company's Luperox peroxide, can be processed as a thermoset in resin transfer molding (RTM) processes, resin infusion and flex molding, and provides a thermoplastic part that is easily thermoformed (see photo), welded or adhesively bonded, and is readily recyclable. The company adds that Elium can reduce processing cost compared to traditional thermoplastic technologies, because no added heat is necessary and conventional thermoset processes can be used. **www.arkema.com/en/**

Low-density glass/polyester SMC

AOC LLC (Collierville, Tenn.) introduced its new low-density (1.2) sheet molding compound (SMC), which reportedly has properties equivalent to standard SMC but at 37 percent lower mass. Moreover, the material can be processed with a Class A surface. AOC's Jeff Klipstein, in a conference presentation, noted that achieving the same properties at lower density *and* Class A looks in a single SMC formulation is difficult because, ordinarily, adding more glass fiber reinforcement enhances mechanical properties but tends to degrade the molded surface quality. The company's new, low-density formulation of polyester and glass fiber was described as competitive with aluminum in terms of cost and weight savings. Work is ongoing to further reduce density while maintaining properties and surface quality. **www.aocresins.com**

Ultralow-density SMCs

Core Molding Technologies (Columbus, Ohio) showed two new ultralow-density sheet molding compound (SMC) formulations: The first, its trademarked Mirilite SMC, has a low nominal density (specific gravity of 1.2), and demonstrates automotive Class A surface performance, yet weighs 37 percent less than traditional Class A SMC material systems. Mirilite is intended for exterior applications in automobiles and heavy trucks, including hoods, door panels and trunk deck lids. The second product, Econolite, is a less expensive but nevertheless ultralow-density SMC (specific gravity of 1.18) for utility applications that do not require premium surface appearance. Evolved from the company's highly successful FeatherliteXL and Airilite SMC systems, the economical formulation is intended for reinforcement structures and other components that do not require a Class A painted surface finish. **www.coremt.com**

Polyurethane prepregs

Evonik Corp. (Parsippany, N.J.) discussed its latest product, Vestanat PP, a polyurethane (PU) matrix system based on aliphatic diisocyanates for PU prepregs. The latent resin system is mixed and combined with the fabric reinforcement to form the prepreg, but doesn't react until processing temperature is reached. At that point, the isocyanates become reactive. Notably, the product is said to be stable at room temperature and requires no refrigeration. Further, its cure profile is reportedly tailorable to any process. Sub-two-minute cycle times are possible in compression molding processes, says the company. **http://crosslinkers.evonik.com/product/crosslinkers/en/products-services/vestanat/pages/VESTANAT-PP.aspx**

Ultralightweight Class A SMC

Continental Structural Plastics (CSP, Auburn Hills, Mich.) officially announced its Tough Class A (TCA) Ultra Lite, a 1.2 specific gravity SMC formulation. This new SMC material is reportedly already approved by major automotive OEMs and will be used on a production vehicle, beginning in January 2015. CSP says Ultra Lite offers a 21 percent weight savings over the company's mid-density TCA Lite product, and a 35 percent savings over standard SMCs, thanks to treated glass bubbles (microspheres) that replace calcium carbonate and reportedly enhance resin/paint adhesion. The new lightweight formulation is said to deliver the same mechanical properties as standard SMC, with the same Class A surface qualities. **www.cspplastics.com**

Basalt fibers, dry and compounded

Mafic (Kells, County Meath, Ireland) promoted its basalt fiber for automotive and other uses. Mafic mines and melts the basalt rock in Ireland, then ships fiber to Ontario, Canada, for distribution as well as compounding. Fibers are available in diameters from 11 to 16 microns, and product forms include 300-tex direct roving and 600- to 4,800-tex assembled roving, with sizing systems compatible with polyester, vinyl ester and polyurethane. Chopped fiber, mats, weaves and geogrids also are available. **www.maficbasalt.com**

New polyamides for auto applications

Invista (Wichita, Kan.), reportedly the world's largest nylon 6/6 producer (as a subsidiary of Koch Industries that acquired DuPont's textile nylon business a decade ago), showcased its Torzen engineering polyamides for automotive applications. Torzen Marathon PA66 resin has been improved to withstand higher temperatures for longer periods, yet reportedly still provides ease of processability, attributable to its low melt viscosity. It retains high performance properties up to 230°C/445°F operating temperature, and exhibits a melt viscosity 40 to 50 percent lower than conventional polyamides, says the company. **http://eps.invista.com**

Mold release alternative

Another new exhibitor, startup **Youtec** (Nagareyama-shi, Japan, and Los Altos, Calif.), touted an alternative to conventional semipermanent mold release technology. It's a new mold coating, described as "diamond-like," and applied via vapor deposition. A carbon/hydrogen-containing gas is pumped into a vacuum chamber, explains general manager Mitch Yanase, and a high voltage is applied to create a plasma state. The positively charged plasma is attracted to the negatively charged metal mold, and a thin but durable carbonaceous film is deposited on the mold surface. The surface coating reportedly eliminates the need for mold release. Youtec welcomes development partners, and plans, eventually, to build a North American facility. **www.youtec.co.jp**

Prototyping, preforming and production services

Laystitch Technologies (Warren, Mich.) revealed that it is now partnered with Coliant Corp. (Warren, Mich.), an innovator in the area of smart, heated clothing including motorcycle jackets. The partnership is intended to give Laystitch the freedom to devote time and resources to R&D for both wearables and composites. Laystitch says that the partnership will enable it to satisfy customer requests for services, such as prototyping, preforming and actual part production, which weren't always possible, previously. The company plans to build a new facility in Sterling Heights, Mich., to house the new efforts. Those endeavors will be aided by new machinery, including a 200-lb/hr, 10-head stitching machine. The new center should be open in about eight months. The company also is working with Oak Ridge National Laboratory's (Oak Ridge, Tenn.) lignin-based, very large tow (610K) carbon fiber, which Laystitch says its equipment can transform into stitched preforms. **www.laystitch.com; www.coliant.com**

UNITED STATES POSTAL SERVICE®

Statement of Ownership, Management, and Circulation (Requester Publications Only)

1. Publication Title: HIGH-PERFORMANCE COMPOSITES	2. Publication Number: 1 0 8 1 _ 9 2 2 3	3. Filing Date: October 1, 2014
4. Issue Frequency: BI-MONTHLY	5. Number of Issues Published Annually: 6	6. Annual Subscription Price (if any): $45.00

7. Complete Mailing Address of Known Office of Publication *(Not printer) (Street, city, county, state, and ZIP+4®)*
6915 Valley Avenue
Cincinnati, OH 45244-3029 HAMILTON COUNTY

Contact Person: Ross Jacobs
Telephone *(include area code)*: 513-527-8800

8. Complete Mailing Address of Headquarters or General Business Office of Publisher *(Not printer)*
6915 Valley Avenue
Cincinnati, OH 45244-3029 HAMILTON COUNTY

9. Full Names and Complete Mailing Addresses of Publisher, Editor, and Managing Editor *(Do not leave blank)*

Publisher *(Name and complete mailing address)*
Richard G. Kline, Jr. 6915 Valley Avenue Cincinnati, OH 45244-3029

Editor *(Name and complete mailing address)*
Jeff Sloan P. O. Box 992 Morrison, CO 80465

Managing Editor *(Name and complete mailing address)*
Mike Musselman P. O. Box 992 Morrison, CO 80465

10. Owner *(Do not leave blank. If the publication is owned by a corporation, give the name and address of the corporation immediately followed by the names and addresses of all stockholders owning or holding 1 percent or more of the total amount of stock. If not owned by a corporation, give the names and addresses of the individual owners. If owned by a partnership or other unincorporated firm, give its name and address as well as those of each individual owner. If the publication is published by a nonprofit organization, give its name and address.)*

Full Name	Complete Mailing Address
GARDNER BUSINESS MEDIA, INC.	6915 Valley Avenue, Cincinnati, OH 45244-3029
Richard G. Kline	796 Huntersknoll Lane, Cincinnati, OH 45230
Rosemary L. Kline	7740 Oyster Bay Lane, Cincinnati, OH 45244
Steven R. Kline	259 Hill Road, Southern Pines, NC 28387

11. Known Bondholders, Mortgagees, and Other Security Holders Owning or Holding 1 Percent or More of Total Amount of Bonds, Mortgages, or Other Securities. If none, check box. → ☒ None

Full Name	Complete Mailing Address

12. Tax Status *(For completion by nonprofit organizations authorized to mail at nonprofit rates) (Check one)*
The purpose, function, and nonprofit status of this organization and the exempt status for federal income tax purposes:
☐ Has Not Changed During Preceding 12 Months
☐ Has Changed During Preceding 12 Months *(Publisher must submit explanation of change with this statement.)*

PS Form 3526-R, July 2014 *[Page 1 of 4 (See instructions page 4)]* PSN: 7530-09-000-8855 PRIVACY NOTICE: See our privacy policy on www.usps.com.

13. Publication Title: HIGH-PERFORMANCE COMPOSITES
14. Issue Date for Circulation Data Below: September 2014

15. Extent and Nature of Circulation			Average No. Copies Each Issue During Preceding 12 Months	No. Copies of Single Issue Published Nearest to Filing Date
a. Total Number of Copies *(Net press run)*			23,323	24,457
b. Legitimate Paid and/or Requested Distribution *(By mail and outside the mail)*	(1)	Outside County Paid/Requested Mail Subscriptions stated on PS Form 3541. *(Include direct written request from recipient, telemarketing, and Internet requests from recipient, paid subscriptions including nominal rate subscriptions, employer requests, advertiser's proof copies, and exchange copies.)*	17,363	18,140
	(2)	In-County Paid/Requested Mail Subscriptions stated on PS Form 3541. *(Include direct written request from recipient, telemarketing, and Internet requests from recipient, paid subscriptions including nominal rate subscriptions, employer requests, advertiser's proof copies, and exchange copies.)*	N/A	N/A
	(3)	Sales Through Dealers and Carriers, Street Vendors, Counter Sales, and Other Paid or Requested Distribution Outside USPS®	N/A	N/A
	(4)	Requested Copies Distributed by Other Mail Classes Through the USPS (e.g., First-Class Mail®)	N/A	N/A
c. Total Paid and/or Requested Circulation *(Sum of 15b (1), (2), (3), and (4))* ▶			17,363	18,140
d. Non-requested Distribution *(By mail and outside the mail)*	(1)	Outside County Nonrequested Copies Stated on PS Form 3541 *(include sample copies, requests over 3 years old, requests induced by a premium, bulk sales and requests including association requests, names obtained from business directories, lists, and other sources)*	3,352	2,619
	(2)	In-County Nonrequested Copies Stated on PS Form 3541 *(include sample copies, requests over 3 years old, requests induced by a premium, bulk sales and requests including association requests, names obtained from business directories, lists, and other sources)*	N/A	N/A
	(3)	Nonrequested Copies Distributed Through the USPS by Other Classes of Mail *(e.g., First-Class Mail, nonrequestor copies mailed in excess of 10% limit mailed at Standard Mail® or Package Services rates)*	N/A	N/A
	(4)	Nonrequested Copies Distributed Outside the Mail *(include pickup stands, trade shows, showrooms, and other sources)*	1,550	2,498
e. Total Nonrequested Distribution *[Sum of 15d (1), (2), (3) and (4)]*			4,902	5,117
f. Total Distribution *(Sum of 15c and e)* ▶			22,266	23,257
g. Copies not Distributed *(See Instructions to Publishers #4, (page #3))* ▶			1,057	1,200
h. Total *(Sum of 15f and g)*			23,323	24,457
i. Percent Paid and/or Requested Circulation *(15c divided by 15f times 100)* ▶			78.0%	78.0%

* If you are claiming electronic copies, go to line 16 on page 3. If you are not claiming electronic copies, skip to line 17 on page 3.

16. Electronic Copy Circulation	Average No. Copies Each Issue During Previous 12 Months	No. Copies of Single Issue Published Nearest to Filing Date
a. Requested and Paid Electronic Copies ▶		
b. Total Requested and Paid Print Copies (Line 15c) + Requested/Paid Electronic Copies (Line 16a) ▶		
c. Total Requested Copy Distribution (Line 15f) + Requested/Paid Electronic Copies (Line 16a) ▶		
d. Percent Paid and/or Requested Circulation (Both Print & Electronic Copies) (16b divided by 16c × 100) ▶		

☐ I certify that 50% of all my distributed copies (electronic and print) are legitimate requests or paid copies.

17. Publication of Statement of Ownership for a Requester Publication is required and will be printed in the November 2014 issue of this publication.

18. Signature and Title of Editor, Publisher, Business Manager, or Owner: Richard G. Kline President
Date: 9/30/14

I certify that all information furnished on this form is true and complete. I understand that anyone who furnishes false or misleading information on this form or who omits material or information requested on the form may be subject to criminal sanctions (including fines and imprisonment) and/or civil sanctions (including civil penalties).

PS Form 3526-R, July 2014 *(Page 3 of 4)* PRIVACY NOTICE: See our privacy policy on www.usps.com

MARKETPLACE

MANUFACTURING SUPPLIES

RECRUITMENT/HELP WANTED

ADVERTISERS' INDEX

WWW.PREPREGS.COM
dyoung@prepregs.com

apcm

P.O. Box
1366 Norwich Rd.
Plainfield, CT. 06374
Office: 860.564.7817
Cell: 860.608.4696
Fax: 860.564.1535

Adhesive Prepregs for Composite Manufacturers

REAL CARBON

707 PORTWAY AVE, UNIT 104
HOOD RIVER, OR 97031
541-359-2980
WWW.REALCARBON.COM

CUSTOM CARBON FABRICATION
PROTOTYPE DESIGN AND DEVELOPMENT

CINCINNATI TESTING LABORATORIES

A Subsidiary of Metcut Research Inc.

Machining & Testing of Advanced Composite Materials

Comprehensive Testing Expertise

- Mechanical • Physical • Thermal
- Enviromental • Fatigue

MMC,CMC, & PMC Experience

Email: info@cintestlabs.com
www.cintestlabs.com
1775 Carillon Blvd., Cincinnati, Ohio 45240
Phone: 800/811-9220 • Fax: 513/851-3336

entec
Composite Machines, Inc.
Toray Group

- Proven Filament Winding Equipment
- Control Systems & Software
- Automated Custom Machinery
- Composite Research & Development

www.entec.com • 801-486-8721

Adhesive for High Performance Structural Bonding

Epoxy EP31

- Extraordinarily high shear and peel strength
- Room temperature curing
- Superior electrical insulation properties

MASTERBOND®
ADHESIVES | SEALANTS | COATINGS

+1.201.343.8983 • www.masterbond.com

NCTM NCC

The Companies of North Coast
North Coast Tool & Mold Corp.
North Coast Composites, Inc.

www.northcoastcomposites.com
216.398.8550

To advertise in the
***High-Performance Composites* Marketplace**
contact Becky Helton:
bhelton@gardnerweb.com or 513.527.8800 x224

CARBON FIBER: KEY TO

Carbon composites are effective solutions for repairs

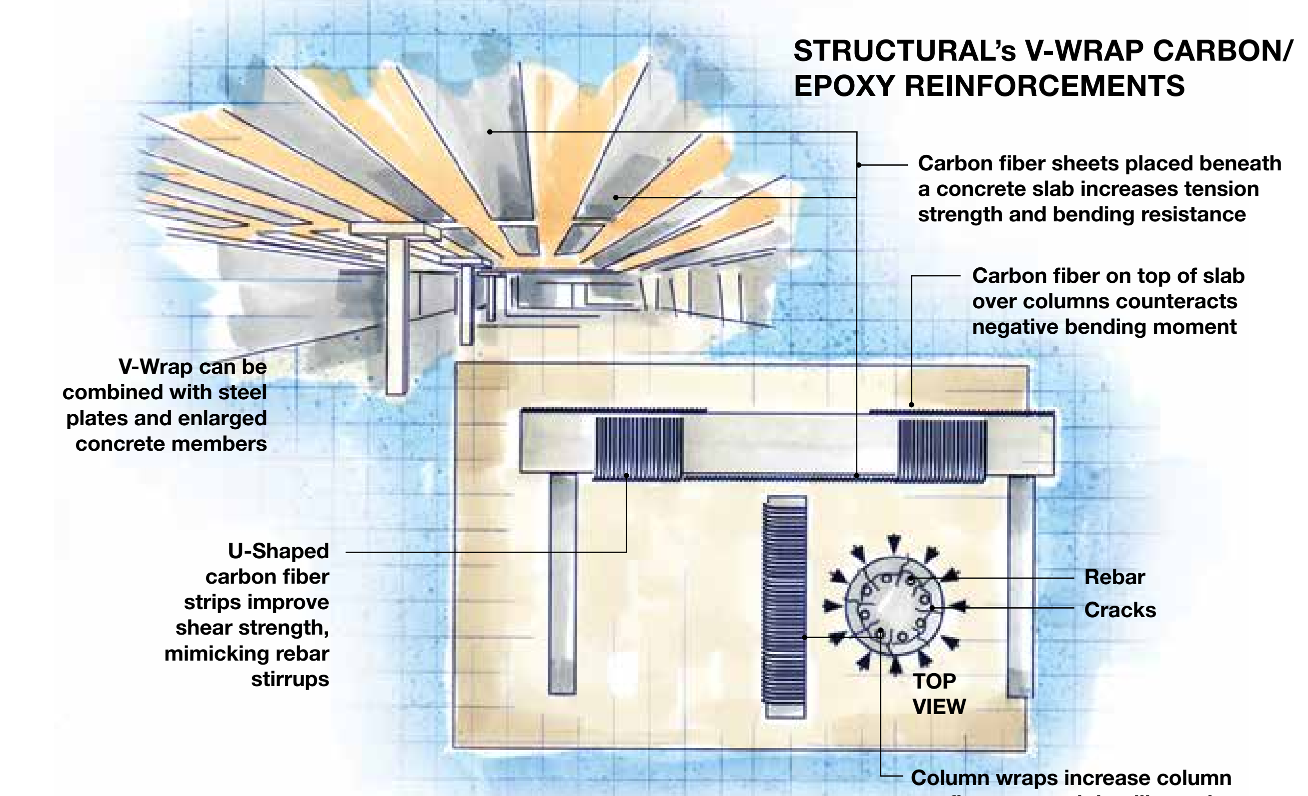
Steel-reinforced concrete is among the most widely used building materials in the world, but it faces potential threats, including damage from seismic events, and cracking due to temperature-related expansion and contraction. The latter is common, and permits moisture invasion, and the resulting corrosion and expansion of steel rebar deteriorates the concrete, resulting eventually in loss of structural capacity. In many cases, distressed structures can be repaired. They also can be strengthened to comply with changes in load demands or code revisions. Further, design or construction deficiencies can be corrected to improve load-bearing capabilities.

Carbon fiber composites play a major role in such repairs and upgrades, and do so at significantly less cost than new construction. According to Jay Thomas, VP of strengthening solutions at Structural (Hanover, Md., a Structural Group company), more than 20 million ft^2 (1.85 million m^2) of carbon fiber already have been installed in reinforced concrete buildings in the U.S. alone. Structural, in the business for nearly 40 years, comes well-prepared. "We take a lot of factors into account, including constructability, aesthetics and cost, and essentially, reverse engineer the building's structure to improve performance," he asserts.

Percentage of ultimate capacity

"Both structural repair and structural strengthening require knowledge of the global behavior of the entire building," Thomas explains, noting that the task is sometimes complicated by the fact that the engineer has no firsthand knowledge of how the structure was originally designed or built. "A design must be tailored for each specific situation and its load conditions." To that end, Structural's engineers first conduct a comprehensive inspection. The structure's elements are catalogued as to type (e.g., round vs. rect-

STRUCTURAL's V-WRAP CARBON/EPOXY REINFORCEMENTS



DESIGN RESULTS

- Uni carbon fiber, placed in accordance with a structural design, enhances strength of reinforced concrete.
- Careful surface preparation ensures that wet-out carbon fabric adheres to the concrete to provide "composite" action.
- Carbon composites used in concert with other construction methods is a cost-effective strengthening solution.

COST-CONSCIOUS REHAB

and upgrades of reinforced concrete.

BY SARA BLACK
ILLUSTRATION / KARL REQUE

Source: Structural

Reinforcements for rehabilitation projects

When Courthouse Square (Salem, Ore.) was in need of repair and strengthening, to address design and construction errors, V-Wrap carbon was part of the solution. The V-Wrap on this column in the Salem parking garage (inset) was combined with a bigger column footer and a cast-in-place capital (square casting around column top) that increases punching shear capacity.

angular columns, slab construction, etc.) and condition, and compared to the original construction drawings, if available. A key step is locating and mapping the reinforcing steel inside the concrete, which is accomplished with ground-penetrating radar (GPR) equipment. Other nondestructive testing methods (e.g., pin testing) are used to measure the concrete's resistance to penetration. Typically, cores extracted from the concrete are subject to microscopic examination and compressive strength tests in the laboratory. The goal is to identify, quantify and evaluate compression strength problem areas.

The investigative team uses the site inspection data to build a virtual layout of the building, using modeling software developed for repair/strengthening applications. SAP2000 from Computers & Structures Inc. (Walnut Creek, Calif.) is one of several programs used. "What the modeling ultimately helps determine is, can the building withstand the load requirements desired by the customer? Are required upgrades constructable and cost-effective, when compared to replacement?" says Thomas. Answers to these questions help the team develop and cost a specific repair or rehab strategy.

"Carbon fiber is one of several solutions we can implement," he points out. If the modeling shows that the required actual load demand exceeds the existing capacity by more than 40 percent, the strengthening options must be able to carry significant primary loads. Options include bonded steel plates and enlargement of existing concrete structural members. However, if the increase in load conditions is *less than* 40 percent, the most cost-effective solution, he contends, is Structural's trademarked carbon fiber/epoxy V-Wrap material. Made with a proprietary unidirectional fabric of intermediate-modulus carbon fibers supplied by Toray Industries Inc. (Tokyo, Japan, and Decatur, Ala.), the material can be used alone or in combination with the options listed above. Labor costs typically drive strengthening projects, so the cost of the carbon isn't a factor, Thomas claims, and the relative ease of application can actually help reduce project costs.

"Composite" action

V-Wrap works because it becomes an integral part of a concrete member via bonding, resulting in what Thomas calls "composite" action. The term is a reference to the fact that the carbon/epoxy laminate and the concrete column or slab to which it's applied act *together* to bear applied loads. To achieve this effect, however, surface preparation is crucial, Thomas stresses. Grit-blasting and grinding with specialized abrasive disks (with the dust and debris vacuumed away) ensure a clean surface on undamaged concrete. "The concrete is like a big, hard sponge," he explains. "You've got to open the pores and get the resin to fully penetrate to achieve an effective bond."

Dry V-Wrap fabric sheets are wet-out at the job site, using Structural's in-house-designed field saturators. (A saturator dips fabric in a resin bath and then passes it through precisely gapped rollers and/or scrapers, to yield a wet layup with a precise — and project-specific — resin content, without air bubbles that could result in voids.)

Where and how V-Wrap is applied is guided by Structural's extensive experience, the modeling results and, in ➲



Source: Structural

Cost-conscious strengthening

Structural reports that workers (inset) can apply V-Wrap composite sheeting to a concrete slab at a fraction of the cost of new construction.

some cases, limitations imposed by fire codes. As shown in the drawing (p. 62), V-Wrap material placed beneath a horizontal slab increases its tension strength and bending resistance; strips are placed on the slab's bottom surface with the fiber direction parallel to the slab's steel rebar: "The V-Wrap is mimicking the action of the existing reinforcing steel, and augmenting its strength," he explains.

Fiber sheet placed on a slab's upper surface — over supporting columns, for example — counteract the slab's negative bending moment. For additional beam shear capacity, typically where a beam is connected to a column, V-Wrap is applied to the beam in a "U" shape that mimics the beam's steel shear stirrups. The stirrups and fiber prevent or minimize formation of 45° shear cracks that can occur if the beam/column intersection is overloaded. Finally, carbon fiber is exceptional at increasing confinement and ductility in concrete columns. When wrapped horizontally around the column, the fiber wrap acts as additional reinforcing ties around the column circumference.

Thomas cautions that the effects of strengthening local structural elements must be analyzed carefully to determine their influence on the structure's global behavior. "Increasing the bending capacity of a structural element may overstress it in shear or, possibly, affect the surrounding elements, and lead to even bigger problems or even localized failure," Thomas notes, pointing out that carbon fiber's effectiveness depends on the original stiffness of the structural element to which it is applied. "Flexural strengthening is most effective on concrete members that were originally lightly or moderately reinforced," he explains. Adding carbon fiber to an already very stiff element doesn't contribute much, because the element must deflect to engage the bonded fiber. Structural follows guidance from the American Concrete Institute's ACI 440.2R-08, *Guide for the Design and Construction of Externally Bonded FRP Strengthening Systems for Strengthening Concrete Structures* (2008), which, in essence, discourages the use of excessive FRP. "Full-scale testing has shown that more is not better," he notes. "Too many plies create stresses that exceed the concrete's tensile capacity and can actually cause the FRP to fail by peeling it away from the concrete under high loads.

To ensure that the upgraded structure will perform in service as predicted, load tests, both cyclic and monotonic (steadily increasing load), can be performed before and after the strengthening, using hydraulic actuators, to validate that the addition of the carbon fiber has achieved the required increase in capacity. And to verify that V-Wrap is bonded securely, Structural conducts pull-off adhesion tests: "The V-Wrap, per ACI 440, has to pass a 200-psi test," adds Thomas.

Samples of success

Thomas cites a recent job in Miami, Fla., which involved converting a former shopping mall to a control center for a telecommunications company. A ~25 percent increase in load-carrying capacity was necessary to handle the 150-lb/ft^2 (730-kg/m^2) loads created by the company's equipment. The structural floor, a one-way slab, is supported by precast, prestressed joists that rest on continuous cast-in-place concrete beams with precast soffits (*soffit*, here, is the underside of a beam, in tension). "We selected an approach in which multiple plies of carbon strips were bonded to the sides and bottoms of each joist, to increase bending moment capacity," explains Thomas. U-wrap strips anchored the longitudinal strips at each end. Beams were strengthened by placing carbon strips on their undersides to increase bending capacity at mid-span, and four U-wraps were applied for shear. V-Wrap sheets also were placed on top of the slab, on each side of, and centered on, column locations to strengthen the beams.

In Salem, Ore., the five-story Courthouse Square complex, built in 2000, housed city government offices, retail outlets, a public transit hub and underground parking. But buckling floor tiles, water seepage, windows that no longer opened and cracking walls forced building closure. Thomas says Structural's initial inspection identified errors in the structural design *and* construction mistakes, in columns, shear walls, slabs, footings and masonry cladding.

"The building's serious flaws demanded a complex combination of repairs, including concrete enlargement, bonded overlays (i.e., adding additional concrete to slabs) and V-Wrap," Thomas recalls. The parking garage and office space columns were fitted with formwork to create capitals using cast-in-place reinforced concrete, to increase their punching shear capacity (i.e., so that the flat slab would be better supported). V-Wrap came into play as column wraps (see photo, p. 63).

Structural works on *hundreds* of projects each year, but Thomas says it's still a challenge. "Unknowns such as structural conditions and load paths, or the location — or lack of — existing reinforcement," he says, make each project unique. And as long as there's concrete, there'll be work to do. ■

LEARN MORE
@
www.compositesworld.com

Read an expanded version of this article at short.compositesworld.com/VWrapRehab.

Read about another composite strengthening option in "GFRP rebar replaces steel in parking garage," *HPC* June 2013 (p. 46) or visit short.compositesworld.com/GlassRebar.