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Vulcan Launch Vehicle: OUT-OF-AUTOCLAVE FAIRING

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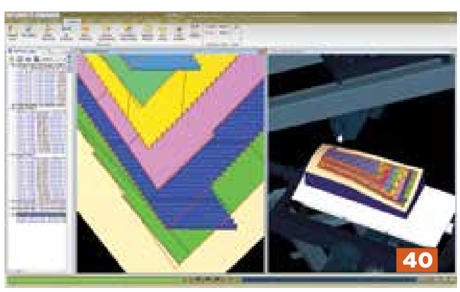
COLUMNS

DEPARTMENTS



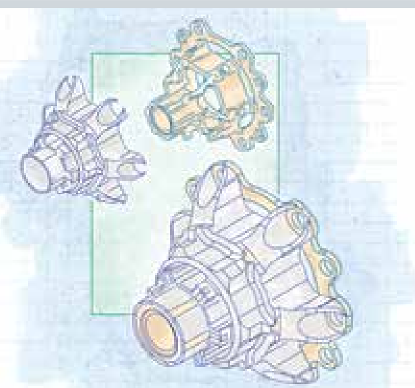
FEATURES

ON THE COVER

United Launch Alliance (ULA, Centennial, CO, US), has employed Ruag Space (Zurich, Switzerland) to design and build its *Vulcan* launch vehicles. This elaborate semi-cylindrical jig, which incorporates hundreds of small vacuum pads, helps transport laminates during an advanced manufacturing process that enables previously unprecedented *one-piece* manufacture of lengthy payload fairing sections. See p. 32.

Source /Ruag Soace

FOCUS ON DESIGN



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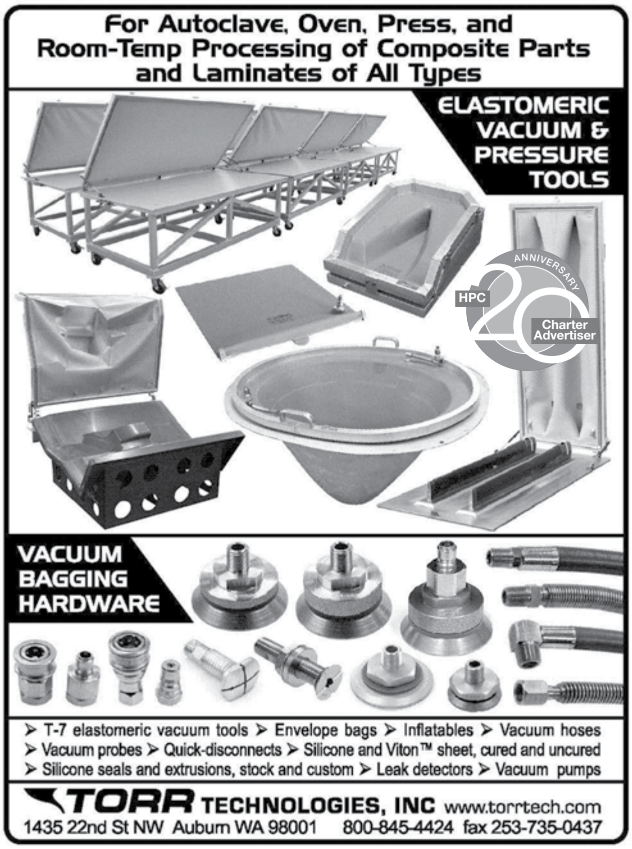

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PUBLISHER	Ryan Delahanty rdelahanty@gardnerweb.com
EDITOR-IN-CHIEF	Jeff Sloan jeff@compositesworld.com
MANAGING EDITOR	Mike Musselman mike@compositesworld.com
SENIOR EDITOR	Sara Black sara@compositesworld.com
SENIOR EDITOR	Ginger Gardiner ggardiner@compositesworld.com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

CW CONTRIBUTING WRITERS

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

CW SALES GROUP

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

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WEBINARS

Digitalization of Composite Aeroengine Development

EVENT DESCRIPTION:
The drive to boost aircraft operating efficiency continues to fuel the adoption of composites in aeroengines. This market demand, combined with recent and continuing advances in composite material technologies, is shifting the competitive landscape for aeroengine OEMs and their supply chains. In this webinar, John O'Connor will discuss best practices for composite development in the aeroengine industry and provide an overview of technology that is making it faster to develop composite definitions that support a full digital thread across the entire development process.

Join us as we discuss the use of Fibersim software to support analysis, design, and manufacturing of composite aeroengine components.

TOPICS TO BE DISCUSSED:
- Understanding best practices of composite design and engineering in the aeroengine industry
- Industry trends related to engineering and design of composites for aeroengines
- How technology can support a digital thread for composites aeroengine components
- Introduction to Siemens PLM Software's composite development solutions for analysis, design, and manufacturing

DATE AND TIME:
Jan. 25, 2017
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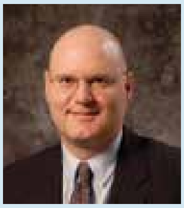

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Braided Fabrics Offer Significant Cost Savings Through Simple Processing, Reduction In Waste, & Superior Performance

EVENT DESCRIPTION:
A&P Technology's braided fabrics are replacing woven fabrics in applications driven by light-weighting and cost-efficiency. QISO®, a quasi-isotropic fabric in a single layer, enables re-duced lay-up time, less waste and superior impact resistance. Bimax®, a ±45° fabric stabilized with hot melt axials, provides easy lay-up without concern over misorientation, and TX-45™, a true ±45° is much lower cost than the incumbent spirally slit woven material, and more cost-efficient than ±45 materials produced by cutting diagonally 0/90 woven fabrics.

PARTICIPANTS WILL LEARN:
- QISO, a single-layer, quasi-isotropic fabric, offers cost and process savings, high strength, damage tolerance, impact resistance, dimensional stability, low CTE and simplifies the build of complex curvatures.
- Testing comparing QISO and plain weave quasi-isotropic laminates of the same thickness.
- Hybrid triaxial fabrics that can be created in a single layer.
- Braided ±45° braided fabrics that can be produced in a variety of widths and areal weights.

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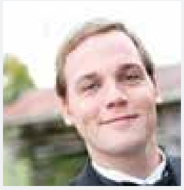

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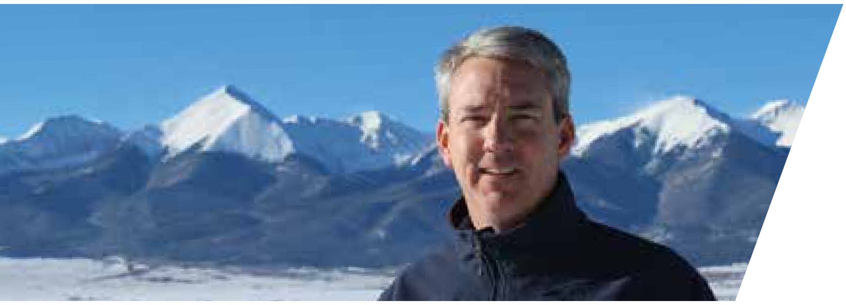


How to develop the next-generation workforce?

My wife and I have three boys. The youngest is 17, a junior in high school and starting to think more seriously about his life after high school. Like a lot of kids his age, he has a variety of interests and skills, but no clear sense yet of how he might apply these in college or career. And, like a lot of kids his age, he doesn't know what he doesn't know about what it means to be an engineer, sales person, sous chef, welder, electrician, attorney — or any other job. Further, the odds are pretty good that the job does not yet exist that my youngest son is likely to turn into a career.

So, how do my wife and I help guide him as he begins to assess his post-high school options? Like a lot of parents, we want our kids to find meaningful work in which they can apply their skills and interests and feel a sustainable sense of satisfaction. We want them to have the intellectual and emotional tools necessary to adapt to a fast-changing work world. We want to empower them with the desire and energy to pursue professional opportunities as they present themselves. We want them to earn a living wage.

Because he's my son, and because — like a lot of you — my work spills over into my family life, my youngest is keenly aware of composite materials and the composites industry. He knows how composites are being applied in aerospace, automotive, wind energy and many other end-markets. He understands that there is tension between legacy materials and composites as the latter displaces the former. He knows that as a relatively small but expanding manufacturing community, the world of composites fabrication is feeling some of the growing pains that come with the application of advanced materials.

My advice, which my son at least *seems* to be listening to: Pursue a degree in business, but sprinkle in coursework on supply-chain management, manufacturing management and technical materials. Then, pursue work on the business-development side of the composites industry, helping customers understand what composites are and how they can be applied. There is, I argue, great need for such skills — among many — in this industry.

We'll see, over the next few years, just what path my son chooses. But regardless of his choices, the truth remains that many of us are closely aligned with two populations that could be of great help to each other: Young people in need of career options and guidance, and a composites industry in need of new talent. Connecting the two will be of paramount importance to the future of composites and to the future for many of our kids.

This, of course, is not new news. Baby Boomers are in the midst of a well-publicized and very long retirement process, taking with them decades of knowledge and experience that will be difficult to replace. Many of you likely are seeing this happen in your own workplace, or see it coming. The question is, how do we respond?

The short answer is that the response is already underway. From Seattle to Salt Lake City to Toulouse, teachers, professors, community colleges and manufacturers are working very hard — often together — to help train students, like my son, for work in the composites world. They're reaching out to college-age kids, high school-age kids and adults, helping them understand what the opportunities are, and then helping them prepare to take advantage of those opportunities.

CW will, in 2017, take a closer look at how the composites industry is tackling workforce development, and we will help you understand how these efforts can help you and your business put new talent into your facility. And, perhaps most importantly, we hope to stimulate thought and discussion about what each of us can do to help guide and mentor the students around us, to help them see, appreciate and pursue the opportunities composites offer.

As we work on this story, I encourage you to contact me directly if you or your company is involved in workforce development. What is your goal? What is your strategy? How have you deployed resources? Who are you working with? How successful have you been? What lessons have you learned?

You can reach me at jeff@compositesworld.com. I hope to hear from you.

JEFF SLOAN — Editor-In-Chief

Teijin acquires CSP: A safer growth choice?

» The news on Sept. 13 that Teijin (Tokyo, Japan) had agreed to acquire Continental Structural Plastics (CSP, Auburn Hills, MI, US) for US$825 million and become a Tier 1 supplier of high-performance automotive composites came not as a bombshell, but more of a weather alert with tsunami-like reverberations throughout the composites industry.

Mr. Jun Suzuki, Teijin's president & CEO since January 2014, was now saying some impressive things about pursuing "business models that help provide value-added solutions by combining and integrating our own materials." But his message to shareholders in August 2016 cautioned that "growth in the People's Republic of China continues to decelerate, …the Japanese economy was sluggish amid slowing growth in personal consumption." Also, "UK's decision to exit the EU made the global economy … rapidly shrouded in increasing uncertainty." He stated, "Growth is expected to continue primarily in the US." So it sounds like a *safer* choice for Teijin for investing its energies.

Teijin's presence in Auburn Hills is clearly another step into vertical integration of the supply chain.

Globally, Teijin had been a longstanding commodity supplier of polycarbonate to the information technology sector for use in compact discs (CDs) and DVDs, but decided to reduce its polycarbonate programs, withdrawing from Singapore and stressing its polyphenylene sulfide (PPS) business, forming a joint venture with SK Chemicals Ltd. (Gyeonggi-do, South Korea).

Many of its prior advanced composites-related announcements had us wondering, "What will Teijin do next?" And the answer was usually, *nothing*. My memory is fading fast, but I can recall some Teijin announcements that left us hanging, with no follow-on programs or announcements.

- In December 2011, Teijin and General Motors (Detroit, MI) agreed to create a joint venture and they opened the Teijin Advanced Composites Application Center (TCAC) in Auburn Hills, MI.
- In October 2013, Teijin's Sereebo program was announced, involving mass-production of carbon fiber-reinforced thermoplastic parts in less than 1-minute molding times, but had too little substance for observers to understand its technical worthiness.
- In March 2016, Teijin's Toho Tenax Europe was to join the Technology Development Project, aimed at furthering Industry 4.0.
- And on May 14, 2016, Teijin was set to build a 3,000-ton-per-year US carbon fiber plant.

I love the *Japanese business culture* and the intensity of the efforts it inspires. When Toho Rayon acquired our former BASF carbon fiber business in 1992, I was an ambitious 46-year-old manager and asked my new Japanese president if I should learn to speak Japanese. He replied, "Tom, you're too old, and you'll mispronounce too many words so they will laugh at you, not with you."

Instead, he taught me how to conduct business with the Japanese. He showed me the proper way to present my business card, with my name facing the person and holding it between my thumbs and forefingers. At dinners, the highest-ranking Japanese executive must always be seated in the middle of the table, facing the door, so that new attendees may come to him and present their business cards. The second- and third-ranking men sit on either side of the highest executive, and those in the visiting delegation sit exactly opposite their counterparts. During dinner, you never allow your business counterpart's glass to become empty; it is your duty to keep it refreshed. He will politely cover it when no further refreshments are needed.

These simple rules of business etiquette must be learned and while they don't guarantee a successful relationship, violating or overlooking them can create a lack of hospitality and trust. In the same manner, Japanese materials engineers must learn how to work with their new US automotive manufacturing colleagues.

Teijin's ability to learn to work with CSP, hopefully, will proceed in an orderly fashion. Each has great knowledge, although CSP has much greater *applications* experience, especially in molding Class A surface finish products. Perhaps Teijin can bring in their thermoplastic polymer connections to improve cost or create a better material understanding.

When placed into the global context of what other major materials suppliers have done, Teijin's presence in Auburn Hills is clearly another step into vertical integration of the supply chain. It can be compared to Toray's earlier US expansion in Greer, SC to be closer to Boeing and Hexcel's expansion into France to support Airbus. It's a matter of choices, and Teijin has, finally, made a strong one.

Investing in the US automotive market, apparently, is the safer, less risky business choice for Teijin from a global perspective compared to a similar investment somewhere in China or even in Europe, but I hope the company will continue to share information about its US activities with us as a world-class operation. CW

ABOUT THE AUTHOR

Tom Lemire, president of T.F. Lemire Consulting Inc. (Irvine, CA, US), brings to his current consulting role 47 years of active duty in sales, market development and management at three major, technology-driven global operations that supply materials to the composites industry: Toho Tenax (Rockwood, TN, US), BASF Structural Materials (Charlotte, NC, US) and Owens-Corning (Toledo, OH, US). Lemire served as co-chair of the *CompositesWorld* Carbon Fiber Conferences held in 2009 and 2010 and was a panel moderator or speaker at SAMPE conferences in 2010, 2011 and 2012. He received his BA from Brown University and holds an MBA from Northwestern University's Kellogg School of Management.

Aerospace and industrial composites: Now on divergent paths?

» Late in 2014, I wrote several columns that pointed to a convergence between the aerospace and industrial markets for advanced composites. Several signs pointed to this. SAMPE and ACMA came together that October to form a single CAMX trade show and conference, covering all composites applications. *Composites Technology* and *High-Performance Composites* became this single magazine, called *CompositesWorld*. In the final issue of *Composites Technology* (December 2014), I opined, "We're moving toward a time when aerospace and automotive technical advances will be interchangeable and extend well beyond the use of carbon fiber." Additional columns in the months following built on this theory of convergence, noting the contributions of aerospace, like software tools for composites and nondestructive evaluation to the advances of composites in industrial applications, and the efforts in high-speed fabrication in automotive finding eventual use in aerospace.

The aerospace and industrial markets' advanced composites challenges and their solutions will differ widely.

The convergence model can be illustrated by two highways coming together to form a super-highway to a common destination. After decades of crossing widely disparate materials, processes and designs — both markets now chase similar objectives for multi-material solutions, lower costs and higher volumes.

But what if this isn't a *merging of traffic*, but merely an intersection? Or, to continue the highway metaphor, a "roundabout," where two streams of traffic enter, but the majority continues out via separate roads to *different* destinations? What if the past two years have simply been a transient moment in time and technology where there was a lot of common territory?

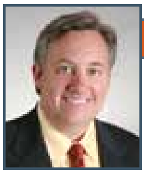
The event that triggered these thoughts was the *CompositesWorld* Carbon Fiber conference in November. The first day was very aerospace-focused. Day two focused on automotive and low-cost, alternative precursors for carbon fiber. As I listened to presentations, it struck me that each market faces very different challenges. And that solutions will differ widely as well.

Start with carbon fiber. The major suppliers of aerospace-qualified carbon fiber could cut the price in half, and it would have a negligible effect on the size of the aerospace carbon fiber market. It is just not that sensitive to material pricing, which represents less than 20% of part costs. On the other hand, if the price of *industrial*-grade carbon fiber were suddenly reduced by 50%, it would open big opportunities in automotive *and* wind energy markets. One could argue that this is a prerequisite to achieve significant penetration and helps explain the strong interest in alternative precursors such as textile PAN, bio-based PAN and pitch.

Significant levels of automation are being developed for both aerospace and automotive. A lot of effort is going into machines to make simple, repetitive carbon fiber elements for aircraft — beams, stringers and frames, for example. This is in addition to multi-million-dollar fiber placement machines already prevalent in wing and fuselage layup, where the molds remain stationary and only the gantry and heads move. The layup machines under development for automotive are focused on small- to medium-sized parts, principally laying up 2D patterns, using wider tapes, with shaping happening during the molding process. These machines have relatively small footprints, move the table as much as the head, and are a fraction of the cost of the aerospace machinery.

Finally, the markets' volume levers are distinctly divergent. Chris Red of Composites Forecasts and Consulting (Mesa, AZ, US) estimates that commercial aircraft structures consumed 7,500 MT of carbon fiber in 2016, and this will grow to slightly more than 10,100 MT in 2025, an increase of about 35%. This represents maturation of widebody aircraft programs and organic market growth. Should Boeing and Airbus elect to put carbon fiber wings on every narrowbody aircraft built (admittedly, a very optimistic scenario) this would add 7,000 MT to this forecast, at 5 MT per aircraft, assuming growth to 1,400 aircraft per year. For OEM automotive, Red's numbers go from just under 12,000 MT to almost 33,000 MT in the same period, nearly tripling the market. And his numbers might be *low*. Andreas Wuellner of SGL Carbon Fibers (Wiesbaden, Germany) envisions 20% of the world's 100 million vehicles built in 2025 using 2 kg each — an annual market of 40,000 MT. This isn't exactly a stretch, either. It could easily be double or even *quadruple* this figure with just a few technology breakthroughs.

As both markets drive through the roundabout into the future, we could be looking at very distinct industries, with different casts of suppliers, manufacturers and technologies. And surprisingly little crossover. CW



ABOUT THE AUTHOR

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

Damage tolerance testing of composites

» Damage tolerance refers to the capability of a damaged composite laminate or structure to maintain its original strength and stiffness. Typically, the damage is produced by drop-weight impacting, which can cause extensive internal damage that is difficult to detect by visual inspection. Damage tolerance testing of composites most often is performed under compression loading because compression strengths are lower than tension strengths and, therefore, more critical in many designs. Additionally, impact damage typically has a greater effect on the compression strength. Compression-after-impact (CAI) tests thus are widely used for assessing composite damage tolerance. For applications in which other loadings are critical, however, other types of tests may be used. For example, damage tolerance of composite pressure vessels is better assessed using tension-loaded specimens following impact. As discussed in my October 2016 column, damage tolerance testing follows the assessment of *damage resistance*, which focuses on the ability of a composite material or structure to *resist* the formation of damage.

Currently the most widely used standard test method for damage tolerance of composites is ASTM D 7137[1]. Not standardized by ASTM until 2005, it originated as a Boeing standard (BSS-7260[2]) in 1982, and is still commonly referred to as the Boeing CAI test. In this test, a 100-mm wide by 150-mm long flat composite specimen is used, with a suggested thickness range of 4-6 mm. Although any balanced and symmetric laminate is acceptable, the use of $[45°/90°/-45°/0°]_{ns}$ quasi-isotropic laminates is suggested for use in material comparisons. The test fixture (Fig. 1) end loads the specimen while supporting it along all four edges to resist buckling. Along the top- and bottom-loaded specimen edges, 8-mm thick flat-face supports prevent both end rotations and end brooming. Along the unloaded sides of the specimen, knife-edge supports prevent out-of-plane deformation but allow rotation. To ensure proper alignment, four axial strain gages may be bonded back-to-back near the bottom outer corners of the specimen and monitored during loading. When an adjustable hemispherical platen is used, minor adjustments can be made to minimize differences in axial strain readings under low load levels to improve alignment during subsequent compression testing to specimen failure. The compression-after-impact strength is calculated as the maximum load divided by the cross-sectional area of the specimen.

The original Boeing CAI test method was used primarily to compare the damage tolerance of composite materials. Meaningful material comparisons, however, require consistent laminate thickness and ply stacking. Additionally, drop-weight impacting to produce the damage must be performed with

FIG. 1 An ASTM D 7137 compression-after-impact test fixture.

Source (all images) | Dan Adams

FIG. 2 A modular compression-after-impact test fixture for testing larger specimens.

FIG. 3 Compression-after-impact testing of a stiffened composite panel.

consistent impactor shape, impact energy and specimen support conditions, because these considerations affect the damage state produced. Since the CAI strength is highly dependent on all of these variables, it is considered a *structural* rather than a *material* property.

Although ASTM D 7137 cautions against the use of test results in establishing design allowables, the CAI strengths obtained are often used to determine the reductions in maximum compression stress or strain due to impact damage in actual composite structures. When that is the case, the composite laminate used in the test specimen is selected to represent the laminate to be used in the finished part. Similarly, the impactor shape, impact energy and support conditions used when impacting the specimen may be selected to represent impact threats that the finished part will face in service.

> Not standardized until 2005, ASTM D 7137 is still commonly referred to as the Boeing CAI test.

Another common practice is to use impact energy levels that produce barely visible impact damage (BVID) that's difficult to detect during a visual inspection of the composite structure. In contrast, test specimen *size* has often remained at the original 100- by 150-mm dimensions regardless of the intended application. For that reason, questions persist about whether or not CAI strengths obtained using this relatively small specimen can be applied to larger parts or more complex geometries. It's important to note that the 100- by 150-mm specimen size was selected to produce sufficient reductions in compression strength for use in material comparisons yet prevent the impact damage from extending beyond one half of the specimen width. As a result, the Boeing CAI test tends to provide a *conservative* assessment of damage tolerance when applied to larger structures. The reason: the impact damage affects a smaller percentage of the cross-sectional area in a larger structure and, thus, produces a smaller reduction in compression strength.

To better represent actual composite structures, larger CAI test specimens may be used. Recent years have seen an increased interest in the use of *modular* CAI test fixtures (Fig. 2, p. 10), which can accommodate a range of specimen sizes to better » represent the parts used in intended applications. However, all such tests are typically considered as the base level of a *building-block* approach to assessing damage tolerance of composite structures. This approach involves testing reduced numbers of larger, more complex test articles that better represent the actual structure at the element, subcomponent, component and full-scale levels. Progressing up one level to element level testing involves the incorporation of design features, such as stiffeners, cut-outs and curvatures. As an example, Fig. 3 (p. 10) shows a three-stiffener panel subjected to CAI testing.

With the use of a damage tolerance building-block approach comes an interest in developing relationships for scaling test results to reduce testing requirements. However, results to date suggest that, due to the complexity of the damage states produced and the variety of factors that affect damage formation and the resulting damage tolerance, CAI strengths from test specimens do not scale up to larger parts. Additionally, although the use of numerical analyses currently is of great interest for scaling results from specimen- and element-level tests to full-scale structures, replacing physical testing with numerical analyses iss simply not possible at the present. Numerical modeling currently is of limited use for assessing damage tolerance due to difficulties associated with a) the complexity of the damage states produced by impact, b) predicting the formation of the impact damage and c) predicting damage progressions and strength reductions resulting from impact damage. Composite damage assessment, therefore, still relies heavily on physical testing performed following the previously noted building-block approach at multiple levels of test article size and complexity. CW

References

[1] ASTM D7137-12, "Compressive Residual Strength Properties of Damaged Polymer Matrix Composite Plates," ASTM International (W. Conshohocken, PA.), 2012 (originally published 2005).

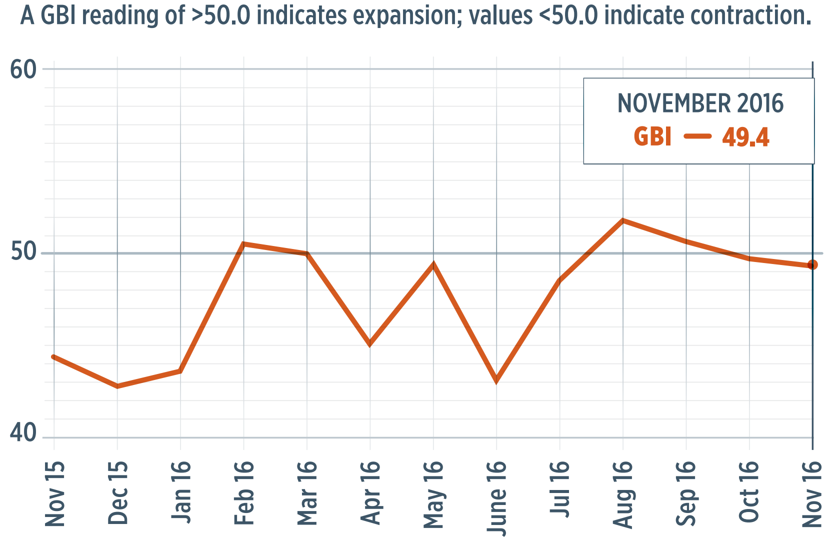
[2] *Boeing Specification Support Standard BSS 7260*, "Advanced Composite Compression Tests," The Boeing Co. (Seattle, WA), revised December 1988 (originally issued February 1982).

ABOUT THE AUTHOR

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

November 2016 – 49.4

The overall Index showed double-digit growth for a third month in succession as future business expectations skyrocketed.



With a reading of 49.4, the Gardner Business Index showed that the US composites industry contracted at a minimal rate for the second month in a row. This was after two months of growth in August and September. The Index compares the current month's business conditions to the previous month. However, when we compare the November 2016 Index to the same month one year earlier, we see that the composites Index has increased four months in a row, with the last three months seeing double-digit growth. This is a positive sign for the composites industry in 2017.

The new orders subindex contracted moderately in November for the second consecutive month. Despite this small dip in new orders, production grew at a strong rate for the fourth month in a row. With production growing and new orders contracting, the backlog subindex contracted at an accelerating rate for the second month in a row. But, compared with one year earlier, the backlog subindex has increased at a very fast rate for five months. This indicates increased capacity utilization for composite part manufacturers. Employment increased for the fourth straight month. Exports continued to contract. They had grown, as November closed out, in only one month since January 2015. Supplier deliveries lengthened in November for the third time in four months.

Material prices continued to increase in November. However, this subindex had been at a consistent level since April, which indicates that material prices were increasing at a constant rate. Prices received increased for the second time in four months. These were the first two months of price increases since August 2015.

Future business expectations skyrocketed in November — this subindex jumped more than 10 points to 77.2, reaching its highest level since February 2015. Among the markets served by the US composites industry, the prominent aerospace industry's subindex grew in November for the third time in five months. The equally important automotive market's subindex, however, contracted for the third month in a row. It had grown in only one month since October 2015. Meanwhile, the ship/boatbuilding subindex, in November, showed significant growth for three straight months. Other manufacturing, which includes miscellaneous consumer goods, contracted in seven of the previous eight months.

Regionally, the US North Central-East was the fastest growing in November. It had grown for four straight months. The West, which had grown three of the previous four months, was the only other region to grow in November.

US-based composites manufacturing facilities with more than 250 employees grew in November for the first time since August 2016. Plants with 100-249 employees, as November closed out, showed strong growth for four months. Manufacturers with 50-99 employees contracted for the first time since June 2016. Those with 20-49 employees contracted for the second month in a row, while fabricators with less than 20 employees contracted for the third month in a row. CW

ABOUT THE AUTHOR

Steve Kline, Jr. is the director of market intelligence for Gardner Business Media Inc. (Cincinnati, OH, US), the publisher of *CompositesWorld* magazine. He began his career as a writing editor for another of the company's magazines before moving into his current role. Kline holds a BS in civil engineering from Vanderbilt University and an MBA from the University of Cincinnati.
skline2@gardnerweb.com

A composites-intensive widebody entry from Asia and a potential composite airframed replacement for the long-retired supersonic *Concorde* headline recent aerospace news.

AEROSPACE

Russian/Chinese JV to field composites-intensive widebody commercial aircraft


Source | www.eastpendulum.com

A notable outcome of Airshow China 2016 (Nov. 1-6, Zhuhai, China) were reports from several media outlets that Russia's United Aircraft Corp. (UAC, Moscow) and the Commercial Aircraft Corporation of China (COMAC, Shanghai) have advanced plans for their collaborative twin-aisle widebody aircraft, so far referred to as Long-Range Wide-Body Commercial Aircraft (LRWBCA). A mockup of the new aircraft was on display at the show, showing 280 seats and nine-abreast economy seating.

An agreement was initially signed in 2012 between UAC and COMAC to study the feasibility of a widebody to compete with Boeing and Airbus. But a *Reuters* market news story dated Nov. 1 by Brenda Goh and Kenneth Maxwell said a document COMAC released at the airshow revealed that COMAC and UAC have now formed a joint venture, which will start operations this year in Shanghai, presumably on initial designs and supplier agreements.

According to a Nov. 4 *Aviation Week & Space Technology* article by Bradley Perrett and Maxim Pyadushkin, UAC will build the aircraft's composite wing, using technology developed by AeroComposit (Moscow, Russia) for the Irkut *MS-21* single-aisle commercial transport (see end note). COMAC will handle fuselage manufacturing, using both aluminum and composites, with final assembly in Shanghai, according to the article. Power will be provided by Rolls-Royce or General Electric engines, and it's possible that a Russian engine could be developed for it by 2030. Projected entry into service will be 2027, say the authors.

The joint venture is apparently focused on replacing the Airbus (Toulouse, France) A330, as that aircraft ages over the coming decade, and the Perrett and Pyadushkin article says that UAC and COMAC are claiming a 10% advantage in operating costs over competing models. Recent acquisitions of aircraft manufacturing technology and equipment companies by Chinese entities, including Brotje Automation (Rastede, Germany), Kuka Aerospace (Clinton Township, MI, US) and Aritex (Barcelona, Spain), indicate that COMAC will likely have access to experienced worldwide suppliers for high-tech assembly of the new plane.

So will a new Chinese/Russian market entrant succeed, especially one with a composites-intensive design? A key to answering that question is the answer to another: Is the *demand* there for another widebody aircraft, in this current market? Another *Aviation Week* article, dated Nov. 4 by Joe Anselmo, cites a maintenance, repair and overhaul (MRO) market survey that shows weak demand for widebody aircraft (e.g., Boeing 777, 747, Airbus A380), with no sign of improvement. On the other hand, the recently released Airbus *Global Market Forecast 2016-2035* report, which claims that China will need nearly 6,000 new passenger aircraft and freighters during that time period, forecasts that 4,230 of that number will be single-aisle planes and 1,740 will be widebody planes *for China*, to meet what Airbus says will be the fastest-growing air passenger market, well above that of the rest of the world.

Read *CW's* previous coverage of the *Irkut MS-21* composite wing fabrication process, involving dry layup and resin infusion, online | **short.compositesworld.com/MS-21wings**

ENERGY

US wind energy prospects under Trump: Industry opinion divided

In the wake of November 2016's US presidential election, *Wired* editorialist Nick Stockton argued in an opinion piece that, "America's Brief Role as a Climate Leader is Probably Over." Stockton contended on Nov. 9, as climate negotiators and a crowd of NGOs, journalists, and other observers from 200 countries gathered in Marrakesh, Morroco to work on the details of the Paris climate change agreement, that although president-elect "Trump hasn't described his climate and energy policies in detail, he has made it clear that he will not honor promises the Obama administration made to combat the intensifying global warming catastrophe." He went on to say, "Trump has called the Paris agreement a bad deal, vowing to pull out or renegotiate the US commitment." Further, Trump's stated commitment to protect internal US development and manufacturing activity is likely to result in the imposition of tariffs on the imported equipment and technologies that have, thus far, helped make renewable energy alternatives in the US, including wind power generation, competitive with domestic coal-fired electrical plants. "Tariffs would make those components more expensive," said Stockton, "and that added cost could get passed along to consumers. So goes renewable energy's competitiveness with fossil fuels."

But Dan Woynillowicz, policy director, and Merran Smith, executive director of Clean Energy Canada, a national climate and energy think tank based north of the US border at Simon Fraser University's Centre for Dialogue (Vancouver, BC, Canada), in an opinion piece that appeared Nov. 14 in *The Globe and Mail* (Toronto, ON, Canada), told a somewhat different story. Although they acknowledged that stock prices for clean-energy companies plummeted not only in the US but in Canada as well in the wake of the Trump victory, and that there is no question that Trump and Clinton differed significantly on the issue of climate change and the opportunities that clean energy technologies offer, the "reality is that clean energy has been booming in the United States for a whole bunch of reasons that don't have much to do with climate change. Things such as health, security and innovation, which lead to high levels of support amongst Republicans — yes, *(Continued on p. 16)*

(Continued from p. 15)

Republicans — for harnessing the power of American water, wind and sun."

Those federal tax credits for wind and solar energy projects? They were passed in December 2015 by a Republican-dominated Congress with bipartisan support. Revoking them now would require a legislative effort that might not be looked upon kindly by the many *Republican* lawmakers who have renewable energy manufacturing and development operations located in their states. In fact, *80%* of installed wind energy projects, for example, are situated in Republican-governed districts.

Similar reasoning has prompted the American Wind Energy Assn. (AWEA, Washington, DC, US), to adopt a watchful, indeed, a rather hopeful, post-election stance. In his AWEA Blog, titled *Into the Wind*, AWEA CEO Tom Kiernan wrote on Nov. 9, the morning after the election, "The American Wind Energy Assn. is ready to work with President-elect Donald Trump and his administration to assure that wind power continues to be a vibrant part of the U.S. economy.

"Mr. Trump has said, 'We can pursue all forms of energy. This includes renewable energies and the technologies of the future.' We look forward to working with him and his appointees to make sure they recognize that wind is working very well in America today as a mainstream energy source."

Kiernan added. "In his victory speech early this morning, the President-elect said, 'We're going to rebuild our infrastructure, which will become, by the way, second to none. And we will put millions of our people to work as we rebuild it.' Wind power is some of the best infrastructure America has ever built and we are on track to doubling it from today's levels by 2020."

Kiernan went on to say that the 2016 Republican Party's electoral platform backed the sort of grid transmission development that continued wind energy development requires, quoting: "'We support expedited siting processes and the thoughtful expansion of the grid so that consumers and businesses continue to have access to affordable and reliable electricity.'"

Further, Dan Reicher, executive director of the Streyer-Taylor Center for Energy Policy and Finance at Stanford Law School (San Diego, CA, US), told *UtilityDIVE* columnist Peter Maloney (UltilityDive.com) that despite the fact that both houses of the US Congress now will be under Republican control, it is unlikely there will be a move to repeal the previously much debated production tax credit (PTC) for wind power development. There is limited incentive to do so, he argues, because it was renewed in December 2015, with built-in reductions on a stepped-down basis, and with definitive expiration dates in 2020. At the beginning of 2017, for example, the PTC drops to 80% of current, so the step-down schedule also offers the incentive for developers of wind projects in particular to push to close financing on their projects sooner rather than later.

Trump's true impact on wind is, of course, in the wind.

CW / MONTH IN REVIEW

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

First North American Pultrusion Conference to take place in Atlanta, GA, US
The American Composites Manufacturers Assn. (ACMA) and the European Pultrusion Technology Assn (EPTA) set the dates for April 4-5, 2017.
12/14/16 | short.compositesworld.com/NAPultrude

IACMI signs membership agreement with Cincinnati Inc.
The commitment as a five-year resource member leverages US$3 million of equipment at the Tennessee Materials and Processing Center.
12/012/16 | short.compositesworld.com/IACMI-CI

Hexcel invests in Carbon Conversions Inc.
Working collaboratively, Hexcel and CCI will work to advance aerospace and industrial applications for reclaimed carbon fiber.
12/12/16 | short.compositesworld.com/Hexcel-CCI

NexGen Composites expanding to Charleston, SC
The composite panel manufacturer will invest US$100,000 in the new facility.
12/12/16 | short.compositesworld.com/NextGen-SC

C^3 Project's carbon concrete researchers awarded German Future Prize
The Federal President's Award for Technology and Innovation is one of Germany's most important scientific prizes.
12/09/16 | short.compositesworld.com/C3-GFPawd

Hyperloop Transportation Technologies amasses >US$100 million investment
Several companies have offered in-kind services, including composites manufacturer Carbures Europe SA.
12/05/16 | short.compositesworld.com/Hyperloop

Final assembly begins for the 787-10 *Dreamliner*
Boeing has moved two major fuselage sections for the first 787-10 to its North Charleston final assembly plant.
12/05/16 | short.compositesworld.com/787-10asby

Chemlease Japan KK is now Chem-Trend Japan KK
Chem-Trend Japan will have the same location and team that has been serving customers across Japan for many years.
12/05/16 | short.compositesworld.com/C-TJapanKK

SGL Group to develop carbon fiber GDL for EU automotive project
EU-funded project INSPIRE is for the development of fuel cell technology in the automotive sector.
12/05/16 | short.compositesworld.com/SGL-

Airbus A350-1000 completes first flight
Development of the aircraft is on track, and entry into service is scheduled for the second half of 2017.
12/02/16 | short.compositesworld.com/A350-10001

China Jushi USA breaks ground on 80,000-MT glass fiber facility

Jushi Group (Zhejiang, China), the largest manufacturer of glass fiber in the world, with a production capacity of more than 1 million MT per year, is putting down production roots on US soil. The company operates three manufacturing sites in its home territory, and opened a fourth (its first overseas) in Egypt in 2014, to more directly supply Europe and the Middle East. Like the site in Egypt, the new US facility will add 80,000 MT/yr of capacity in its Phase I development.

Located in the Pineview Industrial Park, outside of Columbia, SC, construction of the US $300 million plant is slated to begin in first-quarter 2017 and be completed by year-end 2018. Jushi USA will then relocate its headquarters to that site from its current location in Irwindale, CA.

Drew Walker, previously president of high-strength glass fiber producer AGY (Aiken, SC, US), is now president and general manager of the new Jushi USA plant. He said the plant's location offers a skilled workforce and excellent logistics — an adjacent rail line for raw materials and proximity to major north/south and east/west highways for shipping products, as well as connection to the seaport of Charleston. Many weavers and textile producers also are located in the state and the South Carolina Department of Commerce has had an office in Beijing for years.

"Of course South Carolina offers incentives," says Walker, "but its Chinese delegation was also very important. They have developed a good relationship and have been able to address Jushi's concerns." Walker adds that Jushi has the most advanced technology worldwide for glass fiber production. Indeed, the company's 2014 announcement of its E7 high-strength fiber claims a 30% increase in tensile strength and 11% increase in modulus vs. previous boron-free high-strength products when tested in unidirectional fabrics for wind blades. The same technology adapted as 312T roving for pultrusion provides a 15% boost in tensile strength with 10% higher modulus. This is reportedly achieved while being boron- and fluorine-free, using advanced melting techniques such as oxygen firing technology to reduce emissions (waste gas by 80%, nitrogen oxide by 90%) and employing recycling to achieve zero discharge of industrial wastewater. Information on-site at the groundbreaking stated that the new SC plant will feature information technology-integrated smart machinery and intelligent manufacturing control.

Jushi Group president Yang Guoming said that America is where fiberglass was created and was once the largest fiberglass producing nation, but now is Jushi's largest market. This South Carolina facility, he continued, is evidence of "our determination to be further globalized, first creating markets and then supporting them locally. In 1995 our products entered the US market," said Yang. "We are now exporting capital and want to work with the US to promote the fiberglass industry and market."

AEROSPACE

New supersonic passenger jet concept offers affordable speed


Source | Boom Technology

A start-up in 2014, aircraft developer Boom Technology (Denver, CO, US) is now well into the process of developing the *XB-1*, a flying one-third-scale demonstrator of its supersonic commercial aircraft. A mockup of the demonstrator was on display at the company's hangar at Centennial Airport near Denver on Nov. 15. *XB-1* will demonstrate in flight the key technologies for practical supersonic travel, says the company.

At the November 2016 open house, Boom Technology CEO Blake Scholl, company co-founder and chief engineer Joe Wilding, and co-founder and chief technology officer Josh Krall described the idea behind the endeavor. They believe they have a viable business case for the airlines, one that bests the previous longest-flying supersonic transport *Concorde*, retired in 2003. A typical round-trip ticket on the *Concorde* cost about US$20,000 and fuel burn was 6,800 gal/hr, but the trip between New York and London took about 3.5 hours; the *Concorde* was retired due to declining sales and rising costs, and the 9/11-caused aviation downturn. According to Boom, their 45-seat jet will be 2.6 times faster than conventional subsonic jets, yet cost about US$5,000 per seat, round trip, in line with today's business class tickets. Bulky lay-flat seats aren't needed, since overwater flights will take less than half the time of current flights (no jet lag). The group's preliminary design goal is Mach 2.2 (faster than the *Concorde's* Mach 2) with a 9,000 nautical mile range. Sir Richard Branson (Virgin Atlantic, Crawley, UK) has already publicized his intent to buy 10 of the craft.

How will Boom bring profitable supersonic air travel? According to the company's Web site, flyers want to get to their destinations faster. The viability of supersonic flight depends on reducing operating costs sufficiently (i.e., lower fuel burn) coupled with reasonable fares travelers are willing to pay for the speed; this requires just a 30% efficiency improvement over *Concorde's* airframe and engines, with composite materials playing a role, says the company. With more than 1,000 simulated wind tunnel tests already done, three major innovations are an *area-ruled* fuselage (the aft cabin will be tapered to reduce cross-section), a chine or wing extension towards the nose to help balance and control at supersonic speeds, and a refined delta wing with a swept trailing edge that reduces supersonic drag and quiets the sonic boom.

Carbon fiber composites will be used throughout the airframe, for lighter weight and to counteract the significant growth and expansion that the *Concorde's* aluminum design experienced in flight. The *XB-1* will be powered by three General Electric engines with shaped variable geometry inlets. Acknowledging that a ban on supersonic flights still exists over the US, the company says the jet will begin with overwater routes, such as New York to London or San Francisco to Toyko. The sonic boom from a Boom jet will reportedly be much quieter than the *Concorde's*. Boom Technology says that its *XB-1* will begin test flights in late 2017, in Colorado, then move to Edwards AFB in California.

Watch a video explaining Boom Technology's vision | **boomsupersonic.com**

Get a behind-the-scenes look at the *XB-1* | **boomsupersonic.com/xb-1**

BIZ BRIEF

Mafic USA, a unit of Mafic Inc. (Woodbridge, ON, Canada), will invest US$15 million in a new production facility located in Shelby, NC, US. The company's new operations in Shelby will employ about 113 skilled operators, engineers, sales staff and other personnel.

A global producer of continuous and chopped basalt fiber as well as long fiber thermoplastic resins, Mafic ships products to buyers in the automotive, aerospace, alternative energy and other industries. The company currently produces its basalt fiber products in Ireland and its long-fiber thermoplastic resins in Canada.

"We considered a number of locations across the US for our first American manufacturing facility, said Mafic CEO Mike Levine. "North Carolina and Cleveland County had been under consideration from the start, due to its network of specialized suppliers and wide range of potential B2B customers and strategic partners. What sealed the deal for us was the multifaceted support from all levels of government; the state, county and city. In particular, the Cleveland County Economic Development Partnership went way beyond what was expected."

ENERGY

US Offshore wind: First large-scale wind farms proposed off Maryland

Deepwater Wind (Providence, RI, US) and US Wind (Baltimore, MD, US), a subsidiary of Renexia SpA (Chieti, Italy), have submitted bids for the first large-scale offshore wind farm in the US.

Deepwater Wind is the first US wind energy developer to successfully deploy offshore turbines — its five-turbine, 30-MW farm off Block Island, RI is scheduled to begin operation this winter, and its 90-MW South Fork Wind Farm 30 miles east of Montauk, NY is slated for startup in 2022. Off Maryland, Deepwater Wind has proposed the 120-MW Skipjack Wind Farm — 20 turbines if they stay with the Heliade 6 MW turbines made by Alstom, now GE — to be located 17 miles northeast of Ocean City, MD. If approved, construction could begin as early as 2020, with operations projected to start in 2022.

For its part, US Wind has proposed a 750-MW farm, which reportedly would comprise up to 187 turbines, 12 miles offshore of Ocean City and provide power for more than 500,000 Maryland homes. US Wind also holds a lease in the New Jersey Wind Energy Area, seven miles off the coast of Atlantic City, and has responded to the US Bureau of Ocean Energy Management (BOEM), indicating interest in acquiring a commercial wind lease in one of four areas off the coast of South Carolina.

AT *CW* press time, the Deepwater Wind and US Wind proposals were under consideration by the Maryland Public Service Commission (PSC), during a 180-day period that began on Nov. 28.

BIZ BRIEF

C.R. Onsrud Inc. (Troutman, NC, US) is breaking ground on a 55,000-ft² (5,110m²) expansion to its manufacturing plant in Troutman. This US$8 million investment will facilitate the Onsrud family's growing needs. With new state-of-the-art machine tools and processes, this building will expand its capabilities while reducing costs and increasing quality by providing full control of the manufacturing process in-house.

"Yes US manufacturing is alive and well," says Jeff Onsrud, vice president. "C.R. Onsrud is investing in the future." The company has achieved more than 25% growth compared to its best sales year.

Connora awarded US$730,000 for SBIR Phase II

The automotive industry is on the brink of a materials revolution. So say the owners of Connora Technologies (Hayward, CA, US), who believe that their recyclable thermoset resin technology could be the tipping point.

Awarded Phase II funding in October 2016 in the amount of US$730,000 by the National Science Foundation's Small Business Innovation Research (SBIR) program, Connora, led by CEO, Dr. Rey Banatao and CTO, Dr. Stefan Pastine, says it is poised to launch its new class of recyclable high-performance composites from the laboratory into the high volume automotive market and beyond. Connora's focus is to enable cost-effective, efficient manufacture of recyclable *thermoset* composites.

Already used extensively throughout the transportation, aerospace, consumer electronics, civil engineering and sporting goods industries, where superior strength/weight ratios, rigidity, durability and corrosion resistance are prized attributes, thermoset resins have replaced aluminum and steel in many markets despite the material's inherent drawbacks: thermoset composites are currently expensive, slow to produce and intrinsically difficult to repair or recycle. Connora's SBIR Project aims to address these limitations by further developing Recyclamine resins for HP-RTM (high-pressure resin transfer molding) applications in automotive applications.

Where other approaches reduce the reclaimed fiber performance and value of the composites, Connora's recycling approach reportedly preserves the virgin performance and value of the reclaimed fibers *and* reclaims the thermoset resin as a high value, reusable *thermoplastic* resin.

For more on Recyclamine | **short.compositesworld.com/connoraRTM**

BIZ BRIEFS

Gurit (Zurich, Switzerland) has acquired **BASF SE's** (Ludwigshaven, Germany) polyethylene terephthalate (PET) structural foam business, which includes BASF's PET operations in Volpiano, Italy, including its staff, operating assets and product IP in the form of an asset deal. This acquisition is expected to strengthen Gurit's structural core material product range and add a sizable European-based PET production capacity to the company's existing PET operations in mainland China. The BASF Kerdyn product brand will reinforce Gurit's PET product offering to the wind, marine, transport and construction industry. Additionally, Gurit will gain significant extrusion process technology and product innovation know-how. BASF had previously purchased the PET foam business in Volpiano from B.C. Foam SpA. Gurit intends to integrate and further develop its new PET operations as part of its composite materials business unit.

"We would like to welcome the BASF team in Volpiano to Gurit and look forward to dynamically developing the site and business together," says Gurit CEO Rudolf Hadorn.

Plasmatreat North America (Elgin, IL, US) opened its new West Coast facility in Hayward, CA, US, a location able to accommodate more equipment and offering more space to help customers run trials, develop new processes, help educate the market about plasma technology and to provide contract surface treatment services for those who wish to take advantage of the benefits of plasma before purchasing systems for their own use.

Tapping into the carbon fiber brain trust

CompositesWorld's annual Carbon Fiber Conference, gathered its always engaging collection of insightful observers this year in Scottsdale, AZ, US, to predict the ways this key composite reinforcement will impact a variety of markets and the products demanded in them.

Source | *CW* / Photo | Heather Caliendo

Carbon Fiber 2016 Report

Conference speakers predict the outlook for carbon fiber supply and demand.

By Jeff Sloan / Editor-in-Chief

» *CompositesWorld's* annual Carbon Fiber Conference, Nov. 9-11 in Scottsdale, AZ, US, offered its usual insightful look at the current and anticipated application of carbon fiber composites in a variety of markets and products. The opening session kicked off with a seminar presented by Chris Red of Composites Forecasts and Consulting LLC (Mesa AZ, US) on the global outlook for carbon fibers and carbon fiber composites. As usual, Chris included his assessment of carbon fiber supply and demand — this time, through 2025.

Amassing key figures for key markets

A regular on the *CW* conference circuit, market researcher Chris Red (Composites Forecasts and Consulting, Mesa AZ, US) holds forth on the market outlook for this key fiber through 2025.

Source | *CW* / Photo | Jeff Sloan

In terms of consumption by volume, Red noted that the vast majority (75%) of carbon fiber is used in the industrial market, which includes the automotive, pressure vessels and wind energy sectors. The remainder goes to the aerospace market (14%) and the consumer market (11%).

The biggest drivers of carbon fiber use over the coming decade, says Red, will be in categories he labels *automotive*, *pressure vessels*, *wind turbines*, *non-wind energy*, *commercial aerospace structures* and *commercial aero interiors*. His outlook for these is charted in Fig. 1, p. 25.

Globally, Fig. 2 (p. 25) summarizes how Red sees total carbon fiber demand adding up during the coming decade. Note that in five years, Red expects the industrial market *alone* will use more carbon fiber annually (141,800 MT) than the entire world consumes yearly today (101,600 MT).

On the supply side, Red says to expect an increase in global carbon fiber manufacturing capacity in the 2020-2024 timeframe of 100,000 MT to meet a surge in demand. His carbon fiber output estimates are collected in Fig. 3, p. 25.

Dan Pichler, of Germany-based Carb Consult GmbH (Hofheim am Taunus) offered his own summary of the carbon fiber supply and demand situation, and his assessment is more conservative. He estimates that 2015 carbon fiber demand was 58,000 MT, followed by 2016 demand of 65,000 MT. Further, he anticipates 2025 carbon fiber demand will total 175,000 MT. On top of that, Pichler estimates that current actual carbon fiber capacity is 95,000 MT, which means the current market is almost 40% oversupplied. Pichler believes this overcapacity might persist through 2025. Finally, Pichler foresees the addition of more carbon fiber suppliers in Asia, followed by consolidation among carbon fiber manufacturers over the next several years.

Keynoting the conference was Paul Oldroyd, technical fellow, manufacturing and engineering process development, at Bell Helicopter/Textron Inc. (Fort Worth, TX, US), who offered his assessment of the future of carbon fiber application in aerostructures. He noted that the current aerocomposites formula — low volume,

FIG 1	End-market carbon fiber consumption (MT)			
Market	**2016**	**2021**	**2025**	**CAGR (%)**
Automotive	11,825	23,526	32,708	12.03
Pressure vessels	8,206	25,674	45,327	22.24
Wind turbines	17,250	31,744	46,477	10.91
Non-wind energy	3,750	11,440	29,356	24.45
Commercial aerostructures	7,506	10,319	10,110	6.2
Commercial aero interiors	4,649	5,196	5,027	2.7

FIG. 2	Global carbon fiber demand summary (MT)			
Market	**2016**	**2021**	**2025**	**CAGR (%)**
Consumer	15,200	17,100	19,100	2.3
Aerospace	17,900	22,900	23,100	2.62
Industrial	68,500	141,800	220,100	12.38
Total	101,600	181,900	262,400	9.95

FIG. 3	Estimated carbon fiber nameplate capacity vs. actual output (MT)		
Year	**Nameplate**	**Actual**	**Knockdown (%)**
2006	34,841	25,730	60
2011	92,550	55,530	60
2016	153,350	102,130	67
2021	199,060	153,720	82

Source | Composites Forecasts and Consulting LLC

high performance, high cost — "has to be changed." He sees in the wind and automotive markets lessons to be learned, respectively, about how to increase speed and efficiency. He pointed to three variables that he thinks deserve attention and improvement: Optimization of fiber placement with thinner plies and off angles to improve laminate stiffness without sacrificing strength; shorter and more efficient material qualification cycles; and the application of out-of-autoclave processes (from automotive and wind) that can speed manufacturing of aerocomposites.

From outside the composites industry and looking in was Bill Bihlman, president of consultancy Aerolytics LLC (South Bend, IN, US). He offered what he said was an "agnostic" view of materials use in aerostructures, focused primarily on the advantages and disadvantages of aluminum and carbon fiber composites. He noted the well-known hurdles of composites, including relatively high cost (*$300-$350/lb* of finished part), the difficulty of damage detection and the labor intensity of composites manufacturing. He emphasized, however, that airlines increasingly drive airframe material choice, in the process factoring in price, weight, aircraft capacity, range and speed. Bihlman also argued that the direct operating cost of aircraft maintenance should be given greater weight by airlines when considering material use. This is where composites excel, offering operators a chance to lengthen the time interval between major maintenance operations. Regardless, looking forward to replacements for The Boeing Co.'s (Chicago, IL US) 737 and the Airbus (Toulouse, France) A320 passenger jets, Bihlman said "conventional wisdom says aluminum will be featured in narrowbody fuselages," while the wings will be made with carbon fiber. He said these craft are being designed now, and to expect entry into service around 2025.

> Magna expects carbon fiber penetration will be 20% in the luxury car market and 5-10% in the mainstream ....

On the autocomposites front, Tom Pilette, VP of product and process development at Magna Exteriors (Troy, MI, US), was decidedly upbeat about carbon fiber's future in cars and trucks. He said Magna sees persistent demand for lightweighting to offset mass added by new vehicle features and amenities, as well as batteries. This will, he argued, push carbon fiber increasingly into parts like hoods, roofs, doors, and body-in-white (or, body-in-black, he noted). "We would not be in the lightweight composites market if we thought it would remain a niche product," he noted. Indeed, by 2020, Magna expects carbon fiber penetration will be 20% in the luxury car market, and 5-10% in the mainstream automotive market. This could, he estimated, double global carbon fiber demand by 2020. The challenge, he said, will be scaling up composites manufacturing capacity to meet the demand. In this regard, he noted, "The good thing about the automotive industry is that things take time," thus, giving the industry a chance now to start solving capacity problems.

By the end of the conference, overall sentiment seemed to favor the mindset that increased carbon fiber consumption, at least during the next decade, is a given. The question, then, is not *if* it will grow, but *how much*. That remains to be seen. CW

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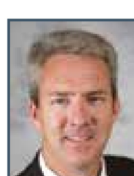
Read this article online | short.compositesworld.com/CF2016Rpt



ABOUT THE AUTHOR

Jeff Sloan is editor-in-chief of *CompositesWorld*, and has been engaged in plastics- and composites-industry journalism for 23 years. **jeff@compositesworld.com**

Plant Tour: Tri-Mack Plastics Manufacturing, Bristol, RI, US

Precision thermoplastics parts manufacturer expands into hybrid composites to help meet OEM demand for higher performance while trimming weight, cost and lead times.

By **Ginger Gardiner** / Senior Editor

» Established in 1974 to manufacture friction-wear plastic parts for aircraft engines, Tri-Mack Plastics Manufacturing (Bristol, RI, US) has become a fully integrated supplier of high-precision, high-performance thermoplastic parts not only for the aerospace/defense industry but for the industrial equipment and medical sectors as well.

"Manufacturers are under constant pressure to improve performance while reducing cost and lead times without sacrificing quality," says Tri-Mack president Will Kain. Tri-Mack has answered industry's need for a single-source partner, providing design assistance and materials/process development through to qualification and commercial production while cutting lead times for its customers. "Projects that were previously allotted 18 months must now be completed in 3 months," notes director of sales and marketing Tom Kneath. "Because we do so much in-house — including tool design and manufacture, molding, multi-axis machining and bonding/assembly — we control the timeline." Tri-Mack has developed a collaborative new product introduction (NPI) process, on which its customers have come to rely in order to meet today's tight development schedules.

Now the company is increasing in both size and technologies offered. Having doubled its new Advanced Composites Center (ACC) last year to 1,115m^2, Tri-Mack is repeating this process for its main building, including

■ From pellets to tapes and hybrids of the two

Tri-Mack has expanded from high-performance injection molded parts to continuous fiber-reinforced thermoplastics and overmolded hybrid composite parts, offering an order of magnitude improvement in mechanical properties while maintaining its minimal development- and production-time manufacturing philosophy.

Source (all images) | Tri-Mack Plastics Manufacturing

expanded engineering and production flow, and has developed automated processes for continuous fiber-reinforced plastics and overmolded thermoplastic composites (a/k/a hybrid, Fig. 1, right).

"We convert metals and thermosets to thermoplastic and thermoplastic composites," says Kneath. "We are using high-temperature, chemically resistant materials and tailored laminates, made from unidirectional tapes. Continuous fiber tape boosts mechanical properties 10x versus injection molding and achieves a 70% weight reduction vs. stainless steel."

Engineered polymer parts

CW's tour begins in Tri-Mack's engineering offices, where Kneath shows an injection molded component for the air distribution system on the Boeing 787. "The advantage in injection molding complex shapes is the low cost of conversion," he explains, noting that injection molding processes can create complex geometries from reinforced thermoplastic pellets in very short order, where converting metals to the same geometries demands hours. "We can mold a full net-shape part in 2-3 minutes with less material waste and machining time vs. metal," says Kneath, "*and* we can insert mold hardware for fastening."

Tri-Mack's extensive materials knowledge is built on the early work of founder Edward J. Mack, a pioneer in polymer chemistry and *tribology* (material friction, wear and toughness), making reinforced/filled polytetrafluoroethylene (PTFE) bushings. The company has since developed expertise with »

FIG. 1 Handling complexity without complications

Tri-Mack's hybrids combine continuous fiber composites with injection molding to cost- and time-effectively add ribs and other geometric complexities.

FIG. 2 Making the most of machinery

Tri-Mack has invested in automated injection molding and CNC machining systems to continuously improve its efficiency and flexibility.

a range of polymers, including polyetheretherketone (PEEK), Solvay's (Alpharetta, GA, US) Torlon polyamide-imide (PAI), SABIC's (Pittsfield, MA, US) Ultem polyetherimide (PEI) and polyimides, such as Vespel (DuPont, Wilmington, DE, US). "Our main customer base is commercial and military aerospace," says Kneath but he adds, "We also supply into specialty applications with demanding load and temperature requirements — for example, cryogenic equipment."

Because of this niche, collaborative engineering is a key strength for Tri-Mack. "We support design for manufacturing, but can also review drawings and perform the necessary validations and quality inspections," says Kneath. Tri-Mack's certifications include AS9100 and ISO 9001:2008, as well as Nadcap for composite bonding. "We have Designated Supplier Quality Representatives (DSQRs), authorized to approve shipments to go right to stock at aerospace OEMs," Kneath observes.

He opens a door which leads from offices into a 1,860m^2 production area filled with automated injection molding and CNC turning machines. "We do have older equipment that still functions well for specific parts," says Kneath, walking past a row of lathes. "But we've also gone to new equipment with more automation because it offers efficiency and versatility," he adds, pointing to a line of automated CNC cells. "These can machine the front of one piece and the back of a second piece simultaneously." (Fig. 2, above.)

> "We are constantly looking forward with the goal of anticipating the next development." - Tom Kneath

The tour then heads through the tool room where Tri-Mack builds its own injection molds. It features the variety of metalworking equipment that is required to make mold components including electrical discharge machining (EDM) centers. Adjacent to the tool room is the injection molding department, which houses 14 presses, ranging from 28 to 720 tons. Tri-Mack's focus on continuous improvement resulted in the purchase of four new injection molding machines and an automated robotic molding cell in the past three years.

The tour exits Tri-Mack's main building and crosses a small roadway to the ACC. "As a manufacturer in New England, where textile mills once led the American Industrial Revolution, we understand we have to keep updating our manufacturing methods," says Kneath. "We are constantly looking forward with the goal of anticipating the next development." However, the decision to add composites was not made lightly.

New capabilities in composites

"Some would say we have always made composites," says Kain, "because the plastics are filled or reinforced with short fiber. But what we're doing now is maintaining *continuous* fiber at specific orientations — an order of magnitude stronger than filled resins."

This development was based on feedback from primary customers as to what new technologies they were exploring. "We evaluated automated tape laying and in-situ consolidation," says Kneath, "but six years ago, when we were looking to make this transition, we felt RELAY would be the fastest, most efficient way to lay tape and make the parts we envisioned."

RELAY is an automated thermoplastic tape placement machine developed by now-defunct Fiberforge (Glenwood Springs, CO, US) for its tailored blank preforming technology (see Learn More, p. 30). When *CW* visited FiberForge in 2006, tailored *metal* blanks were already well-known in the auto industry. In composites, a tailored blank is simply a flat composite laminate built by laying fiber-reinforced thermoplastic tapes in the locations and directions necessary to produce specific properties (Fig. 3, p. 29).

"Our RELAY machine can produce blanks up to 1m^2 at a rate of 7 m/min," says Kneath. It can use glass, carbon and other

FIG. 3 Adopted RELAY technology has taken off

Tri-Mack's RELAY machine, originally developed by Fiberforge, applies prepreg strips onto a movable table, to build a tailored laminate blank.

FIG. 4 RELAY-to-press combo = extra-low porosity

Once completed, tailored blanks are removed from the RELAY machine and consolidated in a heated 500-ton press, reducing void content to <2%.

fibers in unidirectional (UD) formats, and a variety of thermoplastic matrices, but for Tri-Mack's purposes, the focus is on more high-end materials: PEEK, polyetherketoneketone (PEKK), polyphenylene sulfide PPS and PEI. "Nylon is the bottom of that spectrum for us," Kneath comments. With two creels, the system also can run two materials simultaneously.

The computer-controlled RELAY measures, cuts and applies prepreg strips onto a flat table that can move in x, y and z axes. "The first ply is held by vacuum," Kneath explains, "with subsequent plies tacked together via ultrasonic welding." Blanks can be designed with windows and pad-ups, enabling Tri-Mack to optimize the blanks for efficiency and performance. »

FIG. 5 RELAY blanks to parts via pressforming

Consolidated blanks can be converted into flat parts or processed into complex shapes via press forming.

FIG. 6 New, robotic process compresses high-end hybrid production

Tri-Mack's newest hybrid process inputs carbon PEEK UD tape, carbon-filled PEEK molding pellets and metal inserts, and — using this ABB 5-axis robot and an Engel molding machine — eliminates the press forming step and forming tool, to output a finished composite part with integrated standoffs and metal inserts right out of the injection mold.

Once completed, the tailored blank is removed from the RELAY machine's table and placed into a heated 500-ton press to consolidate the laminate (Fig. 4, p. 29), reducing void content to less than 2%. These consolidated blanks can be converted into flat parts or processed into complex shapes via press forming (Fig. 5, above).

Before press forming, blanks must be reheated to thermoforming temperature in an infrared oven. An automated shuttle system with a flexible design moves blanks into the oven and on to the press, where they are formed into complex shapes using molds designed and built by Tri-Mack. "We have production blanks comprised of up to 36 plies," says Kneath. "We could go higher, but haven't needed to yet." He notes that the cure rate of the blanks is controlled to achieve the crystallinity required for semi-crystalline matrices like PEEK, and also to prevent warping. Cycle times, in the press and in the oven, typically are just a few minutes in duration. These thermoformed, shaped laminates can then be machined using a waterjet or one of several multiaxis CNC mills to produce finished parts.

Hybrid composites

Tri-Mack has been using its thermoplastics expertise to develop what it calls *hybrids*: thermoplastic composites overmolded with thermoplastic resin to create complex-shaped ribs, bosses, molded-in inserts and attachment points. Hybrids reduce part count and processing steps, helping to achieve cost/weight goals.

"We see the hybrid composite technology as being able to offer the best of both worlds: the strength and stiffness of continuous-fiber composites with the cost- and time-effective manufacturing of injection molding," says Kneath. He notes that Tri-Mack has been using injection molded PEEK for years to produce complex geometries in a very efficient manner. "The key to being able to extend this advantage to composites," Kneath explains, "is understanding your polymer systems and having families like PEEK and Victrex' new lower-melt PAEK, which enables a true melt-bond between the shaped tailored blank and the overmold." The result is a part comparable to a complex-shaped, load-bearing bracket Tri-Mack demonstrated this past year, which used a uni-carbon/PAEK blank preheated to 200°C and overmolded with Victrex PEEK 150CA30 — 30% carbon fiber-reinforced compound — to achieve a part 60% lighter than comparable metal brackets while exhibiting robust performance in testing (see Learn More).

A new development is an all-PEEK hybrid panel, designed and built by Tri-Mack using its *robotic* molding cell. The material inputs for the 254-mm by 229-mm panel are carbon fiber/PEEK UD tape, carbon fiber-filled PEEK molding pellets and metal inserts. The UD tape runs through Tri-Mack's layup and consolidation process

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Read this article online | short.compositesworld.com/Tri-MackRI

Read more online at the *CW* Web site about the FiberForge-developed RELAY process in the following:

"Tailored carbon fiber blanks set to move into steel stamping arena" | short.compositesworld.com/LvFR7nP1

"Fiberforge announces thermoplastic composite engine brackets" | short.compositesworld.com/RElayBrkt

"Dieffenbacher acquires Fiberforge tape layup technology" | short.compositesworld.com/DB-Relay

Read more online at the *CW* Web site about Tri-Mack's hybrid composites in the following:

"Overmolding expands PEEK's range in composites" | short.compositesworld.com/PEEKover

"Tri-Mack expands capabilities to meet aerospace demand" | short.compositesworld.com/Tri-MackEx using the RELAY machine. Next, a 5-axis robot from ABB Robotics North America (Auburn Hills, MI, US) and an Engel (Schwertberg, Austria) molding machine (Fig. 6, p. 30), work together to form a finished composite shape in the injection mold.

"This eliminates the press-forming step and forming tool, reducing the overall cost to produce the component," Kneath points out. "The injection molding operation also adds standoffs and captures the metal inserts to create a finished part right out of the mold. The result is a lower-cost manufacturing approach for a high-performance solution."

Conservative, steady growth

During *CW*'s tour, the ACC building was still in transition. Crews, installing new equipment and outfitting production areas, were in the process of reorganization and streamlining operations. The ACC now features a quality-control and materials testing lab, with standard physical testing machines and nondestructive testing equipment, including an Olympus (Waltham, MA, US) phased-array ultrasound system. An adjacent assembly and bonding department includes laser marking equipment and epoxy composite bonding cells. The latter are used with Gruenberg ovens (Thermal Product Solutions, New Columbia, PA, US) to accelerate cure cycles. Tri-Mack also has the capability to integrate edge closures and sealing features using room temperature vulcanization (RTV) silicone. The 560m^2 CNC milling room, now located directly behind the press area, features 9 multi-axis HAAS milling centers that include inspection via in-machine probing.

Kain points out that Tri-Mack's growth is a mixture of composites and legacy business. "We understand the cyclical nature of aerospace," he says, "and have lived through many ups and downs." At the same time, the company recognizes the potential of emerging technologies and the importance of getting in early on new manufacturing programs that have long life. One of the benefits of its collaborative approach with customers is a better understanding of where new technology and program adoption curves might intersect. Kneath says current goals are to increase Tri-Mack's composites capabilities, both in size and efficiency: "We have looked at Coriolis [Queven, France] and other equipment for the next generation of products." For the future, he wants to explore technologies that will enable greater complexity and expand part performance. "After all, the more we can do to increase our customers' success, the more we succeed." CW

ABOUT THE AUTHOR

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

Size-unlimited OOA composite process enables next-gen launch system

FIG. 1 United Launch Alliance's *Vulcan Centaur*

This graphic of the new composites-intensive launch vehicle features a two-piece payload fairing, for which each half can be manufactured from CFRP out of the autoclave in one piece via the semi-automated Ruag Space molding process.

Source | ULA

United Launch Alliance selects Ruag Space for lower cost/improved quality out-of-autoclave manufacture of *Vulcan's* composite primary structures.

By Donna Dawson / Senior Writer Emeritus

» For the past decade, United Launch Alliance (ULA, Centennial, CO, US) has been a cornerstone of US space industry launch system activities. The Boeing Co. (Chicago, IL, US) and Lockheed Martin (El Segundo, CA, US) formed ULA in December 2006 as a 50/50 joint venture, bringing Lockheed Martin's *Atlas* and Boeing's *Delta* launch systems together under joint management to ensure reliable, cost-efficient space launch services for the US government and its launch customers.

ULA is now replacing *Atlas* and *Delta* with next-generation launch rockets under the *Vulcan* name. Beginning with the *Vulcan Centaur*, this new, single family of vehicles will provide the full range of capability currently provided by the combined *Atlas*/*Delta* families, says ULA's VP of engineering Mark Peller. Further, he adds, "As we retire the *Atlas* vehicle, it will enable us to retire its Russian-built RD-1 engine." The primary engine option for *Vulcan* is the BE-4, built by Blue Origin (Kent, WA, US), with the AR1 engine, built by Aerojet Rocketdyne (Sacramento, CA, US), as a backup.

Vulcan Centaur (first flight scheduled for 2019) is designed to exceed the *Atlas V's* capability, offering a single booster stage, a high-powered *Centaur* second stage and either a 4m- or 5.4m-diameter payload fairing. "Up to four solid rocket boosters augment the lift-off power of the 4m configuration, while up to six boosters can be added to the 5m configuration," ULA reports. The *Vulcan ACES* (Advanced Cryogenic Evolved Stage) heavy-lift vehicle will follow, scheduled for first flight in 2023. *ACES* will replace the *Centaur* second stage and its propellant will be cryogenic. That means it must house the tanks and piping that handle the ultra-cooled (-150°C) liquid oxygen and liquid hydrogen.

Peller points out that composite materials have been selected for the *Vulcan* primary structures to improve the quality of the product *and to reduce cost.* The key to the cost reduction component is a practical out-of-autoclave (OOA) process developed by ULA's manufacturing partner, Ruag Space.

ULA/Ruag strategic partnership

Headquartered in Zurich, Switzerland, with 10 sites worldwide in Sweden, Finland, Austria and the US, Ruag Space is making OOA its baseline for manufacture of composite structures for launch vehicles, including payload fairings for the European Space Agency's (ESA, Paris, France) heavy-lift launchers *Ariane 5* and *Ariane 6*, and its smaller *Vega* configuration, as well as ULA's *Atlas V* and the *Vulcan* (also see Learn More).

Matteo Rendina, manager of product engineering for Ruag Space, explains the reasoning behind the company's OOA strategy. "Normally, the limits for manufacture of composite products are established by the size of the equipment laying down the carbon fiber — for example, a tape laying or fiber placement machine," he notes. "At Ruag we don't have this limit," he points out, noting, "We can manufacture *any* size the customer needs because we mastered production methods that are not linked to these types of automated machines. This was a strategic decision we have taken."

Disadvantages of this approach are the need for operator assistance in a semi-automated operation, and a slower production rate than a fully automated system. Ruag's analysis, however, shows that given the relatively low production rate, these disadvantages are well offset by the advantages of parts consolidation, low equipment cost, and nearly unlimited size capacity.

As part of the ULA/Ruag strategic partnership, announced in July 2015, Ruag will establish a composites production capability within ULA's Decatur, AL, US, factory and manufacture new composite structures for ULA's *Vulcan* rocket, and manufacture 5.4m payload fairings and 400-series interstage adapters for ULA's *Atlas V* (Ruag has manufactured *Atlas V* components in Switzerland for several years).

Ruag is expected to begin work mid-2017 in Decatur. Hardware delivery for *Atlas V* is planned for late 2019. Hardware development and qualification of the new *Vulcan* composite component structures is planned through mid-2020, with first delivery of *Vulcan* components later that year.

High-performance without an autoclave

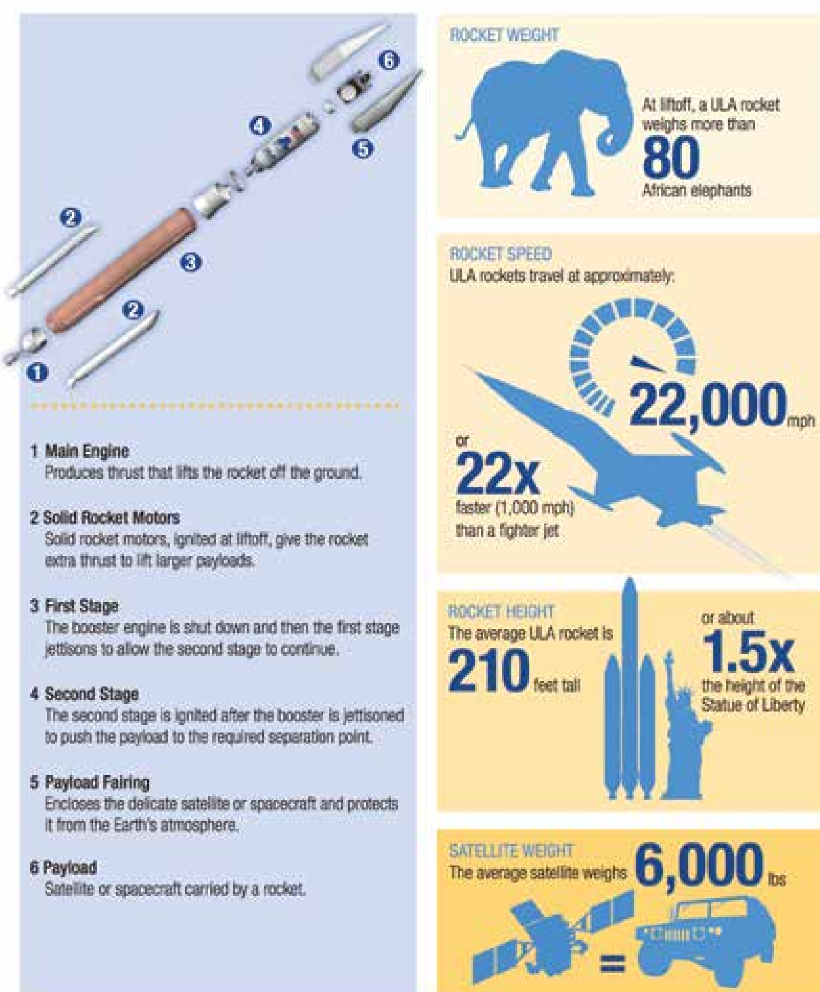
Ruag will build *Vulcan*'s payload fairing, interstage adapter and heat shield. All will be manufactured by the same OOA process, Rendina says, but the material systems and the design details for the laminate layup, sandwich core and thermal protection system will vary among them. The interstage connects the first and second stages of the rocket. A single 360° structure, 4m high, the interstage is built up and cured in one piece. It measures 5.4m in diameter at its base, but is tapered on the forward end to interface with the smaller diameter second stage. The heat shield, at the base of the rocket, is also 5.4m in diameter.

The *Vulcan's* 5.4m-diameter payload fairing, which will be built in three lengths (20.7m, 23.5m and 26.5m), is an excellent illustration of the utility of Ruag's process. Payload fairings are made in two longitudinal half-shells, each comprising a cylindrical shape joined to an *ogive* shape at the nose cone. During launch preparation, the two half shells are fastened together around the spacecraft or other payload, enclosing it for its protection during the first phase of flight. At a specified point, after clearing Earth's atmosphere, the fairing is separated and jettisoned from the launch vehicle, thus permitting the later separation of the spacecraft for entry into orbit.

A huge advantage of Ruag's OOA composite construction for the payload fairing is that each fairing half shell — incorporating the cylindrical and ogive sections — can be made in a *single piece* that consolidates all parts: inner and outer skins, honeycomb sandwich core, and exterior thermal protection system. "These are all cured together as a complete sandwich structure in order to obtain the required mechanical properties," Rendina explains.

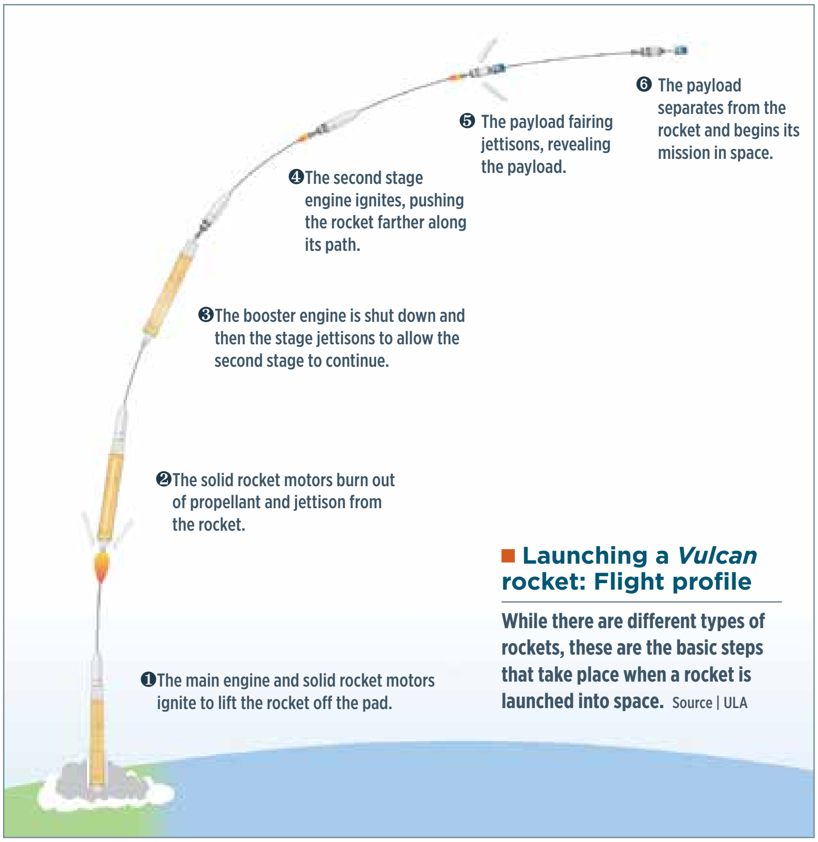
Material preparation

The first step of Ruag's OOA process is material preparation. For the fairing, a woven carbon/glass prepreg fabric supplied by Solvay Group (Woodland Park, NJ, US), »



■ ***Vulcan* launch family: The performance parameters**

The Vulcan family of launch vehicles must handle great stresses as it carries weighty payloads into Earth orbit and beyond. Source | ULA



Launching a *Vulcan* rocket: Flight profile

While there are different types of rockets, these are the basic steps that take place when a rocket is launched into space. Source | ULA

featuring standard-modulus (230 GPa) T300 carbon fiber from Toray Industries (Tokyo, Japan) and S-glass from AGY (Aiken, SC, US) in an unidentified Cytec resin matrix. Other fibers were considered, but "at the end of an exhaustive trade-off study, we confirmed the use of the heritage T300 fiber, which had already been used successfully in both *Ariane 4* and *Ariane 5* payload fairings," Rendina says.

A high-strength carbon fiber would not justify its higher cost, he points out. Although a high-tensile-modulus/high-strength fiber would permit a thinner laminate and that would be an advantage in some applications, with parts of this size, a certain skin *thickness* is required to ensure fairing stability and resilience.

Ruag selected a 0°/90° woven fabric with a combination of carbon fiber woven in the axial and circumferential direction, and some glass fiber in the 90° direction. In some areas, in accordance with the design specification, the 0°/90° fabric is applied at a 45° angle, to obtain a quasi-isotropic 0°/90°/±45° laminate. The *carbon* fiber gives the required stiffness in both directions for stability and limited deflections, Rendina explains, while the placement of glass fibers in the circumferential direction gives the laminate a greater degree of flexibility due to a lower modulus of elasticity (less stiffness) than it would have with carbon fiber reinforcement alone, which proves helpful when the two halves must separate with sufficient clearance from the launch vehicle during flight.

Although the resin could not be identified, it was selected based on its oven-cure compatibility, and the fact that it has a T_g high enough to reduce the amount of thermal protection necessary on the outside of the fairing. "The external thermal protection reduces the thermal heat flux acting on the composite sandwich during atmospheric flight. This helps protect the sandwich structure from excessively heating up, thus holding the operating temperature of the sandwich sufficiently below the T_g," Rendina explains. Further, its outlife permitted time enough to layup such a large part.

Layup of the part

Solvay provides the prepreg fabric in rolls of about 1m wide. The prepreg roll is installed on Ruag's semi-automated fabric lay-down machine, which was built to Ruag's specifications by Eugen Ostertag GmbH, now Eugen Ostertag Automation (Laichingen, Germany). The prepreg fabric is automatically rolled out onto a flat tooling table for layup of the inner skin, guided by a laser projection system from Virtek Vision International (Waterloo, ON, Canada). For areas of part geometry not manageable by the machine, which simply rolls out prepreg fabric in 1m widths and cuts it along the roll line, such as when off-angle orientations are called for, an operator manually trims the fabric at the edges (Steps 1 & 2, p. 36).

The layup for the payload half-shell is subject to intermediate consolidation to remove any entrapped air and avoid potential voids in the laminate, using a proprietary method. Rendina says Ruag achieves an average void content of slightly more than 1%.

After layup and compaction of the inner skin, the skin is transferred from the table onto a male bonding mold by a dedicated lifting and transfer jig, a vacuum-assisted tool designed by Ruag that grips the skin along two sides and along its middle (Steps 3, 4 & 5, p. 36). The inner skin of the ogive-shaped nose cone is laid up with the same prepreg manually, directly over the ogive male bonding mold, adjacent to the inner skin of the cylindrical section.

An aluminum honeycomb core, provided in blocks by Hexcel (Stamford, CT, US), is machined to the required thickness, expanded to the desired shape and bent on a dedicated tool to the corresponding radius for the cylindrical and ogive sections of the fairing. The honeycomb is then manually arranged over the cylindrical and ogive inner skins on the mold.

The outer skin of the cylindrical section of the fairing is then laid up in the same manner as the inner skin, and positioned over the honeycomb core by means of the lifting and transfer jig.

The outer skin of the ogive section is layed up manually on a dummy mold. Thermal protection in the form of a compressed cork provided by Amorim Group (Mozelos VFR, Portugal), is positioned over the layup. The part is transferred to the bonding mold by means of hundreds of small vacuum pads arranged on another dedicated jig (Step 6, p. 36). Lastly, a layer of the cork is arranged over the outer skin of the cylindrical section. The cork, bonded on the outside skin of the fairing's composite sandwich protects the sandwich from the aerodynamic frictional heat generated on the fairing's exterior. The complete part sandwich layup is now ready for vacuum bagging and cure.

Curing process

Curing is performed *once* for each fairing half shell. "The end product of the cure is a composite shell, thermally protected, on which all the subsystems required by the payload fairing will be assembled," Rendina points out. Those are installed mainly on the inside of the fairing (instrumentation, venting system, acoustic protection system), but some are placed on the main structural path (separation systems) and some on the external side of the fairing (interfaces to the ground).

Each fairing half shell is cured in a large oven (Step 7, p. 37), supplied by Luterbach AG (Hildisrieden, Switzerland) according to a specific time and temperature profile established "after investigating the effect of different parameters on the resulting material performance," Rendina says. These include the viscosity and T_g (high) of the resin; the application of a vacuum level that best facilitates air evacuation and achieves thorough consolidation; and realization of a homogeneous cure that curtails hot and cold areas, to limit part distortions.

To ensure the latter, Ruag has conducted extensive computational fluid dynamics (CFD) analyses on the air circulation inside the oven to ensure even temperature distribution over the entire part. After cure, the fairing shell is lifted from the mold by a lifting jig, also equipped with vacuum pads, and transferred to the next station for nondestructive testing.

Ruag has to guarantee the quality of each article delivered to its customers, Rendina says. But to accomplish this cost-effectively, testing must be limited. The company validates its guarantee in several ways. First, it confirms quality and consistency during production of each part. This is especially important during cure. "We diligently pursued, and achieved, a curing process with sufficiently large boundaries from the nominal curing path. We are confident in now having sufficient control parameters to justify the quality of the structure."

Acceptance tests are, therefore, limited to nondestructive inspection (NDI) of the complete shell after cure, plus visual inspections after each postcure operation. NDI is accomplished via a 200-kHz, air-coupled ultrasonic through-transmission with scan resolution adjustable between 0.1 mm and 50 mm. Scan time is about 20 min/m^2. Ostertag supplied the NDI system, which is carried on a robot from Robot Technology GmbH (Grossostheim, Germany). "Further, sacrificial test panels are manufactured together with each composite shell, and samples can be cut out of these panels in-process if material characteristics need to be »

1 & 2 Layup of the fairing cylindrical section inner and outer skin is accomplished on the equipment shown, as described below. Prepreg fabric for layup of the inner skin of the cylindrical shape is automatically rolled out using the semi-automated fabric lay-down machine (shown in the inset), which rides on transport rails that run along the edges of the layout table. Layup on the table is guided by a laser projector system. After layup and compaction, the inner skin is lifted off the tooling table by a vacuum-assisted tool, which transfers the skin to the mold. (*Editor's note:* Because Ruag Space considers aspects of certain early layup steps to be highly proprietary, individual photographs are not available to illustrate Steps 2, 4 and 5.

3, 4 & 5 In parallel to the steps above, the outer skin of the ogive (nose) section of each fairing half is laid down on the dummy mold shown in the upper left background in this photo, and a layer of cork is applied for thermal protection. Meanwhile, the ogive inner skin is layed up manually, directly over the final bonding mold. Aluminum honeycomb core then is arranged over the inner skin of the cylindrical and ogive sections. Then the outer skin of the cylindrical section of the fairing is layed up in the same manner as the inner skin, and transferred over the honeycomb core. Finally, a layer of cork is placed over the outer skin of the cylindrical section.

6 The layup is then transferred to the bonding mold by means of this jig, which incorporates hundreds of small vacuum pads.

measured," Rendina adds. After acceptance, the part is ready for transfer to the Horizontal Integration Station (HIS).

Postcure operations

Before the fairing is mounted on the HIS, two types of separation systems are installed onto this large tool. The separation systems are necessary during flight to separate the fairing horizontally from the launch vehicle, and for separating the payload fairing shells vertically so they can be jettisoned away. When the composite fairing shell is installed into the HIS (Step 8, p. 37), matched holes are drilled in the composite shell and the separation system, and they are connected. (The Ruag separation system consists of hardware that is attached to the fairing to keep satellites or other payloads safely attached to their fairings during the tough journey to orbit and then with precision causes the fairing halves to separate at the right time and delivers the precious loads in orbit with the specified relative velocity, roll and/or spin.)

Next, the fairing sandwich structure edges are trimmed, and other drilling is done for equipment that will be attached afterward. No further machining of the structure's surface is necessary, because it is manufactured and cured to net shape. "We do not do any correction of the geometry after the curing process," Rendina confirms.

The fairing is then moved to the machining station (Step 9, p. 37), where

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

Read more online about the Ruag partnership with ULA and other developments in the realm of private-industry space systems manufacturing in "The emerging commercial space industry" | short.compositesworld.com/CommSpace

7 The complete sandwich structure and thermal protection is vacuum bagged and the bonding mold is moved into a large oven for cure. The cured shell is lifted off the mold by another jig fitted with vacuum pads and transferred to the inspection station. There, the cured shell is inspected by means of air-coupled ultrasonic through-transmission non-destructive inspection (NDI) equipment.

8 The fairing shell is then mounted on the Horizontal Integration Station tooling for post-cure operations, including installation of the separation systems previously installed on the HIS.

9 Two views of the ergonomic workstation, designed for worker safety and comfort, in which mission-specific equipment and devices are installed.

Source (all step photos) | Ruag Space

access doors, venting devices and other mission-specific equipment is installed. Designed for best ergonomic operation, the machining station permits rotation of the fairing so the operator always works in a safe and comfortable position.

The finished fairing is painted *white* for thermal reasons, Rendina says. "The launch vehicle stays on the launch pad for many hours, sometimes under sunlight, and it gets very warm, so we need the white color to keep the ground temperature of the fairing structure as low as possible."

A practical compromise

Today, the volumes demanded in commercial aerospace and, especially, automotive production, are dictating that composites manufacturers who serve those markets pursue greater automation and necessarily, therefore, face greater difficulty in meeting both part performance and customer cost goals. But ULA and Ruag's flexible, semi-automated OOA compromise between the extremes of hand-laid, autoclaved prepreg and fast but size-limited automated tape laying or fiber placement avoids artificial limits and better fits space industry realities. For the small volumes typically contracted in the space market, it's an efficient process that permits builds of launch vehicles beyond conventional bounds yet does much to keep *costs* within customer boundaries. CW

ABOUT THE AUTHOR

Donna Dawson is *CW*'s not-quite-retired senior writer emertius, who now resides and still writes in Lindsay, CA, US, in the foothills of the Sierras.
donna@compositesworld.com

Composites Events

Jan. 23-24, 2017 — Paris, France
ICCM Paris – 19th International Conference on Composite Materials
waset.org/conference/2017/01/paris/ICCM

Jan. 23-26, 2017 — Cocoa Beach, FL, US
41st Annual Conference on Composites, Materials and Structures
advancedceramics.org/events/2017/01/23/conference/41st-annual-conference-on-composites-materials-and-structures

Jan. 23-26, 2017 — Charleston, SC, US
37th High Temple Workshops
hightemple.udri.udayton.edu/Pages/default.aspx

Feb. 28-March 2, 2017 — Moscow, Russia
Composite-Expo
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Feb. 28-March 2, 2017 — Houston, TX, US
HOUSTEX 2017
houstexonline.com/HT17AEM2

March 6-9, 2017 — Ft. Worth, TX, US
AeroDef 2017
aerodefevent.com

March 13-15, 2017 — Beverly Hills, CA, US
SpeedNews 31st Annual Commercial Aviation Industry Suppliers Conference
speednews.com/commercial-aviation-industry-suppliers-conference

March 14-16, 2017 — Paris-Nord Villepinte, France
JEC World 2017
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May 16-17, 2017 — Stade, Germany
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May 22-25, 2017 — Anaheim, CA, US
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The Future of Composites in Construction
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June 27-29, 2017 — Orlando, FL, US
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July 4-7, 2017 — Bologna, Italy
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July 17-20, 2017 — Ottawa, ON, Canada
CANCOM 2017
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Aug. 20-25, 2017 — Xi'an, China
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iccm21.org

Sept. 11-14, 2017 — Orlando, FL, US
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thecamx.org

Sept. 12-15, 2017 — Husum, Germany
HUSUM Wind 2017
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ICOLSE – 2017 International Conference on Lightning and Static Electricity
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Hybrid steel/composite transmission gears

Scalable gear design trims heavy-truck weight, preserves wear life, controls cost

A diversified supplier of hydraulic and electrical components and systems for a wide range of industries, Eaton Corp. (Dublin, Ireland) also specializes in composite powertrain and drivetrain components for cars and heavy trucks. It has spent more than a decade developing hybrid metal/composite technologies, such as the carbon fiber-reinforced plastic (CFRP) overmolded steel differential carrier showcased in this issue's Focus on Design feature (p. 44). But Eaton has taken the technology to another level in hybrid steel/composite gears for heavy-truck transmissions.

A unique feature of this design approach is that it is *scalable*. That is, it is relatively easy for Eaton engineers to increase composites content in the part to meet lightweighting requirements or to shift to greater metal content to reduce part cost, depending on the customer's specifications and budget.

"Both the gears and differential carrier are challenging applications," says Kelly Williams, manager for polymer and nanocomposites materials and processing technologies at Eaton's Corporate Research & Technology Center (Southfield, MI, US). "The approach we used is similar for both, but the designs are a little different. For example, gears are subject to higher loads but lower torque, whereas differential housings are opposite — lower loads but higher torque."

The hybrid gears, then, feature steel in the teeth and hub. "Loading is primarily through the gear teeth, which are also the wear surfaces," Williams says, "so it makes sense to use steel here."

A mix of glass and carbon fiber is used in the flat disc portion of the gear (see photos at left), molded between the metal teeth and interior hub. She notes that a steel/carbon fiber-reinforced composite gear (like the top photo at left) can reduce gear weight by as much as 40% compared to a standard all-steel gear.

Achieving a strong bond between the composites and metal is key in hybrid material applications. Williams' team avoided the use of adhesive in Eaton's differential carrier by grit-blasting the metal surface to increase the opportunity for mechanical bonding. However, adhesive became an important component at the composite/metal interface in Eaton's hybrid gears.

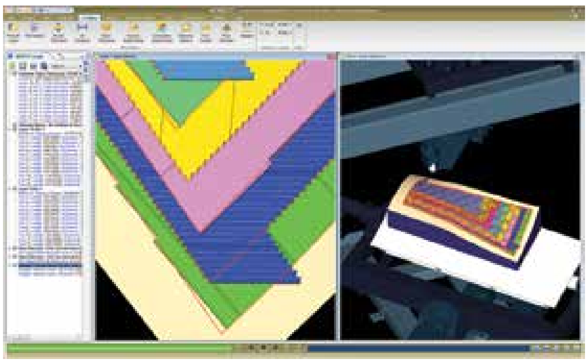
"These were different because we had a sandwich of steel teeth, steel hub and composite in between," says Williams. "So coefficient of thermal expansion [CTE] became more of an issue, with the steel expanding into the composite." The adhesive, she explains, absorbs the inevitable thermal expansion and accommodates the CTE difference between the two materials.

"There is also a difference in loading between the two applications," Williams adds, noting that "in the gears, the load is on the teeth while the composite is stationary, so there is a shear load that the adhesive also helps to address. There is no such shear in the differential — the composite and steel receive the same type of load, though the steel carries a different level or magnitude of loading."

During development, Eaton's hybrid gears were subjected to cyclic temperature testing, frequency loading to simulate vibration and dynamometer testing. The latter involved an engine test rig that measures torque and rotational speed, with periodic inspections for debonding at the steel-to-composite joint. The hybrid gears showed no debonding and achieved 100% qualification. CW

Editor's note: Similar hybrid gears have been deployed for helicopter transmissions | **short.compositesworld.com/HeliGears**

New Products



» VIRTUAL SIMULATION & TESTING SOFTWARE

Composites programming, simulation program update

CGTech (Irvine, CA, US) is now shipping the latest release of VERICUT Composite Applications: VERICUT Composite Programming (VCP), VERICUT Composite Simulation (VCS) and VERICUT Composite Paths for Engineering (VCPe). VERICUT Composite Applications are being used to program and simulate automated fiber placement and tape-laying machinery from machine tool builders that include Electroimpact, MTorres, Fives and BA Composites. New features in version 8.0 include enhanced support for AFP/ATL hybrid machines, more ways to use laser inspection data, display of detailed scrap calculations, and other analysis tools. VCPe gives the user the ability to measure and evaluate the effects of AFP and ATL path trajectory, material steering, surface curvature, course convergence and other process constraints as they would be applied in manufacturing. The software also provides produceability analysis of the fiber angle, based on the curvature of the part, and overlap and gaps needed for structural analysis. Tape course geometry can be written to various CAD formats for further evaluation by the user's analysis methods and tools. VCP reads CATIA V5, STEP or ACIS surface models. It also reads Fibersim, CATIA V5 or other external ply geometry and information. VCP then adds material to fill the plies according to user-specified manufacturing standards and requirements. Layup paths are linked together to form specific layup sequences and are output as NC programs for the automated layup machine. VCS reads CAD models and NC programs, either from VCP or other composite layup path-generation applications, and simulates the sequence of NC programs on a virtual machine. Material is applied to the layup form via NC program instructions in a virtual CNC simulation environment. The simulated material applied to the form can be measured and inspected to ensure the NC program follows manufacturing standards and requirements. A report showing simulation results and statistical information can be automatically created. www.cgtech.com

» METER/MIX/DISPENSE EQUIPMENT & ACCESSORIES

Adhesive/sealant dispensing system

Fluid handling products and systems manufacturer **Graco** (MInneapolis, MN, US) announced that its trademarked Hydraulic Fixed Ratio (HFR) metering system improves throughput and significantly reduces waste and rework in adhesive and sealant dispense applications by providing accurate, on-ratio dispensing and consistent material flow. The meter, mix and dispense system is capable of processing multiple sealant and adhesive materials. The metering function, the company says, consistently delivers accurate ratios and volumes. Additionally, as the system dispenses material, it automatically fine-tunes and adjusts material flows and pressures on the go to achieve a consistent bead. As a result, users reportedly waste less material, reducing rework time and material costs. The system's horizontal pumps can be rebuilt directly at customers' facilities, eliminating costly rebuilds and the need for backup pumps. As a result, the system is said to suffer less downtime, accrues less in maintenance costs, and requires a smaller parts inventory than competing systems, leading to a lower total cost of ownership. The system's intuitive, easy-to-use controls enable users to program as many as 100 different shot sizes and easily configure temperature control. In addition, the system gives users immediate access to data about material use, pump cycles and errors. The system's USB drive allows users to download process data and error logs for further analysis, contributing to increased efficiency and, therefore, throughput. Proprietary algorithms and adaptive technology enable users of the Graco HFR Metering system to reach a new level of material dispensing precision; the system is capable of producing either a constant pressure material output or a constant flow rate material output. www.graco.com/HFRG

» MOLD RELEASE & CLEANING PRODUCTS

HAPs-free mold release

Chem-Trend (Maisach, Germany), a manufacturer of high-performance release agents, purging compounds and other ancillary molding products, has announced additional health, safety and environment (HSE) benefits for its Chemlease EZ Series product line, including semi-permanent sealers, release agents and cleaners for all composites applications worldwide. The EZ Series already complies with the US Environmental Protection Agency's (EPA) National Emission Standards for Hazardous Air Pollutants (NESHAP), which aims to further reduce hazardous air pollutants (HAPs) that are known or suspected to cause cancer or other serious health effects. In the coming months, EPA's NESHAP initiative will expand with tighter compliance monitoring, Europe's Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) standards will include updated regulatory lists, and Thailand's emissions efforts are also expected to increase. www.chemtrend.com

» POLYMER MATRIX MATERIALS

Epoxy intermediates

Dow Automotive Systems (Auburn Hills, MI, US) has developed VORAFUSE epoxy intermediates, which, when combined with carbon or glass fiber fabric, are said to offer improved handling and rapid cycle times for compression molding of composite parts for structural applications. Commercialized on a front roof header in 2016, VORAFUSE is designed to work in processes such as compression molding to achieve fast cycle times. It can be cured in 2-5 minutes for high-volume manufacturing and can be used to enable automated manufacturing solutions. A variety of fabric configurations will accommodate VORAFUSE, including unidirectional tape as well as woven, braided or non-crimp fabric in a range of areal weights. Available in two grades, the VORAFUSE P6300 resin system is designed for high-volume manufacturing with no tack for robotic handling of 2D and 3D preforms and compression molding. VORAFUSE P6100 is formulated to accommodate diverse manufacturing scenarios from autoclave to out-of-autoclave processing on lower-cost tooling for medium- to low-volume applications.
www.dowautomotive.com

» VIRTUAL SIMULATION & TESTING SOFTWARE

Virtual prototyping software updated

Virtual prototyping software and services developer **ESI Group** (Paris, France) has released its PAM-COMPOSITES 2016 software solution. It reportedly provides design and process engineers with its full suite of modules to predict, analyze and correct manufacturing defects of composite structural components across the manufacturing chain. The solution combines ESI Group's existing modules with new enhancements that enable users to identify the origin of defects and then manufacture composite parts with what is said to be a higher degree of accuracy, while reducing material waste and obviating the need for costly and time-consuming trial-and-error approaches. Using the ESI PAM-COMPOSITES solution, users can tailor simulations to the exact nature of the composite material and to their shop floor environment, thus improving process stability and reducing manufacturing defects in products produced in a range of composites manufacturing processes that include draping, thermoforming, liquid composites molding (LCM), resin transfer molding (RTM), automated fiber placement (AFP) and automated tape laying (ATL). In PAM-COMPOSITES 2016, the newly introduced design of experiments (DOE) functionality automatically analyzes variations in the composite material and manufacturing process parameters to enable users to optimize key influencing parameters and improve process stability. The new Die Spotting functionality can automatically morph existing tools to ensure contact with the part. This avoids the bridging effects often seen with thermoformed organosheet components where resin migration and lack of compaction lead to visible defects. It also enables engineers to avoid the incidence of areas with low fiber content or "racetracking" during resin injection or infusion. PAM-COMPOSITES also brings together the PAM-FORM, PAM-RTM and PAM-DISTORTION modules into one bundle. www.esi-group.com/software-solutions/virtual-manufacturing/composites

» PROCESS CONTROL SOFTWARE & SYSTEMS

Model-based waterjet software

Ultrahigh-pressure waterjet machining system manufacturer **Flow International Corp.** (Kent, WA, US) has announced the release of FlowXpert 2016 waterjet machining software, a CAD/CAM waterjet software platform for 3D pathing and cutting that enables users to work more effectively in 3D, with less complexity. The software integration was engineered in partnership with ANSYS SpaceClaim and is said to realize the full advantages of Flow's more than 40 years of waterjet application expertise. Incorporating waterjet best practices — such as application tips, material cut speed knowledge, improved pathing algorithms, and expanded lead in/out customization — the program anticipates what steps are needed to provide a premier cut. Integration with the CAM Flow Sequencer module lets users design a part and path it in the same program. Modifying the geometry of a part is possible without losing the path, and the integration with Flow Sequencer will automatically update the path to accommodate the changes. FlowXpert 2016 also will detect model and path errors and suggest fixes.
www.flowwaterjet.com

» FIBERS & FIBER REINFORCEMENT FORMS

Recycled composite material

Sigmatex (Runcorn, UK) has developed a new carbon fiber composite material within its sigma RF product range. Primarily aimed at the automotive industry, it is a blend of polypropylene fibers (55%) and carbon fiber (45%). Sigmatex says 85% of the fibers are aligned, which the company says provides superior mechanical properties when compared to other recycled materials. Sigmatex also has developed a polyamide version of the material. Sigmatex reports that sigma RF enables the complete manufacture of a noncrimp fabric by reformatting surplus virgin carbon fiber. Targeted applications and end-markets include automotive, sports, leisure and energy.
www.sigmatex.com

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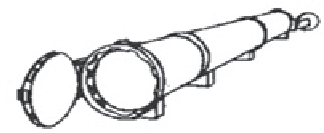

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SHOWCASE

Metal + composite = Less weight, more room

Global supplier develops scaled design approach for metal/composite hybrids in highly loaded automotive applications.

By Ginger Gardiner / Senior Editor

FIG. 1 Making the multi-material vehicle a working reality

This prototype steel and CFRP differential carrier is one example of Eaton's "scaled" design approach for the mixing of materials — one in which the ratio of metal to composite can be adjusted per part and program requirements.

Source | Eaton Corp.

» A diversified supplier of hydraulic, electrical and vehicle components and systems for industrial, aerospace, automotive, marine and other mobility applications, Eaton's (Dublin, Ireland) products include pumps, motors, valves, cylinders and filters, as well as the connectors and fittings necessary to integrate these into efficient solutions. In cars and heavy trucks, Eaton supplies everything from transmissions, traction control devices, superchargers and engine valves to fluid conveyance, fuel vapor management products (e.g., canisters) and plastic components. It has been developing a variety of metal-composite hybrid parts that reduce weight and provide a range of other benefits.

In a paper presented at SAMPE 2016 (May 23-26, Long Beach, CA, US), Kelly Williams, manager for polymer and nanocomposites materials and processing technologies at Eaton's Corporate Research & Technology Center (Southfield, MI, US), discussed the design and manufacturing development of a steel and carbon fiber-reinforced thermoplastic differential carrier (Fig. 1, above).

Scalable mix of materials

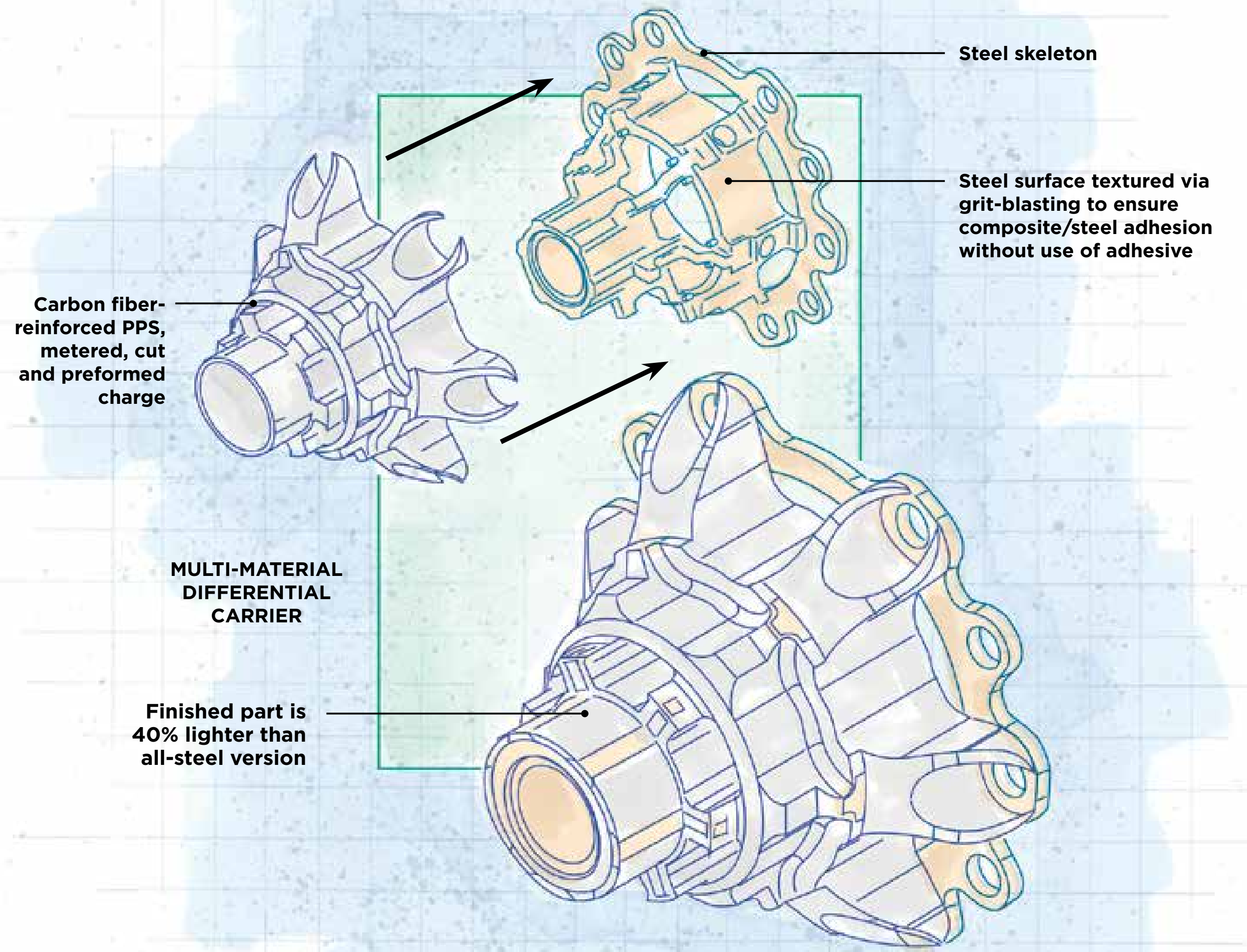
With a background in polymers and composites, Williams' 10 years at Eaton have been focused on how to get more composites into its products. Because the most attractive targets are parts that must endure heavy-duty loads and wear, her job is fraught with challenges. A differential, notably, distributes torque to an automobile's drive wheels. Its name derives from its ability to allow drive wheels linked to a *single* engine and transmission to spin at *different* speeds when a vehicle is turning. The outer wheel travels a longer distance than the inner wheel, and so must turn faster. "Differential housings are high torque and high load-bearing applications," explains Williams. "Using an all-composite construction would not be as durable as cast iron or steel. Thus, the challenge was, how can I match the current long-term durability and performance while saving weight with composites?"

Eaton's response was to develop a design approach for the mixing of materials that can be scaled per part and program requirements. "We can use more composites for lighter weight, but this is also higher cost," Williams explains. "So we have the alternative to scale back the amount of composites, use a little more steel and remain cost neutral. This is what we finalized for this project."

Why steel and not aluminum? Williams' team evaluated aluminum, steel and composites (glass *and* carbon fiber) in terms of stiffness and strength per weight (i.e., *specific* stiffness and strength), as well as cost per meter cubed. "Carbon fiber composites and steel offered the highest specific properties and lowest cost per volume of material," Williams reports.

To decide where each material should be used, Williams' team performed topology optimization analyses, using Optistruct from Altair Engineering Inc. (Troy, MI, US). "That is how we developed the load transfer design," says Williams. "Very high load and torque goes through a steel frame, and medium-level loads go through the composite overmolding."

Steel also is used where there can't be any deflection. Williams explains that the differential housing holds pinions and gears: "Shafts go through it, so I have to control the housing dimensions. I can't have creep or warpage, so I put steel in those areas which



DESIGN RESULTS | **Eaton CFRP Overmolded Steel Differential Carrier**

- The multi-material part — a skeletal steel component overmolded with a carbon fiber-reinforced composite — reduces finished part weight by 40% vs. a legacy cast-iron design.
- Increased strength enables 10% diameter reduction, allowing potential downsizing of axle and axle housing, freeing up package space and reducing overall chassis weight.
- Attachment between dissimilar materials performed in mold without adhesive or secondary operations, achieves 100% qualification in performance and long-term durability tests.

Illustration / **Karl Reque**

locate other parts, for example where gears have to mesh." She points out that those were machined locations in any case, "so we left them metal, and we also left wear surfaces in steel to maintain long-term durability."

Williams notes that this design approach could also be used for other Eaton products, such as pump housings and transmission casings. In fact, Eaton already has prototyped a number of hybrid metal/composites applications, such as transmission gears (see this month's Applications story on p. 39, and see Learn More).

CFRP overmolded steel skeleton

The final differential carrier design comprises a steel skeleton overmolded with carbon fiber-reinforced polyphenylene sulfide (PPS), the latter from thermoplastics supplier Celanese (Dallas, TX, US). The tradenamed FORTRON bulk molding compound is reinforced with fibers roughly 2.5 cm long and processed by Williams' team in a compression molding press (Fig. 2, p. 46). "We bolt the steel skeleton to the press, put in the hot-melt compound and overmold." Skeleton placement on the bottom enabled good, »

FIG. 2 Manufacturing a hybrid differential carrier

The steel skeleton is bolted to the bottom platen of a compression molding press (left). A metered, cut and preformed CF/PPS bulk molding compound charge is then placed on top and molded onto the steel skeleton (right). Source | Eaton Corp.

concentric flow. The extruded charge placed onto the skeleton had already been metered, cut and preformed to shape.

Williams points out that because the differential is intended for passenger cars and light trucks — high-production-volume vehicles — the cycle time must be limited to minutes. "The exact requirement depends on the platform we're producing the differential for, and how many machines we have available to run the part."

The finished part not only cut weight but also reduced the differential diameter by 10%. "A reduction in diameter reduces the overall package size," says Williams. The differential has to fit inside an axle and axle housing. Although Eaton only makes the differential, Williams notes that potentially reduced size here could cascade to downsize other parts, including the axle, axle housing and, eventually, the entire chassis.

LEARN MORE

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

Read more about Eaton's hybrid metal-composites prototypes in the online Side Story to this feature article titled, "Metal + Composite: History of hybrid part prototypes" | short.compositesworld.com/EatonSS

Read "Saving Pounds with Plastic-Metal Hybrids" in sister publication Automotive Design & Production online | short.compositesworld.com/PMHybrids

Read about IACMI online in its *CW SourceBook* showroom online | compositesworld.com/suppliers/INSTITUTEF and in "IACMI starting to walk the talk" | short.compositesworld.com/IACMI16

The weight reduction effect is similar. Williams explains, "For a small passenger car differential, using carbon fiber composites, we can save roughly 5 lb (40%), and we can cut 12-14 lb (40%) for a light duty truck. This could also cascade through, because the axle would not have to support as much weight and the chassis could also be lighter." This could then impact wheels and suspension components.

Design/test of a robust bond

Eaton realized early on that one of the key challenges to multi-material designs is making sure the bond between the metal and composites is robust. To that end, it conducted cohesive zone modeling analyses with the University of Michigan (Ann Arbor, MI, US) to examine the metal/composite interfaces and predict the behavior of the structures in an effort to identify potential vulnerabilities.

Williams continued forward from this work, trying to minimize the amount of processing required to achieve attachment between the reinforced plastic composite and the steel. "We didn't want to use adhesive in an extra step after molding the CFRP," she explains, "so instead, we sought to bond during the molding process." Her team then pursued mechanical interlocking in place of chemical bonding. They evaluated three options to increase surface area and encourage mechanical interlock: drilling holes in the steel, dimpling the steel and texturing the steel with grit blasting.

"It was decided that the through-holes provided a significant risk of decreasing the strength of the metal frame, of increasing the potential to initiate stress cracking, and would also be a high cost to machine," Williams recalls. "This left the dimpled and textured methods." Stress analysis revealed that the textured

FIG. 3 Overmolded hybrid makes the grade

Eaton's CFRP-overmolded steel differential carrier passed both cyclic temperature and vibration testing (left) and dynamometer testing (right) to achieve 100% qualification. Source | Eaton Corp.

samples, prepared via grit blasting of the steel prior to overmolding, provided twice the target performance at the lowest manufacturing cost.

Williams' team tested the steel-to-composite bond by subjecting the overmolded differential to cyclic temperature testing, examining whether or not thermal expansion would have a deleterious effect on long-term performance or durability. They also applied a frequency loading to simulate vibration, up to a maximum of 50 times the acceleration of gravity. Combining the cyclic temperature and vibration testing in a process dubbed "shake & bake" (Fig. 3, above left), Eaton inspected the differential at set intervals for delaminations and found none.

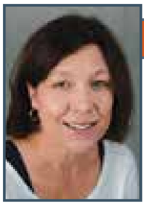
Eaton also subjected the differential to dynamometer testing (Fig. 3, above right). Used to measure the output of an engine, a dynamometer monitors torque and rotational speed. "Though we don't subject this test rig to temperature differences, it does generate heat during the testing," says Williams. Again, the test piece was inspected regularly, looking especially for debonding at the steel-to-composite joint. And again, the part experienced no debonding and achieved 100% qualification.

Manufacturing prove-out, new opportunities

Although Eaton's success makes this development appear easy, it is important to point out that the work began in 2011. "We are re-evaluating this program now for commercial scale-up and viability," says Williams, adding it is one of the projects that Eaton is pursuing through the Institute for Advanced Composites Manufacturing Innovation (IACMI), the public/private US composite materials and process development consortium with centers in Knoxville, TN and Detroit, MI, US (see Learn More). "We took this program to TRL 4," adds Williams, noting that the goal now to is scale it up through manufacturing, and that work at IACMI is targeted to begin this month.

One notable change will be a move away from a thermoplastic to a thermoset composite, in collaboration with Eaton's partner Dow Automotive Systems (Auburn Hills, MI, US). The original motivation behind thermoplastics was to achieve the required complex geometry in a low cycle time molding process. However, Williams explains, "We had issues with the thermoplastic's stiffness and being able to control the dimensional stability." She believes that Dow will be able to meet cycle time requirements while offering necessary improvements in part performance.

"We've proven that we can develop a range of hybrid-material part solutions and that these parts can handle drivetrain loads," says Williams. Once the next phase of validating and scaling hybrid manufacturing processes is completed, Eaton's expansive reach into vehicle and industrial applications should provide an exciting new realm of opportunities for composites. CW



ABOUT THE AUTHOR

CW senior editor Ginger Gardiner has an engineering/materials background and more than 20 years in the composites industry.
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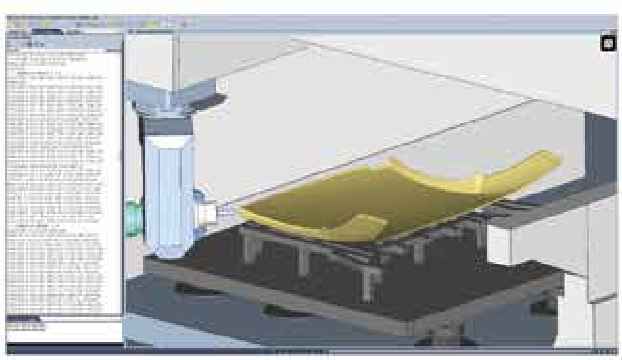

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