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Structural Adhesives, Part II: AEROSPACE ADHESIVES — UNSEEN, EVERYWHERE, *INDISPENSABLE*

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DEPARTMENTS

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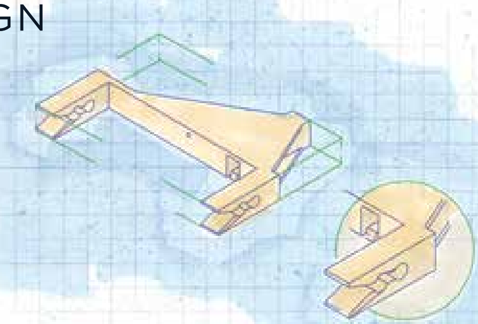
ON THE COVER

Although metallic fasteners are required for redundancy in structural joints, structural adhesives are a necessity for many aerospace bonding applications, especially as composites-intensive aircraft like this Boeing 787 increase in numbers in air carriers' commercial aircraft fleets. Adhesives also function uniquely in special applications as shims and surfacing films for lightning strike protection. Read more on p. 96.

Source / The Boeing Co.

FOCUS ON DESIGN



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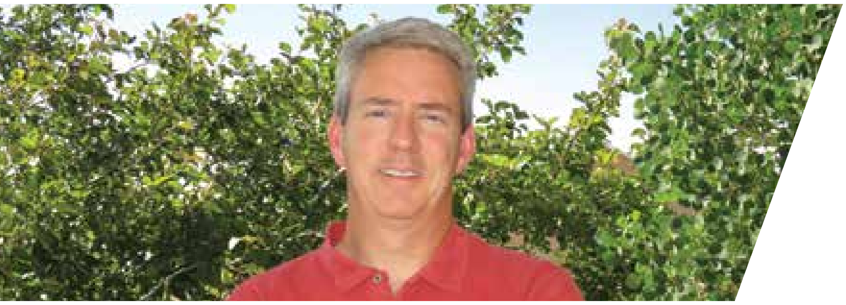


It's mid-August as I write this. Most of my family (three students and a teacher) is headed back to school, signaling, sadly, that summer — although not technically over until the solstice, more than a month away — is rapidly coming to an end. And this means that the Jeff Sloan 2016 End of Summer Book Report is due.

Jeff Sloan's 2016 End of Summer Book Report

I read several books this summer, but three stood out to me as particularly compelling and, even if not overtly related to composites (as we know them), focused on the creative application of design engineering and materials to achieve a specific goal. Which qualifies them as fodder for my report:

***The Wright Brothers*, by David McCullough.** McCullough, a well-known chronicler of major events and people in American history, has earned a reputation for careful, detailed research. *The Wright Brothers* fits this mold well and documents Wilbur's and Orville's struggles to develop an aircraft that could sustain human flight over (for the times) a very long distance. Several things struck me: First, the brothers willingly and frequently put themselves at great risk to fly their planes. There were crashes too numerous to count, ranging from low-altitude/low-speed types to spectacular higher-altitude calamities that could easily have killed one or both. Second, the brothers' sister, Katharine, deserves as much credit for supporting and encouraging them as Wilbur and Orville do for launching the age of human flight. Third, looking back on how much they struggled to develop those first planes, it seems incongruous that human flight has become as advanced and … common as it has become. The Wright brothers themselves had a difficult time appreciating the breadth of industry and innovation their achievements would launch, and certainly never thought trans-oceanic flight would be possible.

***The Arsenal of Democracy*, by A.J. Baime.** The phrase "arsenal of democracy" was coined by President Franklin Roosevelt in a speech he delivered on Dec. 29, 1940, in which he demanded — foreseeing that the US would eventually enter World War II — that the American manufacturing community become a *military* manufacturing community to "outbuild Hitler." The book focuses on the effort, led by Edsel Ford (son of Henry), to have Ford Motor Co. build a new factory near Detroit to produce badly needed B-24 *Liberator* bombers to aid England, which was being pummeled by the German Luftwaffe. Edsel, perhaps naively, promised that the Willow Run plant would produce one bomber every hour (which it eventually did). What makes this story remarkable is not that the B-24 helped save England and win the war, it's that Willow Run made a single plane at all. Edsel and his team had to overcome a litany of obstacles: Edsel's chronic health problems, bizarre and complicated resistance from Henry Ford, an overwhelming number of ongoing design engineering changes, racial tensions, labor shortages, corporate betrayal and material shortages, any one of which — alone — could have crippled the effort.

***The Martian*, by Andy Weir.** If you were like me, you saw *The Martian* on the big screen before you read the book, and if you were like me, you were glad you read the book. The premise is simple: American astronaut Mark Watney is stranded on Mars and not only has to survive for hundreds of sols (days), but eventually launch himself off the planet to hitch a ride back home. The big takeaway from the book is that Mars is immensely inhospitable to human life — the number of life-threatening risks are too numerous to count. Watney, however, is armed with good humor and a solid base of scientific knowledge, both of which get him out of many a scrape. But I learned from this science-based work of fiction that whoever finally makes a real-life excursion to Mars is going to be surrounded by composite materials — in suits, in habitats, in vehicles — because their high strength and low weight will be a priceless combination.

What stitches these three books together is simple: Endurance, persistence, hope, optimism and uncommon intelligence and creativity to solve really difficult problems.

It was a good summer.

JEFF SLOAN — Editor-In-Chief

History, myths and urban legends of pultrusion

» Sometimes we see new things when looking back. In 1881, a patent was issued for a process that used natural sunlight for UV cure to make artificial leather. This seems quite similar to pultrusion without a curing die, much like the oven-cured and UV-cured pultrusions of today.

In the mid-1940s and early 1950s, as the availability of thermoset resins increased, many industrious minds worked to take advantage of new possibilities. With no Internet available to enhance communications, we can see that the same end goal was reached by independent activities. As a result, several patents of pultrusion-type processes were granted during these early years.

The earliest clue to the "birth" the pultrusion process that I've found is the patent by J.H. Watson in 1944 for "Manufacture of a string or the like," #2,419,328. Then, in 1950, M.J. Meek filed his "Method for fabricating a glass rod," #2,684,381. Rodger White, in 1952, filed his patent, #2,818,606, for "Manufacture of articles from thermosetting materials." These were followed by W.R. "Brandt" Goldsworthy in 1953, with his patent #2,871,911, titled "Apparatus for producing elongated articles from fiber reinforced plastic material." Refinements and variations of the pultrusion process continue to this day.

The reverse forming guide

Also called a constant velocity guide, this device was developed to eliminate wrinkling and reduce stretching of wraparound fibrous mats as they were continuously applied, with single, lengthwise seams, prior to entry into the pultrusion die. The mat flows up through the flat portion in the foreground, around the corner (thus the name "reverse forming") and then gradually takes the intended cylindrical shape, encasing the continuous fiber stream as it passes through the guide's forming tube. Source | David Green

Many stories of pultrusion development have been told. One I heard is from the old-timers who worked for Glastic Corp. (Cleveland, OH, US). Glastic was the first to provide commercial pultruded products into the marketplace, so the story might have merit. Its process pulled resin-impregnated fibers into an open die and then, while the fibers were stationary, the die was closed and the impregnated fibers were cured. The mold then opened to permit the machinery to pull the cured section of the materials stream from the mold and pull as yet uncured materials into it. This was a stop-and-reset process in which the parts were separated farther down the line. According to this story, on a line that was making a rod-like shape one day, the operator got lazy (or inventive?) and didn't open the die but rather just pulled the new material into the mold while it was still closed. It worked! So this procedure was perfected and then used to make products sold into the marketplace.

Eventually, Rodger White, a founder and owner of Glastic, wrote his patent, mentioned above, which described this *intermittent* pultrusion method as a *pull-and-purge* process. A president of another company told me that, because of that patent, his company, also an early pultruder, had to close its doors to outsiders and claim that they only did *continuous* pulling and *didn't* purge (with the materials of the day, *very* unlikely).

> Many interesting stories have been told about the early days of pultrusion. Some of them are true.

Another story reportedly occurred in Chicago, where a particular group of pultrusion pioneers had worked for several days to get a small part to run. One day, the part was finally processing and the staff, concentrating its attentions on supporting and maintaining the fragile process conditions and *not* watching the end of the line, shortly thereafter heard a city cop knocking at the shop's door. It seems that the part had got out a window, gone over the building next door and was now blocking traffic on the next street over! This is quite believable, because I have seen and heard of unattended machines having similar consequences when an automated cut-off failed.

Raw materials have progressed mostly by adapting products made for other uses. We need to thank the Alaskan oil pipeline for our pultrusion mat. I recall the mats that were first available to pultruders were fluffy and weak and would not work for today's profiles. To insulate the pipeline so that it didn't melt the permafrost and sink, Owens Corning (Toledo, OH, US) developed a mat to wrap the pipeline. When the pipeline was completed, the machines and capability were available. Somehow, that capacity and the pultrusion industry found each other. That's how today's continuous strand mat was born.

For years there seemed to be a West Coast way and a Midwest way. Sometimes they copied each other; sometimes they shared ideas; and sometimes they hid the same secrets. I recall expanding on a West Coast idea for use in the Midwest: It was a mat-forming guide for a tube. My first encounter in the early 1970s with a somewhat similar guide was from a description and photograph of guides made by Goldsworthy. Those guides provided for one mat to wrap around the part circumference with only one seam running the length of the parts. (We had been doing this on very inside mats, but not on mats with other mats beneath them). In the Goldsworthy designed guide, the mat came from behind the guides in a plane oblique to »

the material direction and did place a layer on the outside of the product. They were a step above others that were in use. Because mat will stretch and fabric will wrinkle, they were quite long. The extra length allowed for forming with more *uniform* mat stretching and reduced the mat's tendency to wrinkle. These guides did allow for one circumferential mat to enter the raw material stream and form with other materials beneath them, but problems remained.

I was at Pultrusions Corp. (Aurora, OH, US) at the time and Hugo, the toolmaker, was a very talented person with more than 60 years' experience (he went on to provide tooling for others, and I don't think that he stopped until he was around 100). He duplicated Goldsworthy's guides, but the fact that they permitted mats to stretch was ultimately undesirable. Setting out to correct that, I took a piece of paper the width of the mat, formed one end into a tube and found that the paper had a tendency to naturally curve, going back on itself to form the round, tube-like shape. When I took this formed paper to Hugo and asked if we could do *this*, he used his genius to turn that concept into metal and made a guide for mats that was extremely effective. I called it a *reverse forming* guide (see photo, p. 6) because the mat enters the guide through the flat portion, goes around the corner and enters the round portion, encircling, in the process, the continuous fibers and other reinforcements that are already gathered together and passing through the guide. Others have called it a *constant velocity* guide, which is a pretty good title because the "path" the mat travels through the guide, as it changes from flat to circumferential, remains at a constant width regardless of its shape, and this helps reduce the mat's tendency to distort or stretch as it travels through the guide.

In the early days, every raw material salesman or engineer that first saw those guides said that they were the cause of all problems. As time passed, they became the *standard* guides and were promoted by those same people.

One of the best-formed guides of this type was made overnight by a sewing machine guide maker in Missoula, MT, US. With nothing more than my spreadsheet calculations for the blank and a smaller guide to look at, he was able to make a finished, working model. This shows that if we use the fabrication expertise readily available to us today and take the initiative to search for improvements, we can write tomorrow's history and, perhaps, provide tomorrow's legends. CW

ABOUT THE AUTHOR

David E. Green (Aurora, OH, US) is a consultant with 47 years' composites experience within the engineering arena of the pultrusion field and currently serves as application/development engineer for Tencom Ltd. (Holland, OH, US). He is the inventor on several patents oriented towards pultrusion and the composites industry, and has provided expertise in the development of materials, products and methods. Green can be reached at **gdavidegreen@aol.com**.

The power of personal connections

» There's a classic line out there in cinema, that goes something like, "Hey, I know this guy who knows a guy…." It's usually uttered when the speaker is helping someone out of a predicament, and is often associated with something illegal, or at least embarrassing. There's another line: "It's not what you know, but who you know." This adage implies that it's more important to be connected than it is to be competent.

It's unfortunate that the above lines have negative connotations. Although I believe competence is essential to doing a good job, knowing where to go when you need an answer or have a thorny problem to solve, is critical. For the most complicated of problems, knowing someone who can help, or knowing someone who knows someone who can help, makes us all more valuable to our organizations and our customers. While our internal colleagues are often good resources, going outside to get additional perspectives or specialized knowledge can accelerate the solution-finding process and can result in a better solution. In a global world, where the right answer may lie halfway across the planet, one of the most valuable assets any of us can possess is a strong professional network. This is as important in the world of composites as in any industry.

> "Old-timers" need to figure out a better way to connect to the generations that are entering the workforce.

I personally am fortunate to be connected to a large number of people within the composites industry across a number of countries. I have worked for companies that required (or better, allowed) me to travel extensively across the US and internationally, and to work in Europe for almost two years in a role that entailed significant travel. I have amassed many contacts over the years — and have boxes of business cards to show for it.

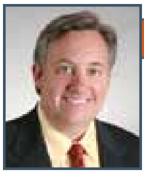
I realize not everyone gets such an opportunity. But there are other routes to connectivity. At least as significant in terms of impact on my network has been my participation in professional societies, in particular the Society of Plastics Engineers (SPE, Bethel, CT, US) and the Society for the Advancement of Material and Process Engineering (SAMPE, Covina, CA, US). Any of us can take advantage of what these societies offer — local, national and international scientific conferences, exhibitions and networking platforms — simply by signing up as a member and attending. But the real benefits come from *participating* in this kind of organization at a deeper level, by presenting at conferences, or serving as a session chair, on a conference committee or as a board member. These activities have served me very well.

Despite the value such organizations provide, membership in professional societies globally has declined substantially over the past decade, and the average age of members has increased. Clearly, young engineers and scientists are not joining at the rate previous generations have done. Several theories have been proposed to explain this decline, including that, in the interest of cost reduction, companies have been less willing to pay the annual membership dues, and that younger professionals rely extensively on social media to interact with others. I, too, use tools such as LinkedIn and Twitter, but they are poor substitutes for face-to-face and telephone interaction when looking for an answer or a solution.

The Internet, on the whole, has contributed to our ability to "self-diagnose" many problems, including those involving scientific questions, or to find suppliers of particular products or solutions, and some would argue that a strong network is not as important as it used to be. Until, of course, it *is* important. Although there are dozens of Web sites that provide medical advice, we don't trust ourselves to perform our own surgery! Sometimes, external expertise and training are — literally — just what the doctor ordered.

It's also clear that we "old-timers" need to figure out a better way to connect to the generations that are now entering the workforce and will enter it in the coming decade. The implications for the future of the composites industry are significant. As I write this, we just finished our Institute for Advanced Composites Manufacturing Innovation (IACMI, Knoxville, TN, US) summer members meeting. In addition to industry representatives and professionals from our university and national laboratory partners, we invited, and had extensive interaction with, graduate and undergraduate student interns, as well as several high school students. These "in-person" activities will — I hope — demonstrate the value of building networks the old-fashioned way.

We plan to expand this, and I know that SPE and SAMPE are pursuing similar initiatives. Many of us have championed replacement of traditional materials and processes with composite solutions for decades. Those of us who maintain a vision of composites becoming as ubiquitous as steel or concrete will need these next generations to pick up that torch and continue running with it, building connections the way we have — face to face. CW



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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.


JUMP IN!
The water is fine.

Increasing the industrial adoption of composites additive manufacturing

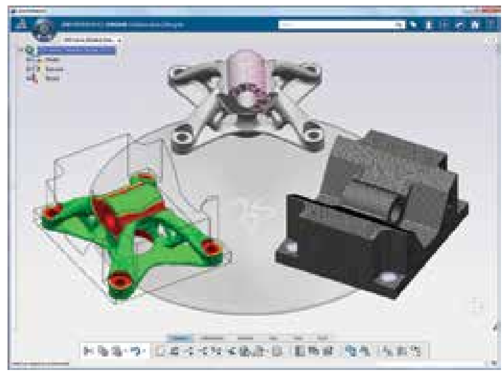
» Additive manufacturing (AM) was first developed for polymeric materials with the goal of producing *prototype* object geometries. Also known as 3D printing — because it can be used to "print" three-dimensional solid geometries of almost any shape from a digital model of the solid — it gave part designers a means to develop prototypes without material removal or the need to make molds. There were enormous economic benefits from this product development innovation — 3D printing is a *tool-less* manufacturing process and, with refinements, has more recently begun to produce *finished* products of polymeric, metallic and ceramic materials.

However, because material properties are directly related to their composition and microstructure, it is essential that the latter be considered in the overall development of AM for the future, if material performance is a goal.

Of primary interest when AM printing with fiber-reinforced materials is the need to predict and measure the anisotropic *deformation* that occurs in the printed element during the process because the printed shape can differ from that of the initial digital model. Thus, simulations that model AM must include a description of anisotropic element shape-change during deposition to allow adjustment of the deposition process to achieve the desired overall geometry as specified in the initial digital description. In addition, simulations should provide the *in situ* material properties as well. By so doing, the performance of the printed element can be anticipated.

Deposition of anisotropic materials is not well understood. Flow orientation of discontinuous fiber suspensions is determined by the kinematics of the fluid flow. Thus, nozzle design for 3D printing with fused deposition can yield flows wherein the fiber phase is well collimated and aligned with the flow direction, or in some cases, transverse to the flow direction. In either case, the resulting properties of the solidified material are highly anisotropic and depend on the relative volume fractions and properties of the fiber and continuous phases.

Another deposition process uses continuous fibers that are fully or partially impregnated with a matrix phase. Here, the matrix phase is brought to the liquid state when the system is deposited. Solidification and adhesion then yield the local geometry. The matrix phase also can be in fiber form and commingled with the reinforcing fibers. The challenge is to provide local pressure to assure fiber/matrix consolidation during deposition, while allowing for flexibility in deposition geometry. Of course, the continuous deposition system must also provide a mechanism for cutting the carbon fiber during the process in order to provide the full range of deposition geometries. Typically, these systems are restricted to laminate structures with thin curvilinear geometries.



Functional Generative Design

Aimed at engineers who are not design and optimization software experts, this new workflow enables the user to perform trade studies and arrive at the best conceptual part shape without resorting to tedious, manual reconstructions.

Source | Dassault Systèmes

To ensure these materials are reliable and function, as built, the way we need them to, it is essential to understand the material properties and the printing processes that can be employed. The use of physics-based tools with multi-scale simulations helps us address these challenges.

In addition, because parts manufactured with AM processes today can be more organic in shape, lighter and more complex than parts made with traditional processes, engineers and manufacturers are changing the way they design parts. However, there are many limitations in today's computer-aided design (CAD) tools, including the lack of ability to access and consume simulation information in an efficient manner. It is doable, but the process is manual and tedious and requires multiple software tools. Further, the disconnect between toolsets has prevented designers from quickly iterating shapes based on the desired performance.

The additive manufacturing industry, therefore, has challenged the design community to develop an efficient product engineering platform where the barriers between design, optimization and simulation would be broken and optimized parts could be explored in the design environment. Challenged by a major aerospace OEM, Dassault Systèmes developed a physics-based, simplified workflow called Functional Generative Design, aimed at engineers who are not experts in conventional design and optimization software.

The designer applies the structural loads and boundary conditions directly to the CATIA geometry, and organizes these into load cases as needed. A topology optimization problem can then be undertaken. The objective function (maximize stiffness, minimize mass, or maximize the first natural frequency) is selected. Constraints are assigned, and then the optimization is initiated. Running in the background is the Abaqus finite element analysis solver, and Tosca, a non-parametric topology optimization tool that identifies the optimal material distribution within the design space. Together, they will generate the ideal shape.

Once the user is satisfied with the shape, the solid body can be calculated. If the designer wants to explore alternative shapes, he »

or she can use the Variant Manager to perform trade studies. The Variant Manager allows the user to review the concepts and assess the results based on KPIs (key performance indicators, see the screen shot on p. 12). Once the trade study is complete, the designer selects the best possible conceptual shape.

In a traditional design environment, at this point, the step of taking the optimized results back to CAD through a geometry reconstruction process is a highly time-consuming and manual process — the designer would have to manually reconstruct the now non-integrated optimized part. Moreover, the associativity with the original design might be lost. But because the new workflow captures the physics of the materials and the process, the designer is able to simulate the stress and distortion the material will be under during the print build, and then calibrate the material for the build and analyze the print temperature and residual stress to account for these factors. This closes the gap between the design and the as-built product, and enables the designer to optimize the process cost, schedule and quality. The designer, for the first time, has access to the optimized part.

AM of fiber-reinforced composite materials provides a platform to examine true structural optimization wherein the external part geometry and the internal microstructural fields are optimized *simultaneously*. For anisotropic materials, this scenario can provide for optimization of fiber/matrix preforms that map the needed properties to the geometric locations that meet specified loading conditions, thereby significantly reducing structural weight. There are numerous multi-functional requirements for typical engineered systems, and the 3D printing approach to design provides an opportunity to meet customer needs with substantially more degrees of freedom in design than conventional homogeneous systems. CW

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R. Byron Pipes was appointed the John L. Bray distinguished professor of engineering at Purdue University in 2004. He is a member of the National Academy of Engineering (1987) and the Royal Society of Engineering Sciences of Sweden (1995). He served as president of Rensselaer Polytechnic Institute (1993-1998), was provost and VP for academic affairs at the University of Delaware (1991-1993) and served as dean of the College of Engineering and director of the Center for Composite Materials (1977-1991) at the same institution.

July 2016 — 48.6

Future capital spending plans measure up 53% compared with the same time period in 2015.

» With a reading of 48.6, the Gardner Business Index showed that the composites industry contracted at a significantly slower rate in July than it did in June. However, the index was still on a slight downward trend, continuing a slide that had begun in February.

New orders, however, expanded for the first time since March. Although this subindex had experienced a significant spike followed by a dip, the general trend in the new orders subindex had been upward since August 2015. The production subindex contracted in July for the second month in a row and had been trending down since March. The backlog subindex also contracted, and did so for the fourth straight month. But, as a result of the trends in the new orders and production subindices, the backlog subindex at the end of July generally had improved since August 2015. The employment subindex contracted for the third time in four months. Exports were virtually flat in July, but maintained the highest level for that subindex since June 2014. The trend in exports had been moving up noticeably since November 2015. Supplier deliveries in July shortened for only the third time since the GBI Composites survey was first reported in December 2011.

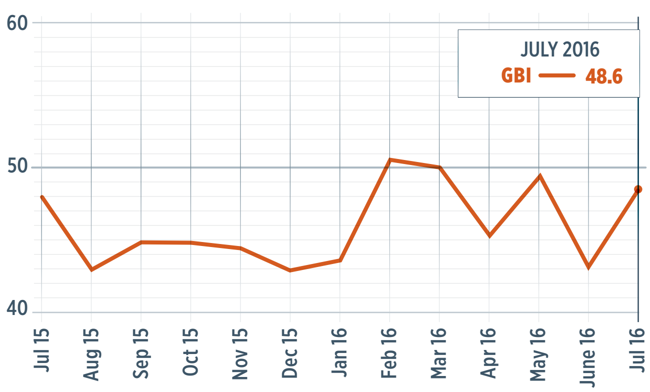
The materials prices subindex had increased, as July closed out, at a consistently high rate since April of this year. Other than a spike in July 2015, it was the fastest increase in materials prices recorded since November 2014. Prices received decreased for the tenth month in a row. The future business expectations subindex, as July came to a close, had been fairly flat for five of the preceding six months.

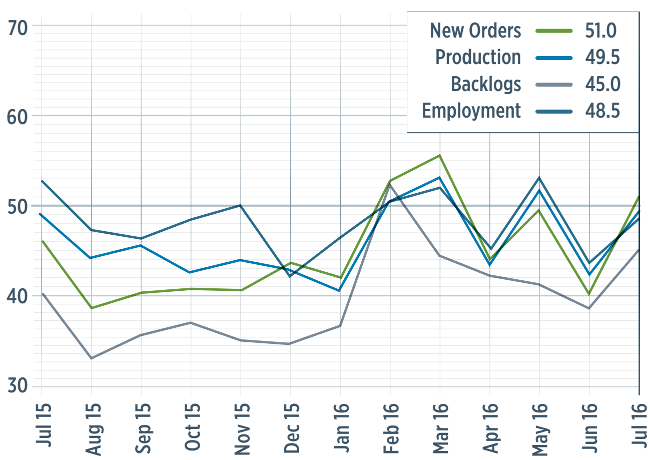
Among composites fabricators, on average, those with plants employing more than 250 employees contracted in July for the eighth straight month. Facilities with 100-249 employees contracted for the second straight month. Companies with 50-99 employees had expanded four of the past six months. Facilities with 20-49 employees contracted after similarly growing in four of the previous six months. Manufacturers with fewer than 20 employees contracted for the fifth month in a row.

The aerospace industry expanded in July for the fourth time in six months. While the aerospace industry has performed well for composites fabricators recently, the automotive industry has contracted in each of eight consecutive months. This mirrors motor vehicle and parts consumer spending, which at the end of July had contracted in five of the previous six months.

Future capital spending plans were almost at what has been, over time, an average level in July. Compared with the same time period one year earlier, future capital spending plans were up by 53%. Month-over-month, they had increased in four of the preceding five months. The annual rate of change had contracted in July at a decelerating rate since February, which was a positive sign for the composites industry. CW

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





ABOUT THE AUTHOR

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Architectural composites make bug biology big, Oshkosh Fly-In hosts big Boeing Centennial, and an offshore wind farm — a US first — gets its first big blades.

ARCHITECTURE

Museum's robotically fabricated CFRP canopy showcases *bio-mimicry*

As part of its first-ever Engineering Season, the Victoria and Albert Museum (V&A) in London, UK, has unveiled an architectural installation that features carbon fiber composites. Developed by a team from the University of Stuttgart's Institute for Computational Design (ICD) and Institute of Building Structures and Structural Design (ITKE), the Elytra Filament Pavilion, a sun canopy robotically fabricated from fiber-reinforced composite structures, is on display in the Museum's John Madejski Garden.

Source | SGL Group

The Pavilion is the result of years of research into the integration of architecture, construction engineering and bionic structures, all of which has been carried out cooperatively by ICD and ITKE. The project demonstrates one way the principles of *bio-mimicry* (imitation of biological structures) and new materials can be applied to architecture through computational design and robotic fabrication methods.

Inspired by the forewing shells of flying beetles called *elytra*, the Pavilion's innovative structure consists entirely of robotically fabricated glass- and carbon-fiber hexagonal elements designed by German architect Achim Menges with ICD doctoral candidate Moritz Dörstelmann, and realized with help from structural engineer Jan Knippers and climate engineer Thomas Auer. Menges and Knippers are affiliated with the University of Stuttgart. The installation emerged from their ongoing research projects, and is their first major commission in the UK.

Each composite element was fabricated with a KUKA robot (KUKA Robotics Corp., Shelby Township, MI, US), which was driven by software that creates a fiber pattern similar to that observed in the beetle's wing. Glass and carbon rovings, wet out with polymer resin, were placed on a hexagonal metallic winding frame; multiple frames were fastened together to form the canopy, which is supported on widely spaced columns that are narrow at the bottom and then spread out like tree branches before they join the sun canopy elements overhead (see photo, above right).

SGL Group (Wiesbaden, Germany) supported the automated fabrication approach by supplying its SIGRAFIL 50K industrial-grade carbon fiber for the installation and assisted the project team. "We were delighted to contribute our materials and expertise to support Stuttgart University's very striking exhibition project for V&A's special Engineering Season. The installation impressively demonstrates the wide-ranging potential for innovative application of composite materials. It also shows the high degree of automation that is now possible in the industrial production of components from composites," contends Andreas Wüllner, head of SGL Group's Composites – Fibers and Materials Business Unit. Notably, the same fibers are used in automated production processes, including those employed to build BMW's *i3*, *i8*, and newer *7-Series* cars.

The Pavilion was installed and subsequently opened this year in May. Most interesting, however, the exhibit, with robotic assistance, will "grow" during the course of the V&A Engineering Season, which runs until Nov. 6. Sensors in the canopy will collect data on how visitors inhabit the Pavilion, and will monitor the structure's behavior, ultimately informing the architects how and where the canopy might grow. During a series of special events, visitors will have the opportunity to witness robotic construction live. The pavilion's lightweight filament structure spans more than 200m^2 but weighs less than 2.5 MT.

Visit the Victoria and Albert Museum's Web site for more information; photos of the installation's build and assembly are available here: **vam.ac.uk/exhibitions/elytra-filament-pavilion#objects**. A video showing the robotic construction of the canopy elements, and installation of the canopy, is available here: **vam.ac.uk/articles/construction-of-the-elytra-filament-pavilion.**

ENERGY

Massive composite turbine blades arrive in Rhode Island

Offshore construction activities are proceeding apace for the Block Island Wind Farm, so named because it is located near the island of that name, offshore of the US state of Rhode Island. Activities were notable for the arrival of 73m/240-ft long turbine blades at Providence-based Deepwater Wind and GE's assembly facility at the Providence port facility (ProvPort).

On June 28, local stevedores began offloading the 15 blades at ProvPort. The blades, and the tower sections, already assembled there, were scheduled to travel by boat to the Block Island Wind Farm site at the beginning of August. Crews from Deepwater Wind LLC (Providence, RI, US) successfully set the first foundation for a commercial offshore US wind turbine on July 26, about 5 km southeast of Block Island, near New Shoreham, RI. Although the Block Island wind farm will be small — five turbines — each of the five, at 6 MW capacity, will generate 15% greater power than *all* predecessors and reduce Block Island residents' electricity costs (now based on diesel power) by 40%. Further, *90%* of its generated power will be fed to the Rhode Island mainland where this relatively small project will nonetheless supply 1% of the state's total electric power.


Source | Deepwater

GE Wind Energy (Fairfield, CT US) is supplying the 6-MW *Haliade* 150 offshore wind turbines for the Block Island farm. The turbine blades, however, were built in Kolding, Denmark by GE Wind's's subcontractor and blade specialist, LM Wind Power.

Meanwhile, installers of the submarine cables for the wind farm and the Island's new connection to the mainland were making significant progress: The *(Continued on p. 22)*


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(Continued from p. 20)

6.5-mile submarine cable that connects the wind farm to Block Island has been installed. In addition, National Grid's 17-mile sea2shore cable connection between Block Island and mainland Rhode Island had reached a major milestone in late June with the successful landing of the cable on Block Island's shore. In July, Deepwater Wind completed the cable connections between the wind turbines themselves.

Deepwater Wind is actively planning other offshore wind projects to serve multiple East Coast markets located 15 or more miles offshore. Block Island is the first offshore wind energy project to be built under US jurisdiction, approved only after a long and difficult uphill battle by many applicants on many fronts along the US Eastern Seaboard. The long US battle for offshore wind, a sharp contrast to the nation's enthusiasm in most quarters for *onshore* wind farm construction, is a curiosity in view of a world scene where most international players have embraced offshore wind as readily, or even more readily, than onshore in an effort to reduce dependence on fossil fuel resources (offshore wind went commercial in Europe before the turn of the century). Read more in the following:

"The markets: Renewable energy (2016)" | short.compositesworld.com/MarketRE16

"US wind energy: Offshore promise remains unfulfilled, onshore strong" | short.compositesworld.com/OffOnProm


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AEROSPACE

Oshkosh's AirVenture 2016 offers big moments


Source | EAA / Photo | Jason Toney


Source | Airbus

Half a million visitors was just one highlight of the 2016 edition of the Experimental Aircraft Assn.'s (EAA) AirVenture airshow event held in Oshkosh, WI, US. Another big one was The Boeing Co.'s (Chicago, IL, US) Centennial celebration — 100 years in aviation. Boeing aircraft on display and in the air show included a 737-900ER, and Boeing historians also presented a retrospective at the Theatre in the Woods.

Epic Aircraft LLC (Bend, OR, US), the manufacturer of an all-carbon composite single-engine turboprop, went big, too, launching an around-the-word *Odyssey* world tour, involving 26 people and six aircraft, which began in Oshkosh, July 6, and ended there after a 21-day, 15,000-mile adventure. Doug King, Epic's CEO, endorsed the tour as a way to validate the integrity of the plane's design and performance, as well as give owners an opportunity to enhance their flying skills.

Airbus (Paris, France) made the Oshkosh event the big stage for its hybrid electric aircraft's debut in the US general aviation market. The *E-Fan 1.1* made a splash in 2015 when it successfully flew across the English Channel under electric power. The latest version, *E-Fan 1.2*, at Oshkosh, incorporated a hybrid electric/gas engine developed by Airbus in partnership with Siemens (Munich, Germany). Airbus says it is committed to developing the hybrid concept to greatly reduce carbon emissions in flight, reduce noise and enable quieter, reduced-emission taxiing while on the ground. Siemens announced in April that a joint development team of more than 200 employees will be assembled to develop breakthrough innovations in electric mobility for commercial aircraft. More info on the *E-Fan* can be found at **BeAFanofEFan.com.**

(Continued on p. 26)


WHAT THE FUTURE IS MADE OF
BGF weaves innovation into every fabric design to create distinctive materials for engineered composite solutions. For over 50 years, we have provided unique finishes, strong bonding chemistries and advanced materials for aerospace, marine, automotive and infrastructure applications. If you can imagine it, we can engineer the precise fiber matrix to make it happen. Find out what BGF can do for you by visiting BGF.com.
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(Continued from p. 24)

Reportedly the fasted ultralight aircraft to date, JMB Aircraft s.r.o's (Chocen, Czech Republic) *VL3 Evolution,* made its first appearance at Oshkosh as well. Capable of 135 kts/155 mph cruising speed, two of the low-wing, two-seat craft flew in from Europe, arriving on July 23. The *VL3* sports a carbon composite airframe, removable wings to ease transport, and stiff sandwich-structure wingskins made with carbon and glass fibers, with no internal ribs. Watch a video of the plane's landing at Wittman Field | **www.jmbaircraft.com/news.html.**

Source | Innegra Technologies

Innegra Technologies (Greenville, SC, US) spearheaded the Advanced Composites Infusion event at the show, a four-day demonstration overseen by Innegra's Russ Emanis and conducted at the Replica Fighter Assn. tent. Two complete aircraft fuselages were infused: The first, a light sport aircraft (LSA) kit plane, the *Star-Lite,* was molded using resin donated by Scott Bader-ATC (Stow, OH, US) and woven reinforcements from Texonic (St-Jean-sur-Richelieu, QC, Canada). The second, a canard-wing kit plane designed by Jeff Kerlo, was molded using epoxy resin donated by Composite Polymer Design/Endurance Technologies (South St. Paul, MN, US) and TeXtreme spread-tow carbon fiber fabrics from Oxeon (Borås, Sweden).

Emanis says distributor Composites One (Arlington Heights, IL, US) had two technical specialists on hand to help with the processing, and German Advanced Composites (Miami, FL, US) donated its MTI infusion hoses. Molds for the demos were provided by *Star-Lite's* owner Brian Burghgraves, and by Kerlo and Emanis, who together are developing the canard aircraft for future kit-plane sales. Scott Bader donated materials for the canard aircraft's pre-event mold construction, including its Seamless Tooling compound for the plugs, tooling gel coat and a tooling resin to make the finished molds. Hawkeye Industries Inc. (Bloomington, CA, US) supplied mold releases, fairing compounds, tooling materials and more. DIAB Americas LP (DeSoto, TX, US) provided core material, and T.E.A.M. Inc. (Wonsocket, RI, US) committed to sponsoring/supplying reinforcement products for the demo as well.

"This is all about education," said Emanis, noting before the event, "We're going to demonstrate single-bag and double-bag infusion methods, and people will see the differences between epoxy and vinyl ester infusion." Unable to attend the airshow? Watch the infusion demos here | **www.facebook.com/ACIOshkosh.**

CW MONTH IN REVIEW

Notes on 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**

Automated Dynamics to partner with Bartell Machinery
New solutions will incorporate advanced composite materials in the fabrication of high-performance products, such as continuous pipe for oilfield applications.
08/15/16 | short.compositesworld.com/ADBartell

Hexagon Composites enters CNG-for-rail market with joint venture
The JV, with Allegheny Creative Energy Solutions LLC and Resonance Mode Inc., will develop compressed natural gas fuel solutions for the rail industry.
08/15/16 | short.compositesworld.com/CNG4Rail

Evonik is conducting research on biodegradable composites
The research is focused on new composite materials that could replace currently used metals for the internal fixation of fractured bones.
08/15/16 | short.compositesworld.com/Comp4Bones

Evolva, US Navy to collaborate on resveratrol-based composites
The biotechnology company is working with the military to develop a new class of structural composites engineered from a uniquely specified Evolva formulation.
08/15/16 | short.compositesworld.com/EvolvaUSN

First carbon fiber tower built in Asia
The edotco Group installed the structure in Taman Tasik Prima, Puchong, Malaysia.
08/15/16 | short.compositesworld.com/edotcoTWR

Aligned carbon nanotubes boost in-plane strength of composite laminates
New paper published by MIT also shows open hole compression strength upped by 14% and bolt pull out bolstered by 30%.
08/15/16 | short.compositesworld.com/CNTsMIT

Origine Bicycles uses lightweight frame reinforced by TeXtreme
An optimized fork built for the French bike brand is 19% lighter than the standard one and the *Origin Axxome* frame shows a marked increase in lateral stiffness.
08/11/16 | short.compositesworld.com/OrigineTX

Fives opens global services center in Alabama
This location joins five other North American service centers as Fives expands to meet the needs of its customers nationwide.
08/08/16 | short.compositesworld.com/FivesAL

Virgin Galactic's *SpaceShipTwo* earns operator license
The Las Cruces, New Mexico-based space tourism company says the US Federal Aviation Admin.'s license will permit eventual passenger flights to the edge of space.
08/08/16 | short.compositesworld.com/SS2license

Rolls-Royce models receive carbon fiber upgrade
The featured material is a compressed carbon matrix that is similar to the forged carbon fiber developed by Lamborghini and Callaway.
08/08/16 | short.compositesworld.com/RRCFupgrde

BIZ BRIEF

Avcorp Industries (Delta, BC, Canada) and the University of British Columbia (UBC) have agreed to explore the establishment of a Learning Factory for Advanced Composites at UBC's Okanagan campus. The two parties, represented by Avcorp CEO Peter George and UBC deputy vice-chancellor and principal Deborah Buszard, signed a memorandum of understanding on July 12 at the 2016 Farnborough International Airshow (July 11-17, Farnborough, UK).

"Avcorp Industries is committed to exploring the establishment of an aerospace industry-first Learning Factory in a way which will push the boundaries of advanced composite manufacturing as well as provide a platform for a new level of research and training in British Columbia," said George. "We are looking forward to working with the UBC-based Composites Research Network in an initial focus on aerospace applications of composite materials and optimized manufacturing processes."

"Composite manufacturing is a growth industry," said Stephen Fuhr, MP for Kelowna-Lake Country. "This learning factory concept provides a solid opportunity for employment, education and innovation. It would also further solidify Kelowna-Lake Country as one of Canada's premier aerospace clusters."

The Learning Factory will integrate industrial production with learning and research and provide UBC students and faculty with new opportunities for research, knowledge translation and hands-on experiential learning. It also will provide technical and skills training opportunities for students from partner institutions, including nearby Okanagan College.

Indiana Manufacturing Institute to focus on composites

More than 300 participants, including representatives of some 20 Indiana composite materials companies, celebrated the opening of the US$50 million Indiana Manufacturing Institute, based in the Purdue Research Park (West Lafayette, IN, US).

The Institute will house the Center for Composites Manufacturing and Simulation, where researchers and graduate students from the Purdue College of Engineering and Purdue Polytechnic Institute will conduct R&D on composite materials to increase energy efficiency for the vehicle production, wind, aerospace and other industries.

The Center for Composites Manufacturing and Simulation is part of a US$250 million U.S. Department of Energy (DoE) initiative to support US President Barack Obama's National Network for Manufacturing Innovation. The DoE project, called the Institute for Advanced Composites Manufacturing Innovation (IACMI), The Composites Institute, is a five-year public/private collaboration that includes a federal commitment of US$70 million and more than US$180 million pledged by industry, state economic development agencies and universities.

Purdue's Product Lifecycle Management Center and the Indiana Next Generation Manufacturing Competitiveness Center (IN-MaC) also will be located in the institute. These three centers will occupy 2,790m² of the 5,760m² Institute facility.

The institute's remaining 2,870m² space will be available for other public or private enterprises that express interest in collaborating on composite materials research with

(Continued on p. 34)

From left are Dan Hasler, president, Purdue Research Foundation; Ian Steff, executive VP and chief innovation officer, Indiana Economic Development Corp.; Craig Blue, CEO, IACMI; Leah Jamieson, John A. Edwardson dean of engineering; Suresh Garimella, executive VP for research and partnerships at Purdue; John Dennis, mayor of West Lafayette; and Kelly Visconti, technology manager for the US Department of Energy's Advanced Manufacturing Office. In back is Prof. R. Byron Pipes. Source | Purdue Research Foundation

(Continued from p. 32)

Purdue University. "Purdue is a recognized international leader in composite materials research and the opportunity and demand for research partnerships between Purdue and industry is great," said Suresh Garimella, Purdue's executive VP for research and partnerships and the Goodson distinguished professor of mechanical engineering. "The opening of the Indiana Manufacturing Institute will enable us to increase these research collaborations and advance our composite materials research for even greater impact."

R. Byron Pipes, the John Leighton Bray distinguished professor of engineering, leads Purdue's Design, Modeling and Simulation Enabling Technology area, which will be housed in the Institute. He served as the host for the ceremonies and summed up the event's significance:

"It is through closer exchanges of knowledge that both industrial and academic enterprises benefit from the assets of the other in order to accelerate the development of their competitive positions," said Pipes. "The Indiana Manufacturing Institute will provide an innovative venue for academic and industrial stakeholders to join together for rapid transfer of technology to societal prosperity. As a national manufacturing institute, IACMI links the Indiana composites manufacturing efforts with our five state partners in Tennessee, Michigan, Colorado and Ohio to build the next generation manufacturing technology for the vehicle, wind and compressed gas application areas."

AEROSPACE

Airbus, Boeing forecasts figure upticks again, boding well for aerocomposites firms

The chief rivals for the international commercial transport aircraft market, The Boeing Co. (Chicago, IL, US) and Airbus (Toulouse, France), each issued their annual 20-year forecasts for global commercial aircraft demand on day one of the 2016 Farnborough International Air Show (July 11-17, Farnborough, UK).

Boeing projects a demand for 39,620 new airplanes during the next 20 years, an increase of 4.1% over last year's forecast. Boeing's annual *Current Market Outlook 2016-2015* estimates the total value of those new airplanes at US$5.9 trillion. The airframer's estimates are up from last year's estimated figure of 38,050 new planes, valued at US$5.6 trillion.

Similarly, Airbus' *Global Market Forecast 2016-2035* predicts passenger traffic will grow at an average 4.5% a year, driving a need for more than 33,000 new aircraft above 100 seats, worth US$5.2 trillion. That's up from 32,585 aircraft, worth US$4.9 trillion, estimated in last year's Airbus annual report.

Both documents reported numbers and percentages describing increases in air traffic, and demand for new and replacement passenger aircraft that continues a general trend upward that has endured for more than a decade (see endnotes). Airbus, for example, says that by 2035, the world's active aircraft fleet will have doubled from today's 19,500 aircraft to almost 40,000. Some 13,000 passenger and freighter aircraft will be replaced with more fuel-efficient types. Boeing, in a statement, says, the single-aisle market will be especially strong, with low-cost carriers and emerging markets driving growth. 28,140 new airplanes will be needed in this segment, an increase of more than 5% over this past year. On the

(Continued on p. 38)

(Continued from p. 36)

widebody side, 9,100 airplanes are in the Boeing forecast, with a large wave of potential replacement demand in the 2021-2028 timeframe. Boeing also projects a continued shift from very large airplanes to small and medium widebodies, such as its 787, 777 and 777X. Because cargo traffic is forecast to grow at 4.2% per year, Boeing projects the need for 930 new freighters and 1,440 freighter conversions.

In the widebody market, Airbus forecasts a trend towards aircraft with greater capacity, and is expecting that the market will require more than 9,500 widebody passenger and freight aircraft during the coming 20 years, valued at about US$2.8 trillion. This represents 29% of all new aircraft deliveries and 54% of those deliveries by value. Most of the widebody deliveries (46%) will be to carriers in the Asia-Pacific region.

In the single-aisle market, Airbus forecasts a need for more than 23,500 new aircraft, worth US$2.4 trillion. This represents 71% of all new units. Asia Pacific operators will take 39% of these deliveries.

Read the full Boeing *Current Market Outlook 2016-2035* at boeing.com/commercial/market

Read the full Airbus *Global Market Forecast 2016-2035* at airbus.com/company/market/global-market-forecast-2016-2035

Read more online in "The markets: Aerospace (2016)" | short.compositesworld.com/MktAero16

BIZ BRIEF

Web Industries' (Marlborough, MA, US) recently announced additions and storage expansion at its plant outside of Atlanta, GA US are the first part of a US$12 million, three-year infrastructure investment plan that will increase efficiency and capacity at Web Atlanta. The facility produces precision composite slit tape and ply kits and provides vendor-managed inventory services to the aerospace industry's manufacturers and part fabricators. To meet growing demand for Web's PrecisionSlit composite slit tape, the company has developed new processes that enable the production of longer slit tape spools with improved slit tape edges and an increased usable lifespan, all of which reportedly offer aerospace companies better manufacturing production rates. The processes take place in a set of linked climate-controlled rooms, where frozen raw material parent rolls are quickly thawed, prepped for formatting in an ISO 8 cleanroom, and then held in temperature-controlled "suspended animation" until slitting can occur. To support rapidly growing use of aerospace prepregs in the southeastern US, Web Atlanta also is expanding its automated prepreg cutting and ply kitting operations. Four additional cutting tables will join Web's existing assets in a customized environment optimized for FOD-free production. The facility will offer the region's aerospace, defense and aviation industries a centrally located, AS9100C-certified supplier of custom-tailored composite ply kits. To handle the projected increase in raw and formatted composites volumes, Web Atlanta has built a new 120,839 ft^3 cold storage freezer, bringing its total freezer capacity to 289,214 ft^3 — one of the industry's largest freezer footprints.

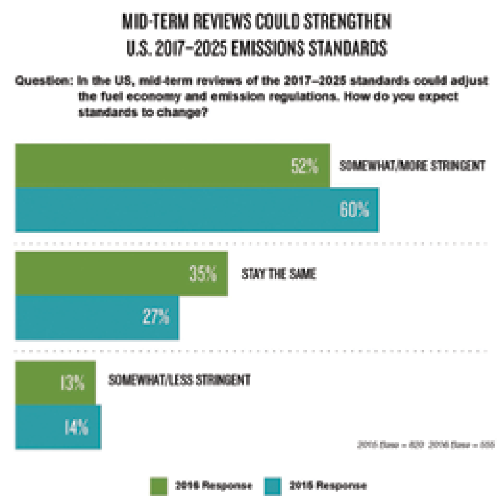
AUTOMOTIVE

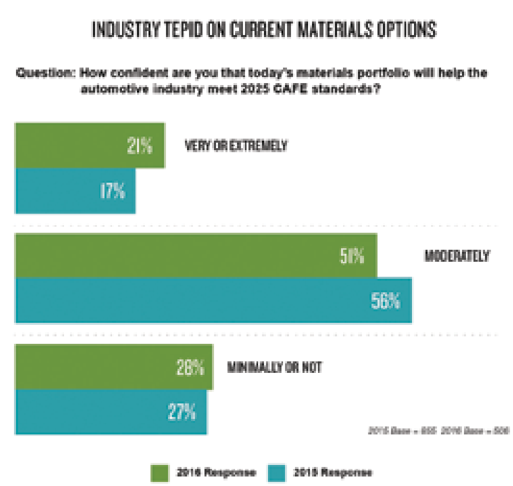
Survey: Lightweighting remains top focus for automakers

DuPont Automotive (Wilmington, DE, US) has published a new survey that says lightweighting and engine-efficiency programs continue to top the list of strategies for automakers as the industry looks for ways to meet 2025 CAFE (Corporate Average Fuel Economy) standards. The recent findings were part of the annual WardsAuto survey, sponsored by DuPont. The survey also showed electrification as an increasingly mentioned technology focus by the respondents.

With the mid-term review of the 2025 CAFE Standards scheduled through 2017, 87% of survey respondents said they expect the standards for fuel economy and emissions to become more stringent or remain the same. At the same time, 90% said low gas prices in combination with slow sales of fuel-efficient, low-emission vehicles will continue to impact programs aimed at meeting CAFE regulations.

Now in its sixth year, the DuPont-sponsored survey with WardsAuto was conducted by Penton Market Research (Overland Park, KS, US). The 600-plus surveyees who responded work for system, component or parts manufacturers, automakers, engine or engine-service companies or in automotive-related industries. Most represent engineering, design, manufacturing, marketing, sales and corporate management perspectives.





Source (both charts) | 2016 WardsAuto Automotive Trends Benchmark Study

Among the questions in the survey, respondents were asked to identify technologies that their companies are focusing on to help meet the 2025 standards. A majority of respondents (63%) named lightweighting and the use of lightweight structural materials, and nearly half (49%) pointed to engine-efficiency programs. Lightweighting was at the top of the technology focus list in terms of goals — 44% of survey respondents mentioned the powertrain and chassis as the primary areas of focus for their lightweighting efforts.

The light-duty vehicle CAFE and GHG (greenhouse gas) emissions rate standards require, on an average industry fleetwide basis, 163 g/mile of CO_2 in model year 2025, which would be equivalent to 54.5 mpg (4.3L/100km) if this level were achieved solely through improvements in fuel efficiency. However, 54.5 mpg is a non-adjusted theoretical laboratory compliance value that does not include special credits for such things as high-efficiency air-conditioning systems and active grille shutters that improve vehicle aerodynamics. Most experts, therefore, believe 54.5 mpg will translate to about 40 mpg in real-world fuel economy.

Respondents continue to be only moderately confident that the current portfolio of materials will help the industry meet the looming standards.

According to the survey respondents, the material families most relied upon to help meet the CAFE standards are aluminum (25%) and multi-material solutions (21%). Advanced composites, engineered plastics and advanced high-strength steel were the top second-tier choices, with all three materials, combined, accounting for 39% of the respondent's choices.

BIZ BRIEF


Source | Automated Dynamics

Automated Dynamics (Schenectady, NY, US) recently moved in to its new 2,790m² building in the Niskayuna Commerce Park in nearby Niskayuna, NY, and celebrated the facility's grand opening Wednesday, July 13, 2016.

Active in the composites industry for more than 30 years, Automated Dynamics currently manufactures high-performance composite structures, develops advanced automated equipment and offers solution-based engineering services. Using an out-of-autoclave process and its patented automated fiber placement (AFP) technologies, the company says it has produced hundreds of thousands of composite parts for more than 500 clients in 17 countries. The new facility reportedly will support its expansion strategy as the company seeks to expand its client base further, globally.

Says company president Rob Langone, "This building provides for our business needs now and over the next few years. It offers our employees a minimal change in commute over our last location and provides customers with a site that is fitting for the products and services we deliver."

In concert with the expansion, Automated Dynamics plans to increase its workforce by more than 60% in the next five years.

CORRECTION

On p. 18 of the August issue of *CW*, in a story titled, "Ashland unveils SMC with specific gravity of 1.2, aims for 1.0," *CW* indicated that Ashland Performance Materials (Columbus, OH, US) and Continental Structural Plastics (CSP, Auburn Hills, MI, US) were the only two firms working on low-specific-gravity sheet molding compound (SMC) formulations. *CW* overlooked the fact that Core Molding Technologies (Columbus, OH, US) introduced in 2013 an SMC called Airilite, with a specific gravity of 1.18. This was followed by another Airilite formulation in 2014 with a specific gravity of 1.2. *CW* regrets the oversight.

BIZ BRIEF


Source | IDI

Thermoset molding compound specialist **IDI Composites International** (Noblesville, IN, US) announced on July 11 the opening of its IDI 3i Composites Technology Center. IDI created the 3i Center to help customers solve their engineering and performance challenges. Launched in conjunction with IDI's 50th anniversary, the 3i Tech Center is located in the company's Noblesville headquarters and is part of the newly dedicated John K. Merrell Center. It will serve as IDI's R&D division.

The company provides customized polyester/vinyl ester-based bulk molding compounds (BMC), sheet molding compounds (SMC) and a new line of structural thermoset composites (STC). The Center was founded to meet increased demand from OEMs and molders, through its manufacturing facilities in the US, France, Puerto Rico and China, for stronger, lower density and higher performing materials. The Center is outfitted with state-of-the-art equipment and connected technology to partner with OEMs and molders to streamline and efficiently manage the breakthrough cycle for the formulation, testing and manufacture of composite materials.

"As markets for our products expand, so does the demand for innovative new materials that can meet and exceed the challenges posed by a variety of environments and applications," says Tom Merrell, IDI's president. "And as our customer base continues to widen, the need to create, produce and test new chemistries and formulas and parts prototyping plays an ever important role in the manufacturing-to-market cycle."

"The 3i Composites Technology Center will promote the sharing of ideas in early stage innovation through inquiry, ideas and innovation — 3i," said Larry Landis, IDI's director, technology and quality, of the origin of the Center's name. "Our 3i Tech Center will have a major impact on future breakthroughs that will benefit the entire composites industry."

CAMX 2016 Preview

ACMA and SAMPE's third CAMX will be the largest composites trade show in the composites industry's largest market. Held in Anaheim, CA, this year, it promises an even more robust exhibition and conference program.

» North America is the world's largest market for composites, and CAMX has become the largest composites trade show and conference in North America. Now in its third year, CAMX is evolving and growing and has become one of the global composites industry's most important events.

CAMX this year heads to the Anaheim Convention Center in Anaheim, CA, US., Sept. 26-29. As it has done in the past, CAMX offers a robust conference program (Sept. 26-29) combined with an expansive exhibition (Sept. 27-29), both designed to give composites veterans and newcomers alike access to a vast collection of composites-related expertise, experience and knowledge that will expand their composites world.

The conference, organized by SAMPE and the American Composites Manufacturing Assn. (ACMA), offers presentations throughout the four-day CAMX event. A host of options are available, ranging from Featured Sessions to Technical Papers to Education Sessions to Pre-Conference Tutorials. Presentations cover a broad range of topics: The currently hot topic of additive manufacturing will be addressed alongside the urgent topics of workforce development, and sustainability. Sessions on always critically important subjects — advances in materials, design, analysis, simulation, processing technologies, testing and evaluation will be set alongside those with always pertinent focus on vital end-markets, including aerospace and defense, industrial, transportation and consumer products. Scheduled session topics will include the following:

- Incorporating Additive Manufacturing into Business, Economics & Market Applications
- Additive Manufacturing: Technology and Application Challenges
- Mixed Materials: What Works – and Doesn't – in Different Market Segments
- Global State of Composites Industry
- Impact of Technological Advancements on Workforce Development: How the Industry is Responding?
- The Road Ahead for Composite Recycling: Obstacles, Options, and Opportunities
- Challenges and Opportunities for the Future of the Wind Energy
- IACMI Program Technology Focus and Updates
- Thermoplastics & Thermosets in High Rate RTM Processing and Technologies
- Global Trends in Automotive Technology: An OEM Perspective
- Lessons Learned from Industry Leaders

As it has done in the past, the CAMX Web site offers MyCAMX Planner, a tool that helps prospective attendees see and evaluate all of the conference and trade show offerings available, and then organize each day to make sure they see the presentations and exhibitors that interest them most. Interested parties may use MyCAMX Planner to conduct searches, communicate with exhibitors, make appointments with exhibitors and tag presentations. They can then link this data with the CAMX app on their mobile devices to keep their individualized CAMX schedules close at hand during the show. Visit short.compositesworld.com/CAMXPlan to create and use the MyCAMX Planner account.

CAMX exhibitors, as usual, will introduce a wide range of new products and technologies. Here's an exclusive first look at what a select list will offer on the CAMX show floor. For additional information, visit short.compositesworld.com/CAMX16.

New prepreg for golf, auto applications

A. Schulman Inc. (Akron, OH, US), an international supplier of high-performance plastic compounds, composites, powders and resins, will launch its Forged Preg next-generation composite material. A. Schulman's Engineered Composites business has developed Forged Preg in collaboration with the world's largest maker of premium, performance golf goods, and the company's fiber supplier. The performance characteristics of the material include high strength and stiffness. The material is said to be relatively thin and is suitable for use in automotive applications that require a lightweight material with high-end look and feel. www.aschulman.com

Education and training offerings

Abaris Training Resources Inc.'s (Reno, NV, US) trainers will be on hand to discuss their newly updated NDI, engineering, manufacturing, mold fabrication, infusion and structural repair courses, designed to meet the specific needs of the composites industry. Special emphasis is on active learning and training programs, encompassing a variety of advanced composite technologies. In addition, many Abaris partners will be located nearby on the exhibit show floor to answer questions about products, such as repair equipment, vacuum bagging materials, additive manufacturing, tooling, laser projection, resins, fibers, prepregs, thermoplastics and other associated material and process solutions.
www.abaris.com

Methacrylate adhesives

Adhesive Systems Inc. (Frankfort, IL, US) is emphasizing at CAMX its lines of methacrylate adhesives, which are engineered for structural bonding of many thermoplastics, metal substrates and composite materials. The adhesives are said to provide durable bond strength and reportedly can adhere even through surface oil and grease. Other features of the line include products with the emphasis on high peel and shear strength, high chemical resistance and high impact resistance. These adhesives have been formulated for a full range of work times and cure durations and can perform at temperatures ranging from -40°F to 350°F (-40°C to 176°C).
www.instantca.com

Prepreg laminates for tooling

Advanced Composite Materials Inc. (ACM, Berryville, AR, US) is featuring its CEL 375 carbon fiber/epoxy prepreg laminate for the composite tooling market. CEL 375 comprises balanced, 0°/90° unidirectional central layers of carbon fiber with a 6-oz woven fabric outer surface for laminate trim and drill. ACM co-cures a nylon peel ply to both outer surfaces for a subsequent bonding surface as well as a protective outer surface layer (typically removed by the end-user). The press-cured prepreg laminate is flat across a 5-ft by 10-ft (1.5m by 3m) area to within 0.005-inch (0.127-mm) constant thickness. Stock laminate is 0.25 inch by 48 inches by 96 inches (635 mm by 1,219 mm by 2,438 mm); laminate up to 0.5-inch (12.7 mm) thick and 60 inches by 120 inches (1,524 mm by 3,048 mm) is available. T_g is 400°F (204°C). www.a-c-m.com

Infrared spectroscopic analysis system

Agilent Technologies (Santa Clara, CA, US) is featuring the Agilent 4300 handheld Fourier transform infrared spectroscopy (FTIR) to analyze coatings, composites, surfaces and polymers. The 4300 FTIR system can be used in field or lab location to nondestructively obtain specific molecular structure on a wide range of materials. Weighing 2.2 kg, the system includes the high-performance spectrometer, and sample interfaces that are instantly interchangeable depending on the specific application requirement. Controlling the hardware is Agilent's Microlab software. www.agilent.com

Pick-and-place add-on for kitting system

American GFM Corp. (AGFM, Chesapeake, VA) and parent **GFM** (Styer, Austria) are offering their Model US-120/CM-10 system with a new, computer-supported Pick & Distribute (P&D) system that automates and semi-automates tasks previously performed manually or via non-computer-supported processes. Model US120/CM10 features a three-zone ply cutter, which maximizes throughput by enabling ply marking, ply cutting and ply offloading simultaneously, thereby enabling the operator to be consistently productive, offloading while separate gantries mark and cut additional plies in separate zones along the machine's length. A linear drive system provides ultrasonic cutting at a maximum of 4,800 inches/min (121 m/min), with acceleration rate of 10-15 m/sec^2, vs. 1.5 m/sec^2 for other models — reportedly twice the output of the other ply cutters. The P&D system starts with an operator on each side of the machine offloading the plies from a given window (area on the ply cutter off-load table), guided by a laser pointing to the correct ply in reverse sequence of plies in that window, but with some gaps in the sequence. The gaps will be filled in at the next tray station, the final sorting station, which enables one operator to easily sort plies from trays that both offload operators have loaded onto trays. Each ply is tracked from offload to layup and verified at each successive station. Finished kits then can be transported to a freezer or directly to a layup station. Kitted plies arrive at the layup station in reverse layup sequence. www.agfm.com »

PET foam core materials

Armacell (Thimister-Clermont, Belgium) will present its ArmaFORM PET Core and PET Foil product lines. ArmaFORM PET Cores are polyethylene terephthalate (PET)-based structural foam cores used in sandwich constructions in the building and construction, transportation, marine and wind turbine markets. The new core comprises two grades, PET GR and PET FR (flame retardant), at densities from 65-250 kg/m^3 and thicknesses from 5-150 mm. The company's ArmaFORM PET Foil is a fully recyclable and thermoformable thermoplastic foil product with high temperature resistance (up to 180°C) that is used in automotive, building and construction and other applications. The extruded thin sheets, made of 100% recycled PET, are supplied on rolls or cut sheets and are available in thicknesses starting at 1.5 mm and in densities between 70 and 300 kg/m^3. www.armacell-core-foams.com

Autoclave-capable pressure hose

Airtech Advanced Materials (Huntington Beach, CA, US) will feature its BBH 1080 autoclave hose. A durable, high-temperature and high-pressure hose construction, it consists of an inner flexible stainless steel conduit overwrapped with a stainless steel braid. A stainless steel armor jacket covers the hose to protect it from the harsh autoclave and production environment. www.airtechonline.com

Polymer research presentations

Ashland Performance Materials (Coumbus, OH, US) will give three presentations at CAMX this year: "Monomer-Free Vinylester Resin for Prepreg Applications," by Jonathan M. McKay, Ph.D, an Ashland research scientist, will detail the development of a styrene-free vinyl ester resin suitable for prepreg applications. Investigations regarding resin stability and optimal cure conditions in both continuous fiberglass and carbon fiber systems will be discussed. "Achieve Desired Appearance and Process Times in a Challenging Regulatory Environment with Low Styrene Resins and Gelcoats," by research scientist Andrew Maher, Ph.D, will review recent developments in the regulatory landscape that continue to pressure boatbuilders to reduce styrene emissions and reduce worker exposure to such emissions. He will describe Ashland's steps taken to reduce emissions from resins and gel coats, and he will describe new ways to reduce worker exposure and comply with new regulations. "Use of Fire Retardant Resins and Gelcoats in Mass Transit, Architecture, and Building Materials," by Kevin Lambrych and Mike Stevens, will educate attendees about the material science of fire retardant (FR) composite materials base on fiber reinforcement, thermoset resins and gel coats. www.ashland.com

Automated equipment and engineering services

Automated Dynamics (Schenectady, NY, US) will present its automated composite production capabilities. The company specializes in the manufacturing of high-performance composite structures, development of advanced automation equipment and solution-based engineering services. Through the use of an out-of-autoclave process, the company brings additive manufacturing to continuous-fiber thermoplastic composite parts. It also offers patented automated fiber placement (AFP) technologies. www.automateddynamics.com

Flatbed cutting systems

Autometrix Inc. (Grass Valley, CA, US) will exhibit and perform demo and test cutting throughout the show using its Advantage model cutting system. Attendees can bring their materials to their booth for on-the-spot test cutting. Autometrix will provide PatternSmith (full 2D patterning software) and auto-nesting demos at the booth throughout the duration of the show as well. Autometrix offers three cutting machine models in static or conveyorized tables for the composites industry. Their machines are designed for cutting prepregs, dry composites and glass materials. www.autometrix.com

Filament winding technology

Autonational Composites BV (IJlst, The Netherlands) is exhibiting at CAMX for the first time, focusing on its ability to develop, engineer and build high-quality filament winding equipment designed for lab-scale and small-series production. The company also helps clients integrate filament winding processes into automated manufacturing and production systems for aerospace, automotive, infrastructure and industrial applications. Products include hydrogen tanks, compressed natural gas (CNG) tanks, automotive driveshafts, propeller and actuator shafts and fuel lines. The Autonational Group will have scale models on exhibit at CAMX, as well as some sample products. www.autonational.com

Reinforcement fabrics and thermoplastics prepregs

BGF Industries Inc. (Greensboro, NC, US) is featuring its PolyPreg thermoplastic composite material as well as its lines of carbon fabrics, aramid fabrics, fiberglass fabrics and Aerialite fiberglass fabrics. PolyPreg is the latest innovation in thermoplastic composite material from BGF industries. PolyPreg is a woven commingled glass/polypropylene fabric. It can be directly consolidated, with the addition of heat and minimal pressure, into a high-strength composite part. Parts made from PolyPreg can be used in many applications — automotive, building and construction, marine, sports and leisure, and transportation. www.bgf.com

Multi-resin-capable thermoplastics line

C.A. Litzler Co. Inc. (Cleveland, OH, US) will feature its improved standard thermoplastics line of prepregging equipment. Its lines are available in solvent, water-based and extrusion-based for various widths and fibers, and can be used for multiple resins/systems. Benefits of the Litzler line include highly accurate metering systems, closed-loop tension control, tow sizing removal systems and flexibility for multiple widths. www.calitzler.com

CNC machine simulation software

CGTech (Irvine, CA, US) composites product specialist Charles Anderton will give a presentation on how to use software to assist in making decisions about automated layup methodologies. "Automated composite manufacturing is an additive process to build a near-net-shape 'fiber-reinforced' part on a mold, using a CNC machine. This presentation will explore the advantages, disadvantages and challenges of automated fiber placement [AFP], automated tape layup [ATL] and hybrid layup strategies for a given set of part designs," says Anderton. "Machine-independent software packages offer the ability to unify programming and simulation efforts of both new and existing programs for a variety of AFP, ATL and hybrid machines." Booth demonstrations of software will include VERICUT Composite Paths for Engineering (VCPe), VERICUT Composite Programming (VCP), and VERICUT Composite Simulation (VCS). Visitors also may receive a thorough overview of the steps necessary to progress from a CAD-designed composite part to CNC programs that can drive an AFP or ATL machine. CGTech also will exhibit its latest version of VERICUT CNC machine simulation, verification and optimization software, which enables users to eliminate the process of manually proving-out NC programs. www.cgtech.com

Composites for infrastructure applications

The **Center for Integration of Composites into Infrastructure** (CICI, Morgantown, WV, US) was established with a US National Science Foundation (NSF) planning grant in 2008 and full grant in 2009, and is currently in its seventh year of operation. CICI is the only NSF Industry/University Cooperative Research Center that is focusing on polymer composites for infrastructure applications. Its primary objective is to usher in innovative new applications and cost-effective rehabilitation schemes, moving composites in civil and military structures, to the next level through collaborative research between member universities in collaboration with both the composites and construction industries. In addition to exhibiting, Dr. Liang of the CICI West Virginia University group will conduct a session, titled, "Fiber-Reinforced Polymer Composites for Infrastructure Applications," to introduce the CICI, its programs, and accomplishments thus far, and showcase ways the Center's R&D efforts have met market needs. The session also will solicit market needs from composites professionals and owners of infrastructure systems and call for participation in CICI's Industrial Advisory Board. cici.um-sml.com

Water-based mold release systems

Chem-Trend (Howell, MI, US) will showcase its Chemlease and Zyvax brands, updated most recently by development of water-based release systems that reportedly perform as well or better than conventional solvent-based products. Reported advantages include increased throughput by minimizing mold fouling, improved part cosmetics and reduced part rework. Chem-Trend's water-based alternatives also afford application flexibility because they can be applied by wipe or with spray equipment onto ambient or hot tooling. www.chemtrend.com

Electric, vacuum-equipped sanders

Clayton Associates Inc. (Lakewood, NJ, US) is featuring its new line of electric-powered vacuum sanders for composite repair and manufacturing. These electric tools reportedly have the power and performance of conventional pneumatic sanders, but are quieter and use no oil, eliminating the possibility of contaminating the composite substrates with oil-laden exhaust oil found on pneumatic tools. Available in a variety of sizes, these tools are set up for connection to a portable or central vacuum to collect up to 99% of airborne particulate. www.vacuumsanding.com

Low-mass, hollow stainless steel screws

Click Bond (Carson City, NV, US) will showcase its new LoMas screw. This product reportedly offers significant weight savings for aircraft and other weight-sensitive applications. Its new A286-grade stainless steel screw is as much as 50% lighter than common steel alternatives and as much as 17% lighter than those made of titanium. The key to the LoMas screw design is that it's hollow — the "low-mass" design approach is successful because of a proprietary deep-draw manufacturing process which reportedly results in an excellent strength-to-weight ratio. The LoMas screw features a unique captive washer that reduces parts count and minimizes the risk of foreign object debris (FOD). Another element of the LoMas screw is its dual-drive design, allowing for both internal NAS 1800 and external hex head capabilities. It's initially available in 10-32 thread format, in 15 lengths (from 0.250-2.00 inches), with a variety of coatings. Other inch and metric sizes will follow. www.clickbond.com »

Easily machinable tooling board

Coastal Enterprises (Orange, CA, US), manufacturer of Precision Board high-density urethane (HDU) tooling board, is introducing its new No-to-Low Dust CNC-machinable Precision Board. This material is said to offer good physical properties, sharp edges and minimal dust during machining. The latter claim will be substantiated in its booth, via a video of Precision Board being machined. Coastal also will offer samples of all 15 densities of the material, rated at 200-300°F (93-149°C). Also on display will be small-scale Precision Board prototypes of custom-bonded HDU composite layup tools and a custom-bonded HDU filament winding mandrel. **www.precisionboard.com**

Commingled and twisted yarn fabrics

Coats (Stockley Park, Uxbridge, UK), will launch Coats Synergex, a range of advanced composite fibers that can be processed into fabric form, using many methods, including commingling and twisting. The thermoplastic and reinforcement fibers can be commingled to meet strength, weight, performance and recyclability requirements. The fibers can be embroidered directly into complex shapes that can be metal-pressed to mold parts. Earlier this year, Coats announced a partnership with Elemental Motor Co. (Waterlooville, UK). The ultra-lightweight wheel arches of Elemental's new *Rp1* sports car have been developed using Coats Synergex, and visitors to the Coats stand at CAMX will be able to see and handle a wheel arch as well as sample commingled and twisted yarns that will be on hand. **www.coatsindustrial.com**

Live closed molding demonstrations

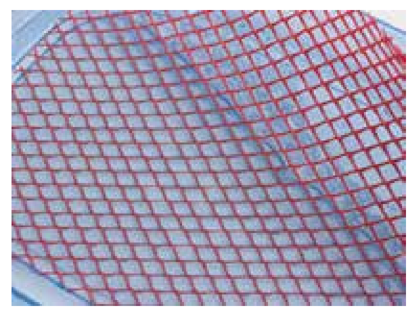
Composites One (Arlington Heights, IL, US), in league with the Closed Mold Alliance, will present its Lean Mean Process Machine demonstrations live on the exhibit floor on all three days of the event — more than 15 process demos, total — in a massive enclosed staging area. Real-world parts will be built, from UAVs and automotive parts to marine dashboards and carbon fiber skateboards to columns repaired with a carbon fiber wrap system and park benches produced from a mold made from silicone. Attendees will see a light RTM workcell in action, producing pipe flanges with corrosion-resistant materials and, for the first time ever, a live SMC/compression molding demonstration, as well as new tooling product technology from Guru by Soul Composites (Ft. Collins, CO, US). Other product partners include 3A Composites, AOC Resins, Airtech International, Ashland, AxsonSika, ChemTrend, Chomarat, Huntsman, Magnum Venus Plastech, Owens Corning, Polynt Composites, Polytek, Sworl, United Initiators, and Vectorply Corp. Tooling is provided by Arrowhead Plastic Engineering Inc. and RTM Solutions; machinery is from Wabash MPI/Carver Inc. **www.compositesone.com**

CNC machining: Real-time monitoring

Machining and machine tool specialist **C.R. Onsrud Inc.** (Troutman, NC, US) will present its CNC machinery as well as its Osync CNC monitoring interface. The company says Osync gives production managers real-time monitoring for their C.R. Onsrud CNC machinery. It also provides live feedback to C.R. Onsrud tech support team in Troutman. **www.cronsrud.com**

Resin infusion/RTM flow media

DelStar Technologies Inc. (Middletown, DE, US) is featuring its Naltex extruded-netting flow media for advanced composite fabrication technologies, including resin infusion and resin transfer molding (RTM). DelStar says the bi-planar design of its netting provides consistent channels that increase flow rates while evenly distributing resin. By offering media with different strand counts, thicknesses and angles, Delstar says it gives customers the option of moving the resin quickly or slowing it down. In addition to Naltex extruded netting, DelStar manufactures Delnet apertured films, DelPore meltblown media, Stratex engineered composites and Alphastar electrostatic media. **www.delstarinc.com**



Modular system enables wet/dry tensile testing

Dia-Stron (Broomall, PA, US) will showcase its automated modular testing systems for single fibers and filaments. The company now offers a new tensile testing configuration based on the LEX820, a high-resolution tensile tester for single fibers and filaments. In this configuration, fiber samples can be measured in uniaxial tensile mode while immersed in a liquid: There is an immersion cell that can be raised and lowered, enabling dry or wet tensile measurements. Dia-Stron also has developed a "cassette hotel," capable of holding up to 200 samples, allowing for 24/7 measurement capability. With increased pressure on internal testing departments to improve testing throughput times and capacity, the hotel can be loaded live during measurements. The Dia-Stron LEX/LDS System is a cassette-based automated dimensional and tensile instrument for composite fibers and filaments. **www.diastron.com**

Thermoplastic honeycomb core

EconCore (Leuven, Belgium) will emphasize the cost advantages of its patented technology for continuous production of thermoplastic honeycomb sandwich materials. Its process integrates three steps: vacuum forming extruded film to a pattern, mechanical folding to honeycomb core structure, and lamination of skin material to the core. The method accommodates a wide range of thermoplastics and is used to produce sandwich materials for applications that range from reusable packaging and graphical displays to automotive, transportation, building and construction and marine applications. EconCore will showcase a number of sandwich materials produced today by its licensees.

Joining EconCore in Anaheim will be spinoff firm and licensee **ThermHex Waben GmbH**, using the patented technology. Special emphasis by EconCore will be placed on developments with metal skin composite sandwich materials and applications, including building and construction, signage, transportation, commercial furniture, as well as glass fiber-reinforced thermoplastic skin sandwich materials for transportation, air cargo ULDs, scaffolding, temporary shelters and field hospitals. www.econcore.com

Static table cutting system

Eastman Machine Co. (Buffalo, NY, US) will present its Eagle S125 Static table cutting system, a solution for both R&D and production cutting of nested pattern pieces from dry and prepreg composite materials in sheet or roll form. Engineered with an industrial design for rigorous use, the S125 includes an advanced electro-pneumatic regulator for precise tool pressure control, built-in surge protection, heavy-duty cable connectors, and a heavy-gauge steel construction with scratch-resistant powder-coated finish.

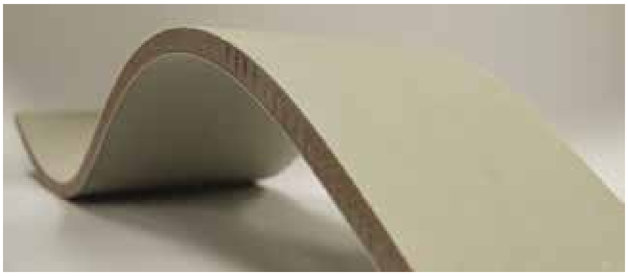
It may be configured in various widths and lengths to match customer requirements. A range of tool head accessory options for marking and printing as well as various cutting surfaces are available to optimize cutting results for any given material. Eastman's line of manually operated cutting machines also will be available for demonstrations and configured for composites applications. Model features are developed in response to new and high-tech materials cutting requirements. Also on offer: Eastman's Cardinal round knives, which are designed for a wide range of applications, including various complex composite blends. www.eastmancuts.com

High-temp urethane foam core

Elliott Co. of Indianapolis Inc. (Indianapolis, IN, US) will feature its line of rigid polyiso/urethane foam core materials. Supplied as blocks, sheets and custom shapes, ELFOAM products are chemically resistant and able to handle ±300°F/±150°C temperatures. Depending on design requirements, ELFOAM's ability to provide insulation, fire resistance and high strength-to-weight performance also can be of value in a variety of panel, tank, slope, insert and equipment applications. www.elliottfoam.com

Custom-designed ovens and furnaces

Epcon Industrial Systems LP (The Woodlands, TX, US) will emphasize its design and manufacture of custom ovens and furnaces. Epcon notes that its engineers conduct extensive design research with each customer to ensure quality and performance based on the customer's needs. Epcon is currently designing a series of large ovens for curing and heat treating, for a Tier 1 supplier to the aerospace industry. Epcon holds several patents on designs for various applications, including combination systems that incorporate industrial ovens, thermal oxidizers and heat exchangers. www.epconlp.com »



Foam core materials

General Plastics Mfg. Co. (Tacoma, WA, US) will feature its FR-3800 FST composite core series. Also featured will be its FR-4700 high-temperature tooling board. The LAST-A-FOAM FR-3800 FST is the first halogen-free polyurethane foam that satisfies fire, smoke and toxicity (FST) requirements and Ohio State University (OSU) heat-release standards. It withstands process temperatures up to 310°F/154°C. General Plastics says this material is a good alternative to PVC foam and honeycomb. It is available in custom sizes and thicknesses, in densities of 3-40 lb/ft^3. LAST-A-FOAM FR-4700 high-temperature tooling board is a high-density, rigid urethane tooling board that withstands peak temperatures up to 400°F/200°C, and continuous-use temperatures up to 350°F/177°C. It is dimensionally stable, nonabrasive and can be machined with standard, high-speed steel cutting tools. www.generalplastics.com

Meter, mix and dispense systems

Graco Inc. (Minneapolis, MN, US) will highlight its PR70 benchtop meter, mix and dispense system, hydraulic fixed-ratio (HFR) metering system, and fiber-reinforced plastic (FRP) chop systems. The Graco PR70 fixed- and variable-ratio systems accurately meter, mix and dispense medium- to low-viscosity materials for potting, gasketing, sealing, encapsulation and syringe filling. Available in several different system configurations, the PR70 series is capable of handling a wide range of material formulations with ±1% accuracy. Also on display will be the Graco HFR Metering System, which packs advanced technologies and precision dispensing into one compact, affordable system. Graco's flexible and precise fiber-reinforced plastic (FRP) chop systems, also to be showcased at CAMX and are ideal for molded fiber-reinforced plastics, such as those used in marine applications. www.graco.com/cwfrp

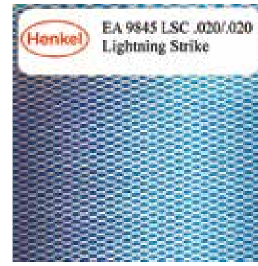
Direct-flow spray equipment

GS Manufacturing (Costa Mesa, CA, US) will introduce its now patented and trademarked X-GUN, which has a patented direct-flow design that reduces clogging and requires less fluid pressure. X-GUN features a proven pneumatic ball-valve design to eliminate troublesome needles, and has no exposed moving parts. It is ideal for high-viscosity and heavily filled materials, such as sprayable granite coatings and core materials. The X-GUN also can be used for gel coat, chopping, wet-out, resin transfer molding (RTM) and adhesive dispensing. With its modular component design, spare parts are interchangeable, which allows a customer's maintenance team to stock fewer part numbers. www.gsmfg.com

Advanced carbon fiber oxidation ovens

Harper International (Buffalo, NY, US) will exhibit its advanced carbon fiber oxidation oven technology, which complements its furnaces for carbon fiber processing. Harper's state-of-the-art oven designs are available for towbands from 300 mm to greater than 4,000 mm and reportedly incorporate a multitude of improvements that boost energy efficiency, minimize the chimney effect, improve throughput velocity, product uniformity and output range, and optimize control of the reaction, which ultimately enhances overall fiber quality. The company's most recent 3m-wide, production-scale oxidation oven demonstrates air velocity uniformity, at 2.2%, and temperature uniformity of ±2.5°C throughout the heated length. A technical presentation, titled, "Enabling a step change in single-line carbon fiber production capacity through advanced high precision large-scale thermal processing equipment," will be presented by Harper's technology experts, who will be available at the booth to discuss oxidation oven technology. www.harperintl.com

Structural paste and film adhesives



Henkel (Düsseldorf, Germany) will highlight its adhesive solutions and mold releases. A key product line in the showcase will be trademarked LOCTITE 9845 Aero epoxy-based surfacing films for composites, which contain lightweight conductive foils to offer honeycomb-cored composites enhanced protection against lightning strike. This out-of-autoclave-capable product reportedly enables a weight savings of 30%, while producing high-quality finished parts. Henkel also offers composite repair solutions to simplify repairs to damage caused by lightning, providing solutions across the aerospace lifecycle. A Henkel technical paper on fast-cure liquid shim materials for structural bonding with long-term durability and fatigue resistance. www.henkel-adhesives.com/aerospace

RTM process automation

Hennecke Inc. (Lawrence, PA, US) will showcase the results of partnering with technology specialists and parts manufacturers to advance the science of composite materials processing. The company will display parts that represent the fruits of these collaborative efforts. Hennecke » and automaker Audi (Zwickau, Germany), for example, refined a high-pressure resin transfer molding (HP-RTM) process to efficiently and economically produce a composite B-pillar, replacing a much heavier steel predecessor. Hennecke also will feature a lightweight automotive latch cover made from carbon-reinforced plastic (CFRP) for the *X-Bow* sports car, manufactured collaboratively on Hennecke's STREAMLINE HP-RTM machine and a "duo" vertical, large-scale machine from ENGEL (Schwertzberg, Austria), resulting in precise control of process automation and cycle time and considerable improvements in efficiency, economy and product quality, especially at high volume. Visitors also may view a leaf spring made for the Mercedes *Sprinter* by Benteler Germany via HP-RTM and the Hennecke PUR CSM (polyurethane composite spray molding) process on a machine equipped with a custom mixhead. The result is lightweight but as strong as its metal predecessor, yet more flexible and shock-absorbing, and impervious to rust. **www.henneckeinc.com**

In-mold metalflake and pearlescent gel coats

HK Research Corp. (Hickory, NC, US) will unveil its designer metallic and pearl gel coat series, which will reportedly enable the composites industry to mimic the new standard in automotive finishes with an in-mold polyester composite coating, and satisfy industry requests for matching the look of today's current trends in automotive. HDX-Metal Flex comes in a wide range of colors, and new colors can be custom formulated from a variety of metalflake colors as well as custom-tinted backgrounds. HDX-Clear offers greater flexibility for the composites manufacturer, and uses a standard metallic "fleck" backed up by standard or new colors customers may request. Both products are based on HK's NPG/ISO clear gel coat technology that has a proven track record over 15 years. **www.hkresearch.com**

Engineered core and more

Hexcel (Stamford, CT, US) will promote composites innovations for aerospace, automotive and recreational equipment. Boeing's 737 MAX aircraft's LEAP-1B engines from CFM International contain an acoustic inner barrel manufactured from Hexcel's trademarked Acousti-Cap engineered core technology, which has individually embedded permeable cap material in each honeycomb cell to create an acoustic septum for reduced noise. It's a leading contributor to the 40% reduction of the area of acceptable noise contour of the 737 MAX engine.

Glass and carbon fiber composite leaf springs for heavy vehicles save up to 70% in weight, offer high corrosion resistance, optimized system integration, improved riding performance and superior fatigue performance. Hexcel's fully industrialized and trademarked HexPly M9 resin family allows for the fast and effective manufacturing of preforms for springs with excellent mechanical performance at competitive costs.

Also on offer will be Hexcel's MiMax multiaxials, made with trademarked PrimeTex ZB, carbon fabrics that are processed for a smooth, closed weave and uniform cosmetic appearance. Their fiber tows are spread, using a special process, in both the warp and weft direction, creating a thinner and more closely woven fabric that reportedly provides better mechanicals and less porosity in a composite and can be used to reduce part mass in products that include hockey sticks, which will be on display. Hexcel continues production of trademarked HiMax multiaxial reinforcements, since acquisition of Formax UK earlier in 2016, allowing manufacturers to process multiple layers of unidirectional fibers in a single fabric. To showcase these innovative reinforcements, Hexcel will be displaying a surfboard made from HiMax carbon fiber multiaxial reinforcements. **www.hexcel.com**

Epoxy and urethane systems

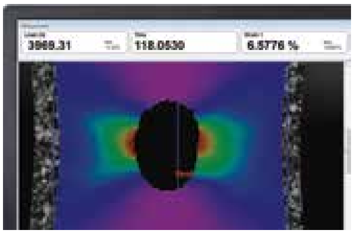
Huntsman Advanced Materials (The Woodlands, TX, US) and **Huntsman Polyurethanes** (Auburn Hills, MI, US) will highlight trademarked ARALDITE LY 3585 epoxy resin with ARADUR3475 hardener, an easy-to-handle, flowable epoxy system for wet compression molding. Cure cycle options range from 65 seconds to 1 hour, depending on part size and mold temperature. Composite parts compression molded with the epoxy system exhibit high shear and impact strengths and glass transition temperatures in the 230°F to 260°F (110°C to 126°C) range. Addtionally, trademarked VITROX HC 98010 polyol/SUPRASEC 9801 isocyanate is a novel polyurethane system that features a low, stable initial viscosity with minimal viscosity increase for thorough fiber impregnation during wet compression molding or spray processing. Tunable reaction times and a snap cure make the products ideal for use on large parts, and they impart good properties with strong adhesion to honeycomb core and reinforcement fibers for good impact strength and toughness. Also atCAMX will be new trademarked EPIBOND epoxy structural adhesive, a next-generation epoxy for aerospace applications with high peel and shear strengths on a variety of substrates. Easy to mix and apply, it can be used at temperatures up to 230°F (110°C). www.huntsman.com/advanced_materials | www.huntsman.com/pu

R&D center opening/50th anniversary celebration

IDI Composites International (Noblesville, IN, US) will highlight the opening of its IDI 3i Composites Technology Center, created to help innovative customers meet their engineering and performance challenges and help them "go beyond the value limitations of conventional materials." Launched in conjunction with IDI's 50th anniversary, the Center is located within the company's Noblesville facility and will serve as the R&D division of IDI Composites International. The Center is equipped with state-of-the-art equipment and connected technology to partner with OEMs and molders to streamline and efficiently manage the breakthrough cycle for the formulation, testing and manufacturing of composite materials. www.idicomposites.com »

Non-contact precision measurement

Imetrum (Bristol, UK) will promote its new integrated material testing system, UVX, which will be available later this year. Designed to seamlessly integrate with the majority of manufacturers' test machines, UVX's



Interchangable extensometer modules simplify testing across commonly used gauge lengths and specimen sizes. The system also is designed to handle a large percentage of ASTM test methods and uses standard material testing language and terminology. The UVX flexi video extensometer, for complex testing, has received certification, proving its accuracy and suitability to a standard equivalent to ASTM E83 B-1.

UVX is based on Imetrum's trademarked Video Gauge software, characterized by its measurement resolution, accuracy, versatility and efficient work flows. Measurement tools are available including two- and three-dimensional optical LVDTs and measurement of true shear strain. Imetrum will demonstrate one of its software tools, Strain Map, which is application-specific and measures and displays strain and displacement gradients, making it a good overview before point-to-point measurement. www.imetrum.com

Olefin-based fiber reinforcements

Innegra Technologies (Greenville, SC, US) will hold its 5th anniversary celebration at the show, while demonstrating how products reinforced with Innegra olefin-based fiber can add value. The company has demonstrated damping, impact resistance, lighter weight, and unmatched toughness in a variety of applications, including many sporting goods, automotive, marine, industrial, wind, medical, blast containment, rope,

netting and more. Products will include Innegra S fiber, an olefin-based, multifilament yarn available in black and white, and Innegra H fibers, hybridized, multifilament yarns that contain Innegra S combined with other high-performance fibers, such as carbon, glass, basalt and aramid. Innegra reinforcement materials are available in woven fabric, multiaxial fabric, scrim, braids, tapes, uni-directional, spread tow, knit and prepreg. In addition, Innegra can be processed in filament winding and pultrusion applications. www.innegratech.com

Contract table rolling/compression molding services

Innovative Composite Engineering (ICE, White Salmon, WA, US) will showcase its capabilities in the areas of tubing production and molding of complex shapes. Able to support every aspect of a project — engineering, design, tooling, testing, manufacturing and product analysis — ICE reportedly can produce tubing from less than 0.1 inch to more than 24 inches (2.54 mm to 610 mm) in diameter via table rolling, in lengths to 18 ft (5.5m). Bladder and compression molding are also offered for highly complex shapes, to high tolerances. The company can work with any prepreg reinforcement fiber type including exotics, and a full range of resins. www.innovativecomposite.com

Engineering/manufacturing services

Janicki Industries (Sedro-Woolley, WA, US), a full-service engineering and manufacturing company, specializes in manufacturing composite and metal parts and tools across all industries, including aerospace, marine, energy, military, space, transportation and architecture. The company will acquaint booth visitors with its large-scale, high-precision 5-axis mills (30.5m by 6.1m), large autoclave (3.7m by 15.2m), 1,100-ton press and large annealing oven. Janicki's extensive in-house tooling and part development experience encompasses a wide variety of composite material systems, including carbon fiber, carbon/glass hybrids, polyurethanes, as well as Invar and steel for tooling. www.janicki.com »

Industrial ovens

LEWCO (Sandusky, OH, US) will exhibit its line of batch, conveyor and field-assembled industrial ovens, and drum/tote heaters. The company's control packages are designed in-house by experienced controls engineers, and include temperature management via simple microprocessor instruments or LEWCO's proprietary software package. The latter is easily customized to meet a wide range of customer requirements. An extensive list of standard options is available, including but not limited to vacuum ports and pumps, transducers, thermocouple jack panels and data-acquisition hardware/software. Control packages are available to meet many industry standards, including AMS2750 and BAC5621 requirements. Ovens reportedly meet the most stringent performance requirements for government and aerospace applications. Temperature uniformity is achieved due to LEWCO's plenum design and effective airflow distribution techniques. The company holds ISO 9001 certification, Six Sigma and service/quality initiatives, and performs root-cause analysis to continuously improve its manufacturing process. www.lewco.com

Feeding and tensioning devices

Izumi International Inc. (Greenville, SC, US) has provided cutting-edge winders, creels, warp and weft feeding and tensioning devices since 1977 for carbon fiber and other critical high-performance fibers in the US and Europe. The company also exports textile machinery parts produced by American companies to Japan and Southeast Asia. At the show, Izumi will showcase its specialty machinery for the textile industry and offer customers technology consulting in the area of fiber handling. On display will be linear motion systems and rodless air cylinders. www.izumiinternational.com

Processing equipment and support

Magnum Venus Products (MVP, Knoxville, TN, US) will feature its full line of pumping systems, spray guns, filament winding systems and more. MVP serves several manufacturers in a variety of industries, including automotive, aerospace, transportation, marine, railway, oil and gas and wind energy. MVP also offers equipment that supports the foam and polyurethane industries, along with polyureas, adhesives and epoxies. www.mvpind.com

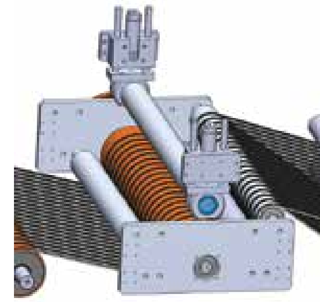
Phenolic resins for inherent FST performance

Mektech Composites Inc. (Hillsdale, NJ, US) is featuring the Cellobond line of phenolic resins, which it distributes for **Hexion Inc.** (Columbus, OH, US). Originally developed by BP Chemicals in the UK, they can be processed at low temperature and used in hand layup, sprayup, vacuum infusion, resin transfer molding (RTM), filament winding, pultrusion and press molding to produce composites with excellent inherent flame, smoke and toxicity properties as well as high-temperature resistance. Cellobond phenolic composites are predominantly used in mass transit, architecture, corrosion, tunneling and ducting and marine applications. Mektech also will feature Durite SC-1008 (meets MIL-R9299C, Grades A and B requirements), which is used to produce prepreg in aerospace and military applications. www.cellobond.com

Temperature control for water circulation systems

Mokon (Buffalo, NY, US) will feature its redesigned Full Range temperature control system for circulating liquids. The control system combines a circulating water system and an Iceman chiller to provide heating and chilling from a single, self-supporting unit. The Full Range system is available in standard heating capacities up to 96 kW, pumping capacities up to 120 gal/min, chilling capacity up to 40 tons and a temperature range of -20˚F to 300˚F (-29˚C to 149˚C). Standard features include stainless steel centrifugal pumps, an efficient brazed plate evaporator, insulated nonferrous plumbing and components, microprocessor-based controller with LED readout, NEMA-rated electrical enclosure with safety disconnect switch, and a heater canister with stainless steel diverter. Mokon builds heating/cooling systems for a variety of applications, including autoclaves, compression, transfer and injection molds (water and oil) and wash-down facilities. www.mokon.com

Multi-tow tension control system



Montalvo Corp. (Gorham, ME, US) will demonstrate its latest multi-tow tension control solution, the Automated Tension Stand (ATS), along with its single web-tension control components. Designed for use in multi-tow applications, the ATS is a drop-in system for existing and new applications, providing a new tensioning zone for every tow, prior to processing. Montalvo says uniform, precise tension is maintained on each tow automatically and continuously throughout processing, maximizing productivity and end-product quality. Montalvo also will highlight its single web-tension control » components used in hand-lay, laminating and converting applications, such as load cells, tension controllers, sensors, safety chucks, brakes and clutches.

Montalvo will deliver a presentation titled "Achieving Automated Tension Control for Multi-Tow and Single Web Composites Manufacturing." It will provide real-world examples of tension-control applications and how components integrate into converting, pultrusion, hand layup, filament winding and prepreg processes.
www.montalvo.com

Thermal analysis systems

Netzsch Instruments North America LLC (Burlington, MA, US) will spotlight three products in its thermal analysis and thermophysical property measurement equipment line: DEA 288 Epsilon, DSC 214 Polyma and DMA 242 Artemis. The DEA (dielectric analysis) unit is employed to monitor the changes in viscosity and cure state of thermoset resins and adhesives, as well as paints and coatings. The DSC (differential scanning calorimeter) is optimized for ease of use in composites analyses and quality control. It measures curing, melting, crystallization and glass transition temperature. The DMA (dynamic mechanical analyzer) system tests the viscoelastic properties of adhesives, rubbers and composites. Netzsch also offers process-control instruments for in-situ cure monitoring. www.netzsch-thermal-analysis.com/us

Superabrasive milling/cutting tools

Niabraze LLC (Tonawanda, NY, US) is featuring at CAMX its line of superabrasive electroplated and brazed products used to cut, mill and grind hard materials, including composites. Electroplated tooling's high diamond exposure is said to provide a free, fast cutting action with better removal rates and less thermal damage than conventional tooling. Niabraze notes that with brazed tooling, superabrasives are chemically bonded to the substrate, making the diamonds part of the tool. This reportedly provides the user with a high-performance, efficient and aggressive tool that can withstand higher rotation speeds and heat during the grinding and cutting process. Products include bandsaw blades, circular saws (from 1 inch to 49 inches in diameter), mounted wheels, hole saws and router bits. www.niabraze.com

Computed tomography equipment

North Star Imaging (Rogers, MN, US), a manufacturer of computed tomography (CT) systems for nondestructive evaluation (NDE) of composite parts, will feature its X5000 system for large-part inspection. CT systems inspect the inside of the composite structure and then generate a 3D model of the part, doing so with relatively high resolution. The 3D rendering capabilities of efX-CT, from NSI software, allow users to generate multiple virtual cross sections through the part in multiple axes, and the resolution achieved reportedly often allows visibility of individual fibers. Delaminations and wrinkles are detectable; porosities are quantifiable and measurable. North Star Imaging also reports that CT is able to measure fiber orientation. www.4nsi.com

Temperature monitoring systems

PakSense (Boise, ID, US) is exhibiting its temperature monitoring solutions, designed to help users determine the quality and safety of environmentally sensitive goods. The company says its solutions address all supply chain segments, including in-transit, facility monitoring, last mile and import/exports. Modular in nature, the solutions can be bolted on to each other, providing overarching visibility of a supply chain. Products range from single-use temperature loggers to automated, real-time monitoring systems. www.paksense.com

Nondestructive inspection systems

Olympus (Waltham, MA, US) will feature its range of composite inspection solutions, including the RollerFORM phased array wheel probe, designed to inspect composites and other smooth-surfaced materials. The tire material of the RollerFORM wheel probe has been developed for high-quality, immersion-like ultrasonic testing. The material closely matches the acoustic impedance of water and permits the efficient transmission of energy to the part. Minimal couplant and pressure are required for its wheel probe to provide coupling and a strong signal, even in difficult scanning positions. The system offers a 25-mm water delay line that enables inspection of composites up to 50 mm thick, and up to 51.2-mm wide beam coverage. The RollerFORM wheel probe, combined with a phased array instrument, such as an OmniScan flaw detector or the FOCUS PX data acquisition instrument, uses 0° ultrasonic beams for manufacturing and maintenance inspections. Common applications include sizing delaminations and quantifying porosity in composite core material. With an integrated indexing button, the RollerFORM wheel probe enables users to map the surface of an inspected material by acquiring multiple one-line C-scans and then combine them in real time into a single image. The built-in laser guide facilitates straight and precise one-line scans. www.olympus-ims.com »

Out-of-autoclave tooling

Penso Group Ltd. (Coventry, UK), in partnership with **JE Engineering** (Coventry) and **Nottingham University** (Nottingham, UK), is featuring in its CAMX booth the results of work they've done on Affordable Carbon Fibre (AffCAR) for the UK niche-vehicle sector. The aim of the AffCAR project was to reduce the cost of vehicle parts and tooling for lightweight structural body panels and deliver a more robust and controlled process outside of the autoclave. AffCAR is now the moniker for a hybrid composite tooling technology known internally as pressclaving, which offers low tooling costs and reduced cycle times, with the potential to support automaker efforts to reach the impending 2020 European vehicle emission target of 95g CO_2/km and become a feasible manufacturing process. AffCAR has been demonstrated on an engine hood for JE Engineering's existing Defender Zulu vehicle. The weight of the panel, with lacquer applied, reportedly achieved a mass saving of 69% against the original steel hood. **www.penso.co.uk**

C-scan ultrasonic inspection system

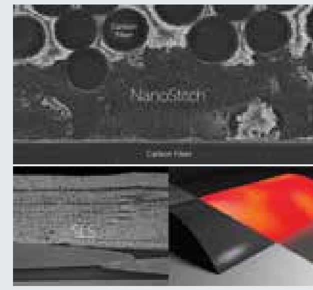
Phoenix Inspection Systems Ltd. (Warrington, UK) designs and manufactures ultrasonic, nondestructive testing (NDT) scanners and transducers for the inspection of composite materials. Its exhibit will introduce CAMX visitors to R-Evolution, the company's ultrasonic array probe, housed in a lightweight, water-filled roller, which delivers fast, immersion-quality C-scan inspections. Ergonomic in design and weighing just 1 kg, R-Evolution is designed to minimize operator fatigue, in particular, when inspecting large areas and during overhead inspections. Also featured is Tracer, a freehand scanning solution that provides x-y positions for C-scan inspections without the constraints that a scanning frame imposes in difficult-to-access areas. The low-cost, lightweight system is reportedly easily carried to a remote inspection site and is quick and simple to set up and dismantle. It is ideal for use with linear phased-array NDT technology to provide fast large-area coverage. Finally, Phoenix ISL is emphasizing Wrap-It, used to inspect complex curves and radii in composite components. A flexible ultrasonic phased-array tool that can be wrapped around a curved surface, Wrap-It can operate on concave and convex geometries. Its conformable ultrasonic phased-array transducer is housed in a rubber enclosure formed to the nominal curvature of the component, and it self-adjusts to changing geometry. **www.phoenixisl.com**

Curing blankets

At CAMX, **Powerblanket** (Salt Lake City, UT, US) is showcasing its epoxy curing blankets, which insulate and distribute regulated heat to the entire surface area of application. With blankets designed specifically for epoxy and resin curing in composite materials, and with the option for custom design, the Powerblanket line has been developed to replace curing ovens and heating elements. Further, Powerblanket curing blankets can be paired with temperature controllers for temperature regulation and programming, including staging and ramps.
www.powerblanket.com

Nano-enhanced prepreg materials

N12 Technologies Inc. (Cambridge, MA, US) is featuring NanoStitch, an interlaminar toughening product based on large-format, vertically aligned carbon nanotube (VACNT) sheets. VACNTs positioned in the z-axis, embedded vertically through the interlaminar layer, suppress delamination and enhance thermal and electrical through-thickness conductivity. In CFRP prepreg systems, NanoStitch is said to significantly improve a range of mechanical performance parameters and fatigue life by 100 times. NanoStitch is manufactured by, and applied onto, prepreg by N12. End-users then manufacture parts from the nano-enhanced material, using conventional processes for lamination, debulk, cure and machining. N12 also will introduce a new product, SLS, which takes the same mass-produced VACNTs and knocks them down into the horizontal plane. This creates a precisely engineered, nanoscale layer of trillions of CNTs that deliver highly efficient, lightweight (e.g., 1-2 g/m^2) resistive-heating and electrical-sensing capabilities. Applications for transfer of heat, power and/or data in-plane offer the potential for multifunctional capability. www.n12technologies.com »



Three new fibers and three papers

PPG Industries Inc. (Pittsburgh, PA, US) will introduce new additions to the HYBON direct single-end fiberglass roving line, the TUFROV long-fiber thermoplastic line and the INNOFIBER specialty glass composition product line. Jacob P. Anderson, PPG's senior project R&D engineer, will present a paper titled, "Effect of Preheating and Size on the Mechanical Performance of Thermoplastic Flake Molding Compound (FMC)." It explores the relationship between flake preheating and size on mechanical performance and demonstrates how increasing preheating temperature and flake length can improve the tensile, flexural and impact performance of FMC panels. PPG technical experts also will offer presentations at the conference. Senior project R&D engineer Sandeep Vennam will present, "Performance Drivers on Fatigue Properties of Glass Fiber Composites," which examines the effects of key performance variables, such as filament diameter, linear density and areal weight on fiberglass composites, and recounts experiments that demonstrate how to significantly improve fatigue performance of large-filament-diameter glass fiber by modifying the fiber processing parameters. Pu Gu, PPG's senior research associate, will present "Durability of Glass Fiber Reinforced Composites in Seawater and Alkaline Environments: The Interface Factor." This third paper investigates the effect of different fiber-matrix interfacial treatments on the durability of glass-fiber-reinforced vinyl-ester and epoxy composites in seawater and alkaline environments. **www.ppgfiberglass.com**

New facilities, expanded services

Pacific Coast Composites (Puyallup, WA, US) distributes advanced composites materials globally and has moved to a new, larger facility in Puyallup. The move expands the company's capabilities with a new processing room and more than 10,000 ft^3 (283m^3) of calibrated, certified freezer space. Pacific Coast Composites also has been awarded a new line of Hexcel dry fabrics. Other services include custom cutting and kitting, slitting and inventory management. **www.pccomposites.com**

Epoxies, acrylics and MMAs

Permabond Engineering Adhesives Ltd. (Somerset, NJ, US) is featuring its expanded composite bonding adhesive line. The line includes single-component epoxies, two-component epoxies, two-component modified epoxies, surface-activated acrylics and methyl methacrylates. Benefits of this technology set include flexible and rigid products with high peel strength and impact resistance; a variety of cure speeds, from seconds to hours; a variety of cure methods to suit production needs; environmental durability; ultimate strength performance and fatigue resistance; and color-matched products available for carbon fiber and glass fiber composites. www.permabond.com

Polyester and vinyl ester gel coats & resins

Polynt Composites (Carpentersville, IL, US) will feature its expanded gel coat line, with two technologies under the Fusion and Impulse product names. Polynt also will feature a new generation of polyester resins under the ARMORSTAR XT product name. A new version of its Core Shell Rubber Vinyl Ester (CSRVE) will be highlighted in the Composites One Demo Zone. Fusion gel coats come in what are said to be bold, rich colors, with good blush resistance, flexibility and

(continued on p. 69)

Multifunctional nonwoven reinforcements

Technical Fibre Products Inc. (TFP, Schenectady, NY, US) will exhibit a new nano-functionalized nonwoven. TFP says incorporation of nanomaterials, such as carbon nanotubes or nanofibers, into or onto a nonwoven, can provide multiple benefits, including enhancement of surface conductivity, EMI shielding, thermal management and structural properties. TFP also will exhibit its novel Tecnofire nonwovens, which provide composites with built-in fire protection. Fabricated from high-temperature-resistant fibers, these resin-infusible materials are incorporated at the surface of a composite, imparting fire protection where it is needed. Activated by high temperatures, Tecnofire expands and protects the underlying structure, improving fire, smoke, toxicity (FST) performance without the structural compromises or time-consuming application associated with alternative technologies. A new development in this range is a Tecnofire grade that can be activated on demand, without heat. The intumescent mat has been designed for use in a remotely activated fire protection system and, due to the presence of conductive fibers, has the added benefit of acting as an EMI shield.

Also on display: TFP's extended range of high-performance veils made from thermoplastic fibers, including polyphenylene sulphide (PPS), polyetherimide (PEI), polyetheretherketone (PEEK), polyamide and polyimide, are designed for use in carbon fiber composites as enhancing interleaves. It has been demonstrated that they can significantly improve mode-I and mode-II fracture toughness by up to 160% and 430%, respectively. www.tfpglobal.com »

(continued from p. 67)

and MACT compliance. Impulse gel coats offer a sparkling finish and good UV- and weather-resistance. ARMORSTAR XT is a new generation of resins that reportedly offers superior toughness and fracture resistance compared to competitive unsaturated polyesters. Core Shell Rubber Vinyl Ester resin, in the Composites One Demo Zone, will show the and toughness of CSRVE by creating an infused carbon fiber composite skateboard. www.polynt.com/en

Non-MDA polyimides and much more

Renegade Materials Corp. (Miamisburg, OH, US) will show its range of non-MDA polyimide products, available exclusively through co-exhibitor **Maverick Corp.** (Blue Ash, OH). A leading supplier of AFR-PE-4 polyimide prepregs for military applications, Renegade offers its exclusive 700°F (370°C) RM-1100 polyimide prepreg, which is qualified or in qualification at multiple international aerospace OEMs. RM-1100 and Renegade's exclusive 600°F (315°C) MVK-14 FreeForm prepregs are approved for export and offer what is said to be excellent non-MDA options to replace PMR-15 as well as titanium in primary structure. Maverick will feature high-temperature polyimide coatings, molding compounds and RTM resins, including MVK-2066, MVK-10 and J1, along with its line of aerospace-qualified, fully certified compression molded parts and components. Renegade will promote its expanding BMI product line, including prepreg systems (RM-3002 and RM-3004), infusion resins (RM-3000 and RM-3010) and adhesives (RM-3011, RM-3006 and RM-3007). Renegade completed several key qualifications of these products this year in support of new commercial aerospace programs that will ramp up over the next few years. Renegade offers RM-3004 OOA BMI prepreg, for use in aerospace structures and tooling, and will broaden its lineup in this area with the launch of a toughened OOA BMI prepreg (RM-3005) early next year. It also will feature its line of low-dielectric prepreg systems, including a low-cost, modified epoxy (RM-2014-LDk) and cyanate esters (RM-5001 and RM-5003) for radome and satellite applications.
www.renegadematerials.com

Composites manufacturing services

Sanders Composites Inc. (San Diego, CA, US), an operating business of the Integrated Polymer Solutions Group, is featuring in its booth its vertically integrated composites manufacturing capabilities. This build-to-print fabricator serves the aerospace market, including the space travel and unmanned aerial vehicle (UAV) segments. Resources and capabilities are in place for the manufacture of composite structures from carbon and glass fiber, bismaleimide (BMI), phenolic, epoxy and silicone rubber. Sanders also emphasizes efficiency and cost-effectiveness combined with innovative, consultative problem-solving. www.sanderscomposites.com »

Uni tapes, prepregs and more

TenCate Advanced Composites (Morgan Hill, CA, US) is featuring its Cetex family of thermoplastic unidirectional tapes, molding compounds and laminates for use in aerospace, defense and industrial applications, such as automotive, consumer footwear, medical, electronics and oil and gas. Recent innovations include TenCate's line of out-of-autoclave (OOA) prepregs, including TC275-1 with QISO quasi-isotropic triaxial fabrics. This combination of materials reportedly provides greater strength compared to traditional woven fabrics and offers layup efficiencies. This product form is the subject of a joint SAMPE paper with A&P Technology, titled "Comparative Evaluation of Quasi-Isotropic Laminates Composed of Either Braided Triaxial Fabric or Woven Fabric, Including Impact and Laminate Performance," by Mike Braley and Brandon Strohminger of A&P Technology, and Barry Meyers of TenCate Advanced Composites. In composite tooling, recently launched products include TenCate's AmberTool HXR product line, which features a multiaxial ply format that reduces layup time while maintaining excellent handling. **www.tencateadvancedcomposites.com**

Hydraulic compression molding press

TMP (Piqua, OH, US), a division of French Oil Mill Machinery Co., will showcase a new French Vision Series vacuum hydraulic press model, available from 30 to 150 tons, which is specially designed for customers who mold composite parts. The Vision press features electrically heated platens with a steady-state working temperature of 500°F/260°C. The platens are drilled for water cooling circulation. The press construction has slab sides with keyways machined in sets to provide correctly proportional loading and exact parallelism of matching components. Customers may choose from a variety of additional press options, including automated loading and unloading, more robust recipe storage and data collection, high-temperature heated platens and platen cooling. **www.frenchoil.com**

Multiaxial reinforcements

Vectorply Corp. (Phenix City, AL, US) is featuring its VectorUltra line of advanced carbon multiaxial fabrics for composite reinforcement. The line ranges from the 2.94-oz/yd^2 double-bias C-BX 0300, to the 94-oz/yd^2 C-4QX 9400, which is a quadraxial, quasi-isotropic reinforcement made from standard-modulus carbon fiber. Hybrid products, including aramid and E-glass, also will be on display. The C-4QX 9400 fabric, which is balanced and symmetric, is a good fit for tooling, panel and thick-section advanced composite applications. Vectorply's standard

VectorUltra products are offered in unidirectional, biaxial, double-bias, triaxial, quadraxial, and multilayered architectures. Vectorply's director of composites engineering, Trevor Gundberg, will participate in an aerospace textiles panel at CAMX. He will discuss the advantages of non-crimp fabrics in the aerospace market during the panel, which will be followed by Q&A. www.vectorply.com

Carbon fiber/thermoplastic tapes and panels

Victrex USA Inc. (W. Conshohocken, PA, US) is featuring its new carbon fiber/polyaryletherketone (PAEK) unidirectional (UD) tape and laminate panels. Branded VICTREX AE 250 composites, the new product family enables a hybrid molding technology that allows the overmolding of a continuously reinforced thermoplastic composite with VICTREX PEEK injection molding polymers. These technologies can be used in the manufacture of primary and secondary structural aerospace applications, ranging from brackets and clips to clamps and housings. Victrex says the hybrid molding technology delivers a combination of benefits in complex parts that have not been possible until now. In addition, weight savings of up to 60% and up to five times greater specific strength are achievable with the technology when compared to metals.

Frank Ferfecki, senior technical service engineer at Victrex, will deliver a paper at CAMX on the performance of thermoplastic PAEK hybrid composite systems. The paper will present detailed CAE material models developed for each of the individual hybrid components and test results used to demonstrate interface strength between hybrid material components. www.victrex.com

High-temperature contact heating press

Press manufacturer **Wickert Hydraulic Presses USA** (Hebron, KY, US) is featuring a new high-temperature, contact heating press that allows processing temperatures up to 425°C. The machine is targeted toward thermoplastic composites fabrication applications, focusing on local, continuous fiber reinforcement and UD tapes. Maximum product dimensions in this press are 1,100 by 1,100 mm. Heat output is 2 x 50 kW which, Wickert says, allows the press to reach the 425°C maximum temperature quickly. The heating plates feature six-zone temperature control, and temperature control is said to be accurate to ±1.0°C. www.wickert-usa.com

Batch curing ovens

Wisconsin Oven Corp. (East Troy, WI, US) will emphasize its line of electrically heated, gas-fired and indirect gas-fired batch curing ovens for composites. Common oven options include data acquisition instruments, vacuum piping, pumps and transducers. The company says its ovens' several benefits include quick heating rates and recovery times. Each oven features a high-pressure recirculation blower, which includes fully enclosed and pressurized supply ducts. The equipment is designed with a combination airflow arrangement, which ensures uniform heat distribution throughout the work chamber. In addition, the ovens are typically guaranteed and certified for ±10°F at 350°F (±12°C at 121°C) temperature uniformity. Tighter tolerances and certification at other temperatures are available. The batch ovens also are available with the E-Pack Oven energy-efficiency upgrade package, which includes thicker wall panels, higher efficiency motors and other energy saving features.
www.wisoven.com

Industrial-grade carbon fiber

Zoltek Corp. (St. Louis, MO, US) a manufacturer of carbon fiber and fiber forms for industrial applications, will highlight its PX35 product line, a low-cost fiber in various product forms, including tow, chopped, milled and pultruded plate. Zoltek says PX35 delivers strength-to-weight performance equal to or better than many aerospace carbon fiber grades. Based on a polyacrylonitrile (PAN) precursor, PX35 is manufactured with a proprietary high-throughput process that is said to produce an affordable fiber that doesn't sacrifice strength or stiffness. Zoltek's fibers are targeted toward structural reinforcements applications in the wind energy, automotive and marine markets.
www.zoltek.com

Mechanical test frame for composites

Zwick USA (Kennesaw, GA, US) will feature its solutions for composites testing, including the AllroundLine testing machine, available in 100-kN and 250-kN versions. This new solution enables customers to perform more than 20 types of tests in compliance with more than 100 standards. Zwick says the AllroundLine machine features a modular design that minimizes changeover time between tests and

increases throughput. A temperature chamber to accommodate non-ambient testing in the range of -70 to 250°C is optionally available. Tests covered by the new solution range from determining interlaminar shear strength (ILSS) to V-notched shear tests to lap-shear tests. Also included are tests for fracture toughness and a static compression to measure residual strength following targeted pre-damaging of a specimen (compression after impact). Additional fixtures for three- and four-point flexure tests, inter-laminar shear strength (ILSS), and the Iosipescu V-notch shear test may be attached via slide-in inserts used in the tensile grips in place of jaws. Zwick also will display its Hydraulic Composite Compression Fixture (HCCF) test device, which lends support for the complexities present in compression testing. Using HCCF, says Zwick, the clamping procedure is simplified and eliminates wedge movement during the testing.
www.zwickusa.com

CAMX 2016 Exhibitor List

Confirmed exhibitors, according to information available Aug. 22, 2016 for CAMX, Sept. 26-29 in Anaheim, CA, US. Show attendees are encouraged to confirm exhibitor booth locations at the CAMX Web site (thecamx.org) or via the CAMX smartphone app prior to arrival at CAMX.

Name	Booth
A. Schulman Inc.	C82
A.B. Carter Inc.	G48
A.P.C.M. Manufacturing LLC	S58
A&P Technology	P2
AAF International	R78
ABARIS Training Resources Inc.	B1
AC&A LLC	C96
Accudyne Engineering & Equipment Co.	G8
Accudyne Systems	R60
ACE Awards	B106
ACG Materials	Q68
Acrolab	S86
ACS International Inc.	P45
Addcomp North America	Q51
Adesso Advanced Materials Wuxi Co. Ltd.	P86-2
Adhesive and Sealant Council	D97
Adhesive Systems Inc.	S26
Advanced Ceramics Manufacturing	F102
Advanced Composite Materials	Q55
Advanced Composite Products and Technology Inc. - ACPT Inc.	K44
Advanced Composites Inc.	N22
Advanced Plastics	N30
Advanced Technology International (ATI)	N56
Adwest Technologies Inc.	F88
Agilent Technologies	G102
Airtech International	Q2
Akar Makina SAN. ve Tic. A.S	M67
AKPA Organik Peroksit Kimya	G28
AkzoNobel Polymer Chemistry	M72
Albany Engineered Composites	G71
Allnex USA	J90
Alpha Professional Tools	C86
Altair	Q92
AMAMCO Tool	B44
American Colors Inc.	P64
American Composites Mfrs. Assn. (ACMA)	D98
American GFM Corp.	C57
American Rotary Tools Co. – ARTCO	G69

Name	Booth
Americas Styrenics LLC	F48
Andpak/Zip-Chem	J91
AMP Composites Co. Ltd.	B31
Andpak/Zip-Chem	J91
ANF Technology Ltd.	S78
AOC LLC	R12
Applied Aerospace Structures Corp.	D31
Applied Graphene Materials	C85
Aramicore Composite Co. Ltd.	F52
Argosy International Inc.	R55
Arkema Inc.	B6
Armacell Benelux S.A.	R66
ASC Process Systems	M66
Ashland	E14
Assembly Guidance Systems Inc.	C5
Associated Industries Inc.	J12
Autodesk Inc.	F28
Automated Dynamics	C12
AvPro — Advanced Processing Technology Inc.	G62
AXEL Plastics Research Lab	S42
Axiom Materials Inc.	T64
Bally Ribbon Mills	E74
Barrday Composite Solutions	C26
BASF Corp.	U47
Becker Pumps Corp.	H22
Beijing Composite Material Co. Ltd.	S68
Beijing Jiapeng Machinery Co. Ltd.	J99
Berndorf Belt Technology USA	J75
BGF Industries Inc.	J41
Blueshift	F51
Bondtech Corp.	G49
Bostik Inc.	R48
BriskHeat Corp.	E72
Bullen Ultrasonics Inc.	M46
Burnham Composite Structures Inc.	G24
BYK-USA Inc.	F34
C.A. Litzler Co. Inc.	L4

Name	Booth
C.R. Onsrud Inc.	B47
CAMX Awards	M98
Carbon-Core Corp./Spheretex GmbH	P75
Carlson Engineered Composites Inc.	S79
Carolina Narrow Fabric	Q78
Century Design Inc.	H64
Carolina Narrow Fabric	S67
CascadeTEK	C81
Century Design Inc.	H64
CGTech	C18
Changzhou Pro-Tech Industry Co. Ltd.	S67
Changzhou Sunlight Pharmaceutical Co. Ltd.	B25
Changzhou Topweaving New Material Tech Co. Ltd.	U12
Chem-Trend LP	N28
Chomarat North America LLC	P40
Chromaflo Technologies	R42
Cimarron Composites	T85
Cincinnati Inc.	F94
Cincinnati Testing Laboratories	C17
Claremont Flock/Spectro Coating Corp.	U46
Clayton Associates Inc.	K35
Clear Carbon and Components Inc.	K40
Click Bond Inc.	G12
CMS North America Inc.	M42
CNAM Center/CAPE Lab, South Dakota School of Mines & Technology	H102
Coastal Enterprises Co.	J97
Coats	K48
Cold Jet	H75
Composites Alliance Corp.	G8
Composites Essential Materials LLC	T28
Composites Consulting Group	D74
Composites Horizons	S6
Composites Innovation Centre	H90
Composites One	R20
Composies One – The Lean, Mean Processing Machine	p22
Composites Washington	H101

Name	Booth
CompositesWorld	P70
CompositeTechs LLC	G96
Compotool	G42
Conductive Composites Co.	D56
Connora Technologies	P78
Contech	E85
Controx-Neuhaüser	H87
Convergent Manufacturing Technologies	M55
Conwed Global Netting Solutions	E73
Coosa Composites LLC	B27
CoreHog	K37
CoreLite Inc.	B42
CPIC North America Inc.	P14
Crane Composites	S50
Creative Foam Composite Systems LLC	Q64
CRG Inc.	D28
CTG International (N.A.) Inc.	E34
Culimeta Technologies GmbH & Co. KG	C97
Daicel ChemTech Inc.	Q52
Dakota Coatings Inc.	H85
Dantec Dynamics Inc.	J55
David H Sutherland & Co. Inc.	M56
De-Comp Composites Inc.	U16
DelStar Technologies Inc.	H17
DEPESTELE	H89
Design Concepts	T45
Dexmet Corp.	H65
DIAB Americas	F22
Dia-Stron Ltd.	C61
Diatrim Tools	Q79
Dino-Lite Scopes (BigC)	L38
Diversified Machine Systems	F62
Dixie Chemical Co.	N42
DNB Engineering Inc.	H92
DowAksa Carbon Fiber	M92
DPSS Lasers Inc.	J17
DUNA-USA	G32
Dunstone Co. Inc.	B12
DWA Aluminum Composites USA Inc.	E68
Dyplast Products LLC	J92
E.V. Roberts	H13
EAG Laboratories	B18
Eastman Machine Co.	E42
EconCore	H48
EFI Composites LLC	P49

SIDE STORY

CAMX 2016 at a Glance

Where: Anaheim Convention Center, Anaheim, CA, US
When: September 26-29, 2016
Theme: Combined Strength. Unsurpassed Innovation.

SCHEDULE

Sunday, Sept. 25
1:00 pm – 5:00 pm – Registration Open

Monday, Sept. 26
9:00 am – 12:00 pm – Pre-conference Tutorials
1:00 pm – 4:00 pm – Pre-conference Tutorials
6:00 pm – 8:00 pm – SAMPE Awards Ceremony
5:00 pm – 7:00 pm – ACMA Membership Awards and Recognition Ceremony and Reception

Tuesday, Sept. 27
8:00 am – 8:25 am – Conference Programming
8:30 am – 9:30 am – Opening General Session
9:30 am – 5:00 pm – Exhibit Hall Open
2:00 pm – 2:30 pm – ACE Awards Presentation
2:30 pm – 5:00 pm – Conference Programming
5:00 pm – 6:00 pm – Welcome Reception

Wednesday, Sept. 28
8:00 am – 11:00 am – Conference Programming
9:30 am – 5:00 pm – Exhibit Hall Open
10:00 am – 12:00 pm – Poster Session – Meet the Authors
2:30 pm – 5:00 pm – Conference Programming
5:00 pm – 6:30 pm – Market Segment Reception

Thursday, Sept. 29
8:00 am – 12:00 pm – Conference Programming
9:30 am – 1:00 pm – Exhibit Hall Open
1:00 pm – 2:00 pm – CAMX Closing Luncheon
2:30 pm – 5:00 pm – Conference Programming

Name	Booth
Electroimpact Inc.	F97
Electrolock Inc.	B17
Electron Heat	G95
Element Materials Technology	B41
Elite Heritage Ltd.	H68
Elliott Co. of Indianapolis Inc.	P48
Ellsworth Adhesives	H81
Elsevier Inc.	F103
Endurance Technologies	J23
Engineered Bonding Solutions LLC	N46
Engineered Solutions	S55
Engineered Syntactic Systems	N91
Engineering Technology Corp.	R77
Entropy Resins	P80
Epcon Industrial Systems LP	D52
ES Manufacturing	F69
Euro-Composites Corp.	C1
Eurovac Inc.	J63
Evonik	E28
Exova OCM	G98
e-Xstream engineering	F83
F&L Industrial Solutions Inc.	J107
Fabric Development Inc.	D15
FEI	E67

Name	Booth
Ferry Industries Quintax	B57
Fiber Dynamics Inc.	E81
Fiber Materials Inc.	G72
Fiberlay Inc.	T67
Fiber-Line LLC	Q57
Fives Machining Systems	H71
FlackTek Inc.	J15
Flow Waterjet	T56
Freeman Manufacturing & Supply Co.	P52
Gabriel Phenoxies Inc.	Q58
GBF Basalt Fiber Co. Ltd.	G92
General Plastics Manufacturing Co.	B7
Genesis Systems Group	E11
Gerber Technology	M18
Globe Plastics	Q76
Graco Inc.	T75
Graphenea	U44
GS Manufacturing	H7
GTI Technologies	D68
Gunnar USA Inc.	R65
Gurit	D42
Hainan Zhongxin Chemical Co., Ltd. (Shanghai Branch)	S77
Hall Composites	D48

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Name	Booth
Hamamatsu Corp.	F87
Harper International	C14
Hawkeye Industries Inc.	S28
HEATCON Composite Systems	R47
HELD Technologie GmbH	R71
Henkel Corp.	F2
Hennecke Inc.	D16
Hexcel Corp.	E22
Hexion Inc.	J18
Hi Tech Products	M86
Highland Composites	H32
Hilltop Technology Laboratory Inc.	J93
Hi-Performance Products Inc.	D84
HK Research	F8
Hollingsworth & Vose	M90
HORN	T5
HOS-Technik GmbH	H79
Hubei Greenhome Fine Chemical Co. Ltd.	S65
Huber Engineered Materials	S2
Hull Industries - a Division of Chant Engineering	U80
Hunan Heaven Materials Development Co. Ltd.	H86
Huntingdon Fiberglass Products LLC	U40
Huntsman Advanced Materials	J2
Hybrid Plastics Inc.	C73
HyComp LLC	D82
Hyosung Corp.	F72
HyperSizer – Collier Research	H8
IC Flow Control	J87
IDI Composites International	H80
IKONICS Advanced Material Solutions	Q84
Imetrum Ltd.	R75
Impact Composites	P55
Impossible Objects LLC	N89
Ingersoll Machine Tools Inc.	D65
Innegra Technologies	R52
Innovative Composite Engineering (ICE)	R85
Institute for Advanced Composites Manufacturing Innovation (IACMI)	M87
Instron	D66
Interplastic Corp.	C2
Intertape Polymer Group	J65
Intertek	N80
IPM Industrial Plastics	F50
IST - Industrial Summit Technology Corp.	F47
ITW Insulation Systems	H18

Name	Booth
Izumi International	U82
J6 Polymers	E52
Janicki Industries	j25
Jiaxing Ason Composite Materials Co. Ltd.	S71
Jiaxing Sunny FRP Industries Co. Ltd	M84
JOBS Inc.	D85
Johns Manville	C46
JPS Composite Materials	G66
Jushi USA Fiberglass Co. Ltd.	E1
Kaneka North America LLC	C30
Kayco Composites LLC	M60
Knowlton Technologies LLC	G80
KraussMaffei Corp.	R70
Krayden	E78
Laguna Tools Inc.	E70
Lans Co.	M94
LAP Laser LLC	S85
Laser Projection Technologies Inc. (LPT)	D22
Leadgo America	H24
Leresche Blades	R63
LEUCO Telcon	T55
LEWCO Inc.	D80
Lindau Chemicals Inc.	G52
Lingol Corp.	J89
Lingrove	P76
Litek Composites Corp.	N36
LMG	C66
LMI Aerospace	D62
LMT Onsrud	G88
Louisiana State University/National Center for Advanced Manufacturing	D95
Lucas Industries	D62
Lucintel	M71
Luna	N83
M.C. Gill Composites Center/University of Southern California	H96
Mafic	F80
Magnolia Advanced Materials Inc.	B2
Magnum Venus Products Inc.	R16
Maine Composites Alliance	E101
Manufacturers Supplies Co.	M76
Marietta Nondestructive Testing LLC	F71
Master Appliance Corp.	F67
MasterWorks Inc.	F55
Matec Instrument Companies Inc.	B3
Materials Sciences Corp.	B22
Maverick Corp.	G22

Name	Booth
MB Superabrasives	B62
McClean Anderson LLC	B50
McCoy Machinery Corp.	N76
McLube Divisiion of McGee Industries Inc.	E10
MDC Mould & Plastic Co. Ltd.	S66
Meggitt Polymers & Composites	N66
Mektech Composites Inc.	Q59
Michelman	G79
Miki Sangyo USA Inc.	G47
Mikrosam AD	A38
Miller-Stephenson Chemical	C36
MISTRAS Group	B51
Mitsubishi Rayon Carbon Fibers and Composites	K6
Modular Web Solutions	R86
Mokon	R51
MONDI	N47
Montalvo	C11
Multiax America Inc.	H25
MultiCam Inc.	L42
Myers Mixers	H45
N12 Technologies Inc.	Q61
Nabertherm Inc.	E92
Nanocomp Technologies Inc.	E80
NASA Game Changing Development	M83
NASA Technology Transfer Program	C65
National Center for Manufacturing Sciences	E96
NDE Labs Inc.	K39
NDT Solutions	D88
NDT Systems Inc.	J57
Nederman LLC	P79
Netzsch Instruments North America	G46
Niabraze LLC	G93
Nikon Metrology Inc.	C92
Nippon Graphite Fiber	E79
NMG USA Inc.	C52
NONA Composites	C42
Nordson Sealant Equipment	J16
North American Composites	C2
North Coast, The Companies of	B68
North Dakota State University, Mechanical Engineering Dept.	H109
North Star Imaging	E65
Northern Composites Inc.	H1
Northwood Machine Manufacturing Co.	S56
Norton	H28

Name	Booth
Oak Ridge National Laboratory	M85
OCSiAl LLC	D69
OEM Press Systems	H23
Olmar SA	J88
Olympus	G16
OMAX Corp.	S59
Omya	M48
Onyx Specialty Papers Inc.	E69
Orbital ATK Aerospace Structures Div.	G83
Owens Corning Composite Solutions Business	M30
Pacific Coast Composites	J11
PakSense	D76
Parabeam BV	R72
Park Electrochemical Corp.	B34
Parson Adhesives Inc.	S75
PART Consulting LLC	M81
Pathfinder Cutting Technology LLC	Q14
Patz Materials and Technologies	C16
Performance Minerals Corp.	P51
Permabond Engineering Adhesives	B43
Phoenix Inspection Systems Ltd.	J59

Name	Booth
Photron USA Inc.	C68
Piercan USA Inc.	B45
Plascore Inc.	P57
Plastic Materials Inc.	S76
Plexus - ITW Polymers Adhesives North America	E47
Polynt Composites USA Inc.	N1
Polystrand Inc.	H74
Polyumac USA	T49
Potters Industries LLC	C79
Powerblanket	J103
PPG Industries Inc.	H42
PPG Industries Semco Packaging & Application Systems	M91
Precision Fabrics Group Inc.	D25
Precision Measurements & Instruments	R76
Prospect Mold & Die Co.	M71
PRO-SET Epoxy	T51
PTFE Group of Companies (Green Belting Industries Ltd., Greenbelt Industries Inc., Mapelli SRL, Biscor Ltd.)	T71
PTM&W	D102
Pultrex Ltd.	R64

Name	Booth
Quatro Composites	J96
R.J. Marshall Co., The	F42
RAMPF Group Inc.	M22
Reed Industrial Systems Inc.	E51
Reichhold LLC2	R2
Reinhold Industries Inc.	D72
Renegade Materials Corp.	G22
Reno Machine Co.	Q86
Revchem Composites Inc.	L46
REXCO	H15
Robbjack Corp.	Q48
Rock West Composites	Q70
Rosenthal Manufacturing Co. Inc.	E57
Rotaloc	N57
Roth Composite Machinery GmbH	T79
Royce International	L34
RT Instruments	H91
Rubbercraft	F73
SAERTEX USA LLC	C27
Saint-Gobain ADFORS	G36
SAMPE	N90

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Name	Booth
Sanders Composites Inc.	F84
Sandvik TPS	C62
Schrödinger Inc.	C72
SCIGRIP Smarter Adhesives Solutions	H47
SCM Group	H27
Scott Bader North America	S46
Seifert and Skinner Group	B75
Sensitech Inc.	H12
SGL TECHNOLOGIES GmbH	C62
Shandong Shuangyi Technology Co. Ltd.	S72
Shikoku Chemicals Corp.	T69
Shimadzu Scientific Instruments Inc.	G90
Sicomin	C41
Sigmatex	L10
Sika Corp.	T3
Siltech Corp.	H6
Sino Composite Co. Ltd.	S10
SL Laser Systems	P60
Smart Tooling	D12
Socomore/Dysol/Dynamold/Magchem	E94

Name	Booth
Sogel Inc.	S51
Solvay	F14
Soul Composites	R56
Specialty Materials Inc.	E75
Spunfab Adhesive Fabrics	B16
StateMix Ltd.	F75
Staubli Corp.	T76
STELIA Aerospace North America	E88
Stiles Machinery Inc.	H58
Stoner Inc.	L43
Strand7 Pty Ltd.	H54
Stratasys	F96
Strongwell	TBD
Structural Composites	T52
Sunstrand LLC	F101
Superior Composites Co. LLC	U40
Surface Generation America	G2
Surfx Technologies	S83
Summetrix Composite Tooling	N48
SWORL (div. of Prairie Technology)	J21
T Plates Global	E71
TA Instruments	D75

Name	Booth
Taconic	R58
Taizhou Huangyan DaSheng Mould Plastics Co. Ltd.	S63
Taricco Corp.	E64
TCR Composites	D11
TE Wire & Cable	N52
Technical Fibre Products Inc.	L39
Technology Design Ltd.	J59
Technology Marketing Inc.	L47
TEI Composites Corp.	F70
TenCate Advanced Composites	K2
Tensor Adhesives - Quin Global US	N60
Texonic	T48
Textile Products Inc.	D15
TeXtreme (Oxeon Inc.)	M63
Textum Carbon Solutions	G76
Thermal Equipment Corp.	D34
Thermal Wave Imaging Inc.	N59
Thermwood Corp.	E15
THINKY USA Inc.	F93
3A Composites/Baltex Inc.	Q42
3D Systems	C70

Name	Booth
3M Aerospace	S22
Tiger-Vac Inc.	N85
Tinius Olsen	C63
Tiodize Co. Inc.	J5
TMP, A Division of French	L36
Toho Tenax America	L2
Tor Minerals	P56
Toray	T84
TR Industries	B23
Tricel Honeycomb	H2
Tri-Mack Plastics Manufactruing Corp.	E61
21st Century Chemical	T65
UCLA Architecture & Urban Design – IDEAS	H106
Ultracor	H16
Unicomposites Technology Co. Ltd.	R557
Uni-ram Corp.	M75
United Initiators Inc.	S47
University of Alabama at Birmingham	H97
University of Massachusetts, Lowell	H95
Univ. of South Carolina, McNair Center for Aerospace Innovation & Research	H98

Name	Booth
University of Southern Mississippi	Q56
University of Tennessee, Knoxville	H108
Utah Composites Industry	C56
Utah Foam Products	B33
V2 Composites	H84
Valmiera Glass UK Ltd.	Q75
Vapormatt Ltd.	H51
Vectorply Corp.	J48
Venango Machine Co. Inc.	H11
Ventilation Solutions	F90
Verisurf Software Inc.	U78
Victrex	Q47
Virtek Vision International Inc.	M18
Vista Metals Corp.	N93
Volume Graphics	N55
Wabash MPI/Carver Inc.	F76
Wacker Chemicals Corp.	C71
Weather-Rite LLC	T57
Web Industries	J3
Weber Manufacturing Technologies Inc.	E48
Weibo International	C13
Weihai Guangwei Composites Co. Ltd.	P86-1

Name	Booth
Weld Mount Systems	G86
Wellco Industries Inc.	F89
Wells Advanced Materials Co. Inc.	N18
Westmoreland Mechanical Testing & Research Inc.	D87
West Virginia University NSF-IUCRC-CICI	H107
Wichitech Industries Inc.	R84
Wickert Hydraulic Presses USA	C43
Wisconsin Oven Corp.	C22
Wolff Industries Inc.	B59
World Autoclave Solutions LLC	N58
Xamax Industries Inc.	B13
XTX Composites Inc.	D29
YXLON/Comet Technologies USA Inc.	T59
Zeus Inc.	M59
Zhejiang Suijin Composite Materials Co. Ltd.	S70
Zhermack SpA	G75
Zodiac Aerospace	G56
Zoltek	C75
Zotefoams Inc.	N86
Zund America Inc.	T42
Zwick USA	F79

■ Injection molded, foam-cored sandwich composites

A joint research project by the Fraunhofer Institute for Chemical Technology and the Fraunhofer Project Centre for Composites Research looked at methods to reduce mass but also improve mechanical performance of long-fiber thermoplastic (LFT) parts. Research led to application of integral foaming and breathing-mold techniques to injection mold a "sandwich" composite in one shot from a single material.

Source (all images) | Fraunhofer ICT

Breathing-mold process yields sandwich composite from LFT

In-cavity foaming and controlled mold-opening technique creates core and faceskins from a single injection molded material, reducing part mass and boosting performance.

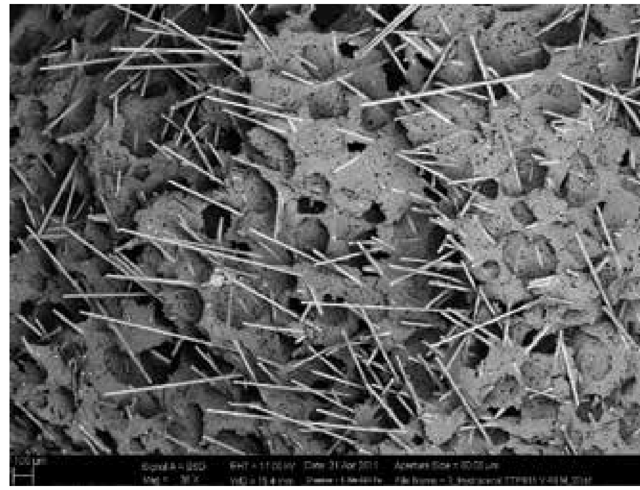
By Peggy Malnati / Contributing Writer

» A joint research project by the Fraunhofer Institute for Chemical Technology (F-ICT, Pfintzal, Germany) and the Fraunhofer Project Centre for Composites Research (FPC, London, ON, Canada) has been looking at methods to reduce mass but improve mechanical performance of injection molded parts made from pelletized long-fiber thermoplastic (LFT). Research has led them to accomplish these goals by injection molding a functional sandwich composite, employing an in-mold foaming technology and the breathing-mold (controlled mold-opening) technique. The result is a foamed core between solid face skins — *both* reinforced with chopped glass — from a single pelletized LFT material, formed in a single shot.

Making foam and faceskins in mold

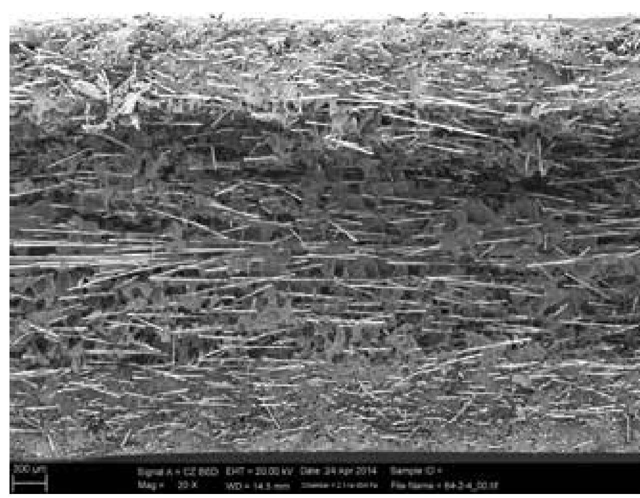
Researchers create the foam by using either a chemical blowing agent (CBA) or physical insertion of an inert-gas blowing agent (PBA). In either case, the blowing agent is introduced to the melt during plastification in the barrel, prior to injection. The rotating screw mechanically mixes the dissolving blowing agent or inert gas (typically N_2 or CO_2) with the polymer melt, creating a single-phase gas/polymer mixture in front of the screw. Control of back-pressure, screw position and shutoff valves/nozzles is carefully managed to ensure that the gas stays in solution before injection into the cold mold, which must be well vented. As the melt flows into the tool, it experiences a pressure drop, which enables the trapped gases to begin expanding. This foams the core.

At this point, the breathing-mold technique comes into play. The tool is held slightly open during initial fill, is shut during the packing stage, then reopened (again, slightly) and held open through part ejection: After injection and a short delay (5-10 seconds) during which skin layers freeze off, foaming is accelerated by controlled mold opening while polymer in the core is still



Integrally foamed reinforced core, close up

This SEM shows the interaction between foam cells, polymer matrix and glass fibers in the foamed cores of parts produced with the breathing-mold technique. Sample preparation — freezing with liquid nitrogen prior to breaking off a section to view — probably contributed to more resin pull out here than would be seen in a normal part.



Core/skin/core section

This SEM shows an integrally foamed part's skin/core/skin morphology. The part was cut across the direction of flow so the viewer is looking into the direction of flow where glass fibers tend to line up parallel to flow in the skins (top and bottom) and perpendicular to flow in the core (middle). Again, note the interaction between fibers, foam cells and resin matrix.

molten. Packing helps consolidate and solidify the skin layers and form the faceskins (see opening photo, p. 80). Opening the tool a precise distance — the gap varies by material and part design but a typical range seen in testing was between 2.5 and 3.6 mm — for the balance of the molding cycle causes a further pressure drop, speeding movement of gas out of the molten polymer. As the melt solidifies, foaming slows to a stop (residual gas is vented off) and then the part is ejected. (Not new, this technique is also called *core back*, *negative embossing*, *foaming with decompression*, or *precision mold opening* and sometimes is used in conventional injection molding to improve surface finish because higher cavity pressures can be achieved.)

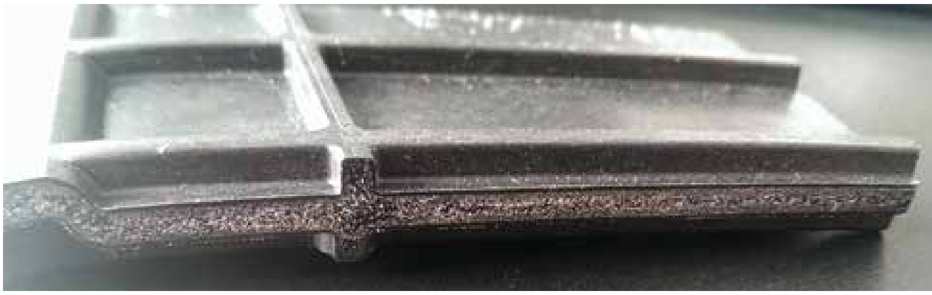
Foams form in the neutral axis where the cellular structure maintains a constant distance between the solid, load-bearing faceskins, which, in turn, form an I-beam or sandwich-like structure. This combination reduces mass/unit area, augments acoustical damping, boosts impact strength, improves dimensional stability (reducing warpage) and increases specific bending stiffness vs. a solid structure of the same design and resin/reinforcement (thanks to a higher moment of inertia). Further process benefits include reduced clamping force, shorter cycle times and lower melt viscosity, yielding a lighter, more structurally sound part at lower energy cost than an injection molded solid resin with reinforcement of the same type, helping to offset higher tooling costs. Significantly, the resulting structure forms consistently across the entire length and width of a part, regardless of its complexity or internal geometry (e.g., ribs; see photos on p. 82).

Blowing agent and pressure options

Those who use the process must select from two foaming options, each of which has inherent advantages and disadvantages. Chemical (CBA) foaming advantages include its availability from many suppliers and that it is added as a masterbatch (where it dissolves, forming a gas during heating and plastification). Disadvantages are that CBAs have temperature limitations and may leave a chemical residue on parts, which can cause discoloration or an odor. Advantages of inert gas (PBA) foaming are that there are no temperature restrictions, it leaves no chemical residue on parts, higher foaming pressures can be achieved, better control of the amount of gas used is possible and more gas can be added to the melt if needed. Disadvantages? Additional equipment and licenses are required.

Processors also must select from two options in regard to filling the tool. In the "low-pressure" option, the tool cavity is only partially filled during injection. Material shrinkage against the tool (that otherwise could lead to short shots) is countered by expanding gas (and polymer) as blowing pressure alone is used to complete the fill. This technique eliminates the need to apply packing pressure after injection. The packing step is bypassed and, therefore, the tool remains slightly open. It also reduces clamping pressures (enabling a standard press to mold larger parts than normal or a smaller, less costly press to mold the same-size part) and yields lower residual stresses inside parts, which then are less prone to warpage. Disadvantages are that it results in a part with higher density (reportedly 5-15% higher, depending on ratio of wall thickness to flow length) and more streaking on part surfaces, which can be an issue in aesthetically sensitive applications.

With the alternative high-pressure process, the mold cavity is filled the conventional way (solely with injection pressure) and then packing pressures are applied only for a few seconds. »



Consistent cross-geometry outcomes

During the integral foaming and breathing-mold process, the skin/core/skin morphology forms across the entire length and width of the part, regardless of part complexity or internal geometry (e.g., ribs). Here, the techniques were applied to a very complex automotive underbody shield with significant ribbing, shown here from the edge, at top left, with a close up at right.

Advantages here are a more homogeneous foam, a part with lower density (reportedly, more than 50% lower density can be achieved) and better part surfaces, because skins freeze sooner and high pressures smooth out rough surfaces after injection. This technique, however, requires a tool with a shear edge and a press with a short-stroke tool frame or multi-core back (which adds to cost), so the tool can be precisely opened part way through the molding cycle.

Interesting benefits

Several benefits occur as a result of combining precision mold opening with integral reinforced foaming. First, as wall thickness increases, the second moment of inertia increases three-fold, making this low surface-mass (low mass/unit area) technology potentially attractive for large, semi-structural parts subject to bending loads, such as door interior-trim panels, spare-wheel wells, seat shells and backrests, underbody shields and instrument panel supports in the automotive industry. Second, because skins solidify before the tool reopens, gas bubbles don't break through and pressures further smooth the surface, leaving a good finish on both sides of the part. In fact, the longer the delay between initial injection and mold opening, the thicker the solid skins become relative to the foamed core (and vice versa), making this a process parameter that can be controlled to meet application needs.

Quantifying process choices on final properties

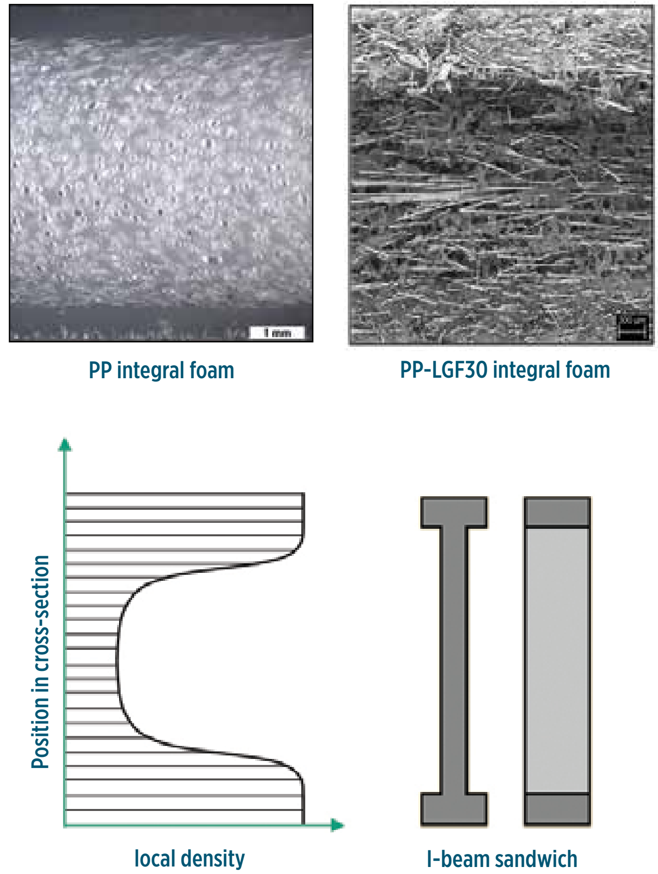
To better understand the effects of various foaming and filling options on final part properties, a research team led by Alexander Roch, head of Thermoplastic Technology Corridor, F-ICT, compared results for two materials during two trials held several years apart:

- 30% LGF polypropylene — PP-LGF30; initial pellet length 11 mm; from Dow Automotive (Midland, MI, US).
- 50% LGF polyamide 6 — PA6-LGF50; initial pellet length 12 mm; from BASF SE (Ludwigshafen, Germany).

Foaming was achieved either with CBA (endothermic commercial grades from Clariant Masterbatches GmbH, Muttenz, Switzerland) or PBA (N_2 in the MuCell microcellular foam process from Trexel Inc., Wilmington, MA, US). All samples were molded on the same injection molding press (Engel duo 700 pico combi M, Engel Austria GmbH, Schwertberg, Austria) equipped with both standard and MuCell injection units. For CBA foaming, a 105-mm-diameter screw was used. For PBA foaming, a second MuCell injection unit and an 80-mm-diameter screw were used. (Existing screws that worked for each process and whose flights were optimized for long-fiber materials were used.)

Researchers molded flat sheets (500 mm by 500 mm) in each combination of resin and blowing agent. Only the high-pressure fill technique was employed, using a shear-edge tool equipped with an edge-mounted, 5-mm-wide needle shut-off nozzle/valve as the gate. Owing to density differences between the two materials, the initial mold gap (PP-LGF30, 3.6 mm; PA6-LGF50, 2.5 mm) was adjusted so the injected volume of material for each shot was a constant, allowing researchers to achieve consistent surface weight (mass/unit area) for both materials. Use of the breathing-mold technique enabled researchers to control plaque nominal wall thickness, density and final volume. All other molding conditions were kept constant for each material system. Unfoamed reference plaques were molded as controls.

Overall, results showed that for constant surface weight, bending stiffness increased by up to 600% and a small increase in wall thickness led to a significant increase in flexural rigidity, regardless of which blowing agent was used. At the greatest density reduction, bending stiffness for PP-LGF30 increased ≈330% with CBA and ≈275% with PBA foaming, while for the PA6-LGF50



Foamed neat vs. foamed reinforced resin

The image at top left shows unreinforced structural polypropylene PP foam. The second image (top right) shows an integrally foamed long-glass fiber PP, with solid skins and foamed core produced by the breathing-mold technique. Unlike unreinforced resins, which tend to brittleness after foaming, the impact strength and bending stiffness of integrally foamed reinforced parts increase significantly vs. unfoamed controls. In the third image (bottom left), local density vs. position in cross-section are graphed to show how the technique produces solid reinforced skins and lower-density reinforced foamed cores. At lower right, the resulting skin/core/skin morphology produced in the breathing mold process can be compared to an I-beam or a sandwich panel when trying to predict mechanical performance.

(where density reductions between foaming agents were significantly different), bending stiffness increased ≈190% with CBA and ≈630% with PBA.

As would be expected, thicker skins (achieved via longer delays before mold opening) yielded increased bending stiffness and impact strength, but tensile properties decreased slightly (possibly because there was less material in the core to resist pulling forces).

Falling Dart impact tests showed that unlike conventional unreinforced foams, which tend to become more brittle after foaming, energy absorption in foamed PA6-LFG50 improved vs. unfoamed controls. Charpy bending tests done on PP-LGF30 showed nearly constant behavior with increasing density reduction. Notably, »

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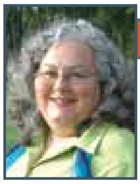
with PA6-LGF50 samples, there was little difference in the degree of impact strength increase, regardless of which foaming agent was used. Among PP-LGF30 samples, those foamed with CBA showed much greater impact strength than those foamed with PBA, but couldn't meet 50% density-reduction targets.

At higher mold-opening strokes, CBA parts had large sink marks. This might be because N_2 gas used in PBA had higher blowing pressures than CO_2 devolved from CBA, and that led to measurably thicker cores and thinner skins for PBA-foamed samples, and the reverse for CBA-foamed samples. (Each gas showed different dissolving, diffusion and foaming behavior. More recent testing using CO_2 for the PBA gas shows it delivers lower pressure but not automatically thicker skins.) Also, researchers theorize that the combination of smaller screw diameter, an additional non-return valve, plus the gas-mixing zone of the MuCell unit caused greater fiber breakage in PBA samples than occurred in CBA samples. Another difference that could have affected results is that PA6 materials were processed at higher melt temperature, which might have enabled blowing agent to leak from the feed zone of the injection barrel. Yet another possibility is that the higher viscosity of PA6 might have hindered bubble formation during foaming.

"By combining chemical or physical blowing agents and the breathing-mold technique, reinforced sandwich composites with significant mass-reduction potential can be produced in a single step and at rates appropriate for high-volume manufacturing," notes Roch. "Given this, we think the technology will be interesting to automotive molders using LFT materials."

Work on the technology has continued, and at this year's SPE ACCE in Detroit (Sept. 7-9, 2016), Roch will present a paper on use of the technology to produce an air-guide panel for a next-generation BMW *7 Series* car (BMW AG, Munich, Germany). The co-molded part uses a hard PP and a soft thermoplastic elastomer (TPE) plus the breathing-mold technique to reduce material usage 20% vs. a solid co-molded part. CW



ABOUT THE AUTHOR

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Class A Cadillac hood

Tier 1 automotive supplier Magna International (Aurora, ON, Canada) designed this composite hood for two models of General Motors' (Detroit, MI, US) 2016 model year *Cadillac V-Series*, using a customized carbon/epoxy prepreg from Barrday Composite Solutions (Millbury, MA, US).

Source | Magna International

Carbon/epoxy *Cadillac* hood

Automated process for prepreg hood inner/outer cuts weight by 20% and yields a Class A exterior via compression molding.

By Sara Black / Technical Editor

» Although they typically keep their research efforts close to the vest, automakers and automotive Tier suppliers nevertheless are always in the process of evaluating the multitude of materials available for lightweighting, in their efforts to meet fuel economy mandates. One example is automotive Tier 1 giant Magna International Inc. (Aurora, ON, Canada), a leading automotive supplier with more than 140,000 employees in 29 countries. The company started a carbon fiber composites program in 2008, says Tom Pilette, its global VP, product and process development. "We began developing composites for structural parts, as well as Class A body panels," he recalls. At that time, Magna made a joint development agreement with commercial-grade carbon fiber manufacturer Zoltek Corp. (Bridgeton, MO, US), using that company's 50K carbon tow materials in its part development efforts. "We saw the lightweighting trend coming," he points out, "but knew it was going to be a long process."

Quote on a *Caddy*

That early work led to an opportunity in 2013 to submit a quote to General Motors (Detroit, MI, US) for composite hoods on the 2016 model year *Cadillac ATS/CTS V-Series* cars, two higher-performance *Cadillac* models. Approximately 7,000 parts are being produced each year for each model, for a total of 14,000 hoods, but the capacity exists for much greater volumes. The hood was a winner of a JEC Innovation Award in the Automotive category, at the JEC Americas 2016 event in Atlanta, GA, US.

Andrew Swikoski, global product line director for lightweight composites, explains that the *Cadillac* hood was a good candidate part for lightweighting, given its location above the car's center of gravity and forward of the axle. The carbon fiber/epoxy composite provides the stiffness needed to avoid hood "flutter" and has resulted in a mass savings of 20-30% compared to aluminum or steel hoods (the range depends on the grade of steel or aluminum to which it is compared).

The hood is produced in an out-of-autoclave compression molding process that takes just minutes per part, yet produces a Class A exterior surface. A key achievement of the hood program, Pilette adds, is that the parts can be post-processed just like metallic versions; that is, the carbon fiber/epoxy material can withstand Magna's conventional metal-part painting process and

Compression process proves potential

This shear-edge steel compression tool, designed by Magna, molds the *Cadillac* hood in minutes on this press at Magna subsidiary Polycon Industries (Guelph, ON, Canada). The part shown here is the carbon fiber/epoxy inner for the *ATS-V-Series Cadillac* hood. It has just completed the compression process and is exiting the tool.

Source | Magna International

its associated bake temperatures — there was no need to resort to offline manual painting and "finesse and filler" steps. "Our goal was to have a composite part capable of seamless, inline finish processing," Pilette points out.

Iterative progress toward success

The hood was designed with a unidirectional carbon fiber inner and outer, with an optional exposed carbon fiber inner, adhesively bonded together. Steel hard points are bonded at hinge and latch attachment locations. The outer panel has a thickness of 1.2 mm, and the inner, 0.8 mm. Working closely with material suppliers Zoltek and Barrday Composite Solutions (Millbury, MA, US) at the Magna-NRC Composites Centre of Excellence — a joint Magna/Canadian research center dedicated to composites located at Magna's Concord, ON, Canada facility — Magna went through "many iterations" of resin chemistry development, prepreg stack design, tool design and cycle time tweaks to achieve an acceptable finished outer surface, says Pilette. The resulting prepreg resin system, supplied by Barrday, is a customized, toughened epoxy. Combined with Zoltek fiber, it makes a prepreg with a high glass transition temperature (T_g) that can handle the Magna paint line's temperatures.

"Typically, a prepreg part charge tends to be a patchwork of multiple plies that takes time to lay up manually," explains Pilette. The Magna team has perfected an automated workcell that creates a molding charge by robotically laying multiple plies of standard-width, 0.02 mm-thick, Barrday prepreg in a 0°/90° orientation, which are CNC cut into a charge pattern that is robotically transferred to the mold. The patented mold tools (upper and lower) feature a shear-edge steel design, with a "unique" and proprietary combination of tooling features that reportedly manage the movement of the stacked plies during mold close and pressure application. Adds Pilette, "The prepreg starts to cure as soon as it hits the heated tool, so the stack has to be placed precisely and stay in place. The tool helps maintain resin consistency, ensures good fiber wetout and part thickness." He notes that Fibersim software from Siemens PLM Software (Plano, TX, US) was a manufacturability tool that "helped tremendously" in developing the prepreg stack pattern for compression molding.

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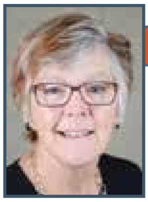
The Barrday material is manufactured in that company's Cambridge, ON, Canada, facility, and molding occurs at Magna subsidiary Polycon Industries (Guelph, ON, Canada). The process begins with automated layup and ply stacking, charge cutting and mold loading. After mold close and press application, cure takes about 10 minutes. A robot removes the molded part, shuttles it to a router cell for trimming, then to a fixture in a bonding cell. Bonding of the inner and outer panels also is automated, and the metallic hinge and closure elements, while positioned by hand, are also robotically bonded, using Pliogrip two-part urethane adhesive from Ashland Performance Materials (Columbus, OH, US). Bonded parts then go to the Magna paint line and, after painting, are shipped to General Motors. "We're now working on cutting that cure time in half, with adjustments to the epoxy," asserts Pilette.

Other panels, more platforms

Now that a robust and successful molding process has been developed, Pilette and Swikoski both say that Magna's goal is to expand the use of this newly developed technology with multiple carbon composite body panels, and to do so on more platforms. "We understand these materials, and with our in-house chemists and laboratory, and collaboration with our supply partners, we can offer solutions to meet our customers' needs," Pilette contends. CW



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Nanocomp Technologies Inc.: Merrimack, NH, US

Its millimeter-length macro CNTs are finally realizing their commercial composites potential, with spacecraft applications leading the way.

By **Ginger Gardiner** / Senior Editor

» From its beginnings in 2004, the Nanocomp Technologies Inc. (NTI) story has been distinguished by tenacious, step-by-step progress toward faster, less cost-intensive production and commercialization of *macro-scale* carbon nanotube (CNT)-based advanced materials. Unlike previously available CNTs, which were powder-like and tended to agglomerate when added to resins, NTI's CNTs are 1-10 mm long but only 3-5 nm in diameter. This remarkably high aspect ratio provides not only good tensile properties, but, exceedingly long compared to their thickness, the CNTs easily entangle. This fact enables NTI to collect them out of its chemical vapor deposition (CVD) furnaces and then convert them, inline, into either continuous fibers or 1.2m by 2.5m nonwoven sheets, offering a more amenable format for composites manufacturers (see Learn More, p. 95).

The macro CNT fiber can be continuously manufactured at the rate of kilometers per day, using inexpensive, readily available inputs, yet reportedly yields properties that produce measurable benefits in end-use components. NTI currently has a capacity of 0.85 MT per year, having scaled up from two furnace-enabled production lines in 2006 — one for continuous MIRALON CNT fiber and one for MIRALON nonwoven sheet — to 13 production lines, six for fiber and seven for sheets, today. Sheet stock then can be slit into tapes, cut

Fig. 1 Three-stage production phase-in

Nanocomp Technologies Inc. has grown from a 50m² facility in Lebanon, NH to Phase II of re-purposing a 9,300m² paper mill in Merrimack, NH (overhead view, above). The Merrimack facility build out is happening in three phases. Phase I houses 13 furnace-enabled pilot production lines, six for fiber and seven for sheet materials. Phase II will house low-rate initial production (LRIP) and Phase III will increase overall production more than 20 times by 2020. Source | Nanocomp Technologies Inc.

Fig. 2 Where it all begins

Hydrogen mixed with carbonaceous materials and a catalyst is injected into a high-temperature furnace, ultimately creating this "CNT sock" comprising billions of CNTs. Source | Nanocomp Technologies Inc.

into tailored sizes or seamed together to make roll stock. Along the way, the company has grown from a 50m² facility in Lebanon, NH to Phase II of its repurposing plan for its current home base, the old 9,300m² Nashua paper mill in Merrimack, NH, less than an hour's drive from the techno-hub of Boston, MA.

CW's guide to MIRALON products and production is NTI president Peter Antoinette. He says that roll stock made from MIRALON sheet can be spooled for processing into prepreg, which has already been demonstrated by Solvay Engineered Materials (Anaheim, CA, US). It also can be used to make honeycomb core. MIRALON fiber, meanwhile, has been used on its own in cables, impregnated with resin in composites and also processed into a dispersed format for 3D printing filament, with a variety of polymers, as well as chopped/compounded for use in compression and injection molding processes.

Although Antoinette touts an almost endless list of unique properties and potential applications for NTI's CNT products, they have actually amassed more than five years of service in spacecraft and are being qualified at several aerospace OEMs. In fact, MIRALON is now classed by the US Department of Defense as "essential for national defense," per the Defense Production Act (DPA) Title III program. Further, NTI has forged partnerships with industrial giants, such as DuPont (Wilmington, DE, US), and has secured commercial sales into data cables and ballistics protection/armor. The latter is key if NTI is to make good on its promise of a next-generation carbon fiber and composites that will deliver the improvement in weight savings, mechanical performance and multifunctionality now in demand for future structures.

Manufacturing macro CNT fiber

CW's tour of NTI's Merrimack facility begins in the building's 2,800m² Phase I pilot-production area (Fig. 1, above). Most of NTI's 75 employees work here or in adjacent R&D labs. The area houses the furnaces and fiber/sheet production lines. Hydrogen (the company produces its own supply on site in an innovative, compact operation) and other common gases, mixed with industrial fuels and a catalyst, are injected into each furnace. As the mixture moves through the furnace, it is heated to more than 800°C »

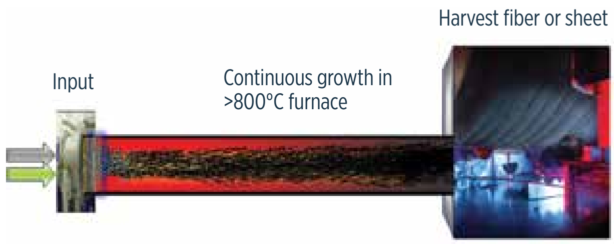

Fig. 3 Multiple socks to flat sheets

Socks generated from a furnace can be collected and wound around a large spool, and then can be flattened and harvested as 1.2m by 2.5m sheets (see Fig. 6, p. 91).

Source | Nanocomp Technologies Inc.

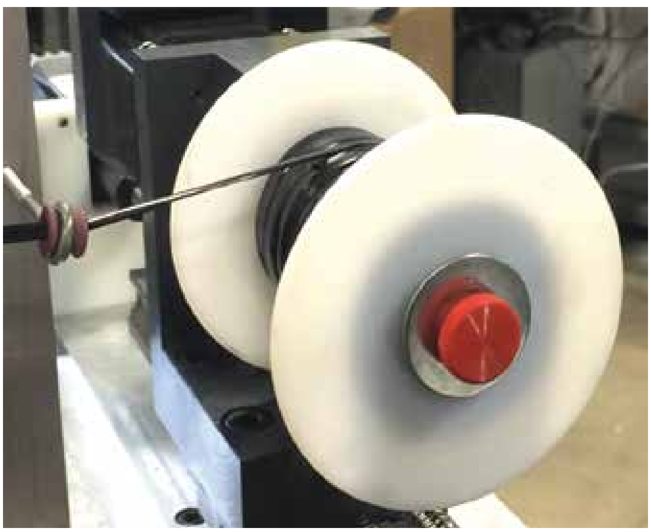

Fig. 4 Single socks to superior fibers

Individual socks also can be mounted on a spinneret, spun into yarn and then spooled, much like conventional fibers. Source | Nanocomp Technologies Inc.

Fig. 5 High aspect ratio = high performance

MIRALON macro-scale fibers' high aspect ratio realizes real-world benefits in applications, including composite laminates and honeycomb core (upper portion of photo), 3D-printed structures (lower center) and conductive injection molded plastic parts (rods/tubes at lower left). Source | Nanocomp Technologies Inc.

to create a cloud comprising billions of CNTs — what Antoinette calls a "CNT sock" (Fig. 2, p. 89).

At this point, what happens to the sock differs, depending on the end product. At the output end of each sheet furnace, a harvest box winds the cloud of entangled CNTs around a gathering drum. The CNT sock then collapses into a felt, which is then heated to flash off the solvent, densifying the sheet (Fig. 3, left). The sheet before densification resembles a very thin, friable carbon felt. Afterward, it is shiny and looks, perhaps not unexpectedly, like the carbon paper used decades ago to produce copies, sandwiched between sheets of typing paper.

"Alternatively," explains Antoinette, "we can collect the CNTs into a spinneret to form a yarn (Figs. 4 & 5, at left). We spin 10-tex filaments and further process to create a 4-ply twisted yarn with a breaking strength of 1.5 N/tex, similar to a 40-tex aramid fiber." (KEVLAR 49 aramid fiber for composites is typically sold as 1,270 decitex, which is a metric unit for fiber linear density; dtex = g/10,000m while tex = g/1,000m).

> New-generation fiber furnaces, coming on line this year, are expected to double production rates.

According to NTI tests (Table 1, p. 91), MIRALON CNT fiber has a tensile strength approaching commercial aramid fibers but at a density that is roughly half that of carbon fiber (CF); thus, its specific tensile strength has the potential to exceed commercial CF products. It also has high knot strength, which means its tensile strength after being tied in a knot is very similar to its unknotted strength. Carbon fiber, by comparison, loses 99% of its strength when knotted, because carbon fiber is made from solid filaments. MIRALON CNT fiber, however, being formed by millions of entangled millimeters-long nanotubes, is essentially the nanoscale equivalent of a stretch-broken carbon fiber — carbon tows pulled to create a pattern of broken filaments, maintaining alignment but enabling movement, and thus increased flexibility (see Learn More). This CNT fiber is, thus, very flexible and easily used as a stitch yarn, for example, or in processes like tailored fiber placement (TFP, see Learn More). It also has a very high surface area, available for bonding to resin and/or for conveying heat or electrical current.

Antoinette says MIRALON's combination of properties is what makes it revolutionary: "You can ground it like stainless steel but also tie it into a knot. It retains properties at cryogenic temperatures and has the same environmental toughness as carbon fiber, but much greater thermal and electrical conductivity." The latter also can be tailored, from parts that function

Material	Composition	Strength GPa	Density g/cc	Specific strength kN*m/kg	Strain to failure %	Max use temp °C
Dyneema/ Spectra	UHMWPE	3.6	1	3,600	2.5	130
Kevlar	Aramid	2.9	1.44	2,014	2.8	260
Carbon fiber	Carbon	4.1	1.75	2,343	1.4	300 - 2,000
NTI Miralon YMC4	CNT yarns	0.8 - 1	0.8	1,000 – 1,250	3.5	450 – 2,000**
NTI Miralon next-gen	CNT yarns	1.7 – 2.2	0.8	2,300 - 2,700	1.8 to 4.0	450 - 2,000**

** with proprietary sizing, current and in development

Table 1 MIRALON fiber properties

According to NTI tests, MIRALON CNT fiber has a tensile strength approaching commercial aramid fibers but at a density that is roughly half that of carbon fiber.

Source | Nanocomp Technologies Inc.

Fig. 6 CNT sheet for armor plating

Rolls of 1.2m wide MIRALON sheet are cut into squares for a commercial soft armor application.

Source | *CW* and Nanocomp Technologies Inc.

Fig. 7 CNTs for injection/ compression processes

NTI reports that chopped MIRALON fiber and pulp perform as well as, or better than, carbon fiber in injection molded (shown here) and compression molded parts. Source | Nanocomp Technologies Inc.

as electrostatic discharge (ESD) and electromagnetic interference (EMI) shielding to data cables and wiring that meet the conductivity and data transfer specifications of current products but at only 30% of the weight. Data and communications cables for satellites were one of the first applications of MIRALON. On a commercial jetliner, which requires approximately 98 km of wiring, Antoinette contends that use of MIRALON products could reduce weight by 2,540 kg.

Just beyond the production area, MIRALON sheet is unrolled on large tables in preparation for cutting into square panels for a ballistic armor customer (Fig. 6, this page). The soft armor, used by police and paramilitary units, includes only a couple of layers of the sheet, but that's enough to reduce backface deformation — the potentially injury-causing displacement into the wearer — by up to 20%, translating into a 25% lighter finished vest. Antoinette says this means a 2.7-kg vest would drop to 1.8 kg and be 30% thinner for improved comfort and maneuverability, yet maintain Level II ballistic protection. He notes this same ballistic performance is extended to composites applications, like tactical plates and helmets, working with partners such as TenCate Advanced Armor (Newark, OH, US).

The final stop on the production floor is, in fact, an example of NTI's continuous push to increase production. A generation "D" fiber furnace is being tested, which will *double* line speeds to 12 m/min. "We plan to roll these machines into production by the end of 2016," says »

Fig. 8 CNTs for 3D printing

Chopped MIRALON fiber is compounded with ABS into 3D printing filament (left) for tool-free production of very durable net-shape parts, such as this avionics housing (right). Source | *CW* and Nanocomp Technologies Inc.

Fig. 9 Macro CNT sheet in space

Launched in 2011, the *Juno* spacecraft uses MIRALON sheet combined with M55J carbon fiber in a composite radiation/EMI shield on the main attitude control thrusters and main antenna.

Source | Nanocomp Technologies Inc.

Antoinette, "but I'd like to see us improve production speed by another '5x.'"

Composites R&D

Antoinette leads the way past an array of quality assurance testing equipment to the next stop, NTI's R&D lab. Here, principal scientist Joe Johnson notes that MIRALON has performance superior to that of carbon fiber in molded polyetheretherketone (PEEK) parts. "Compression molded MIRALON/PEEK does not exhibit the fractures seen in chopped carbon fiber/PEEK parts," he explains. "Meanwhile, we can maintain the near-zero coefficient of thermal expansion, and the parts exceed metal performance as well."

NTI uses MIRALON sheets, cut and mixed with polymers, in both compression and injection molded composites, and has ongoing development projects with HyComp (Cleveland, OH, US) and other well-known compounders and industrial partners that can't be named due to nondisclosure agreements.

This work, alone, reportedly holds enormous promise: Technical and market research results extol the opportunities for electrically conductive injection molding compounds, given the continued miniaturization and functionalization of electronics and electrical components.

Johnson's team also shows *CW* how chopped MIRALON dispersed products are compounded into acrylonitrile butadiene styrene (ABS) plastic and then used in a commercial Fortus 3D printer (Stratasys Inc., Eden Prairie, MN, US) to produce avionics housings and structural brackets and adaptors for spacecraft (Fig. 7, p. 91). NTI is completing development work with the University of Dayton Research Institute (UDRI, Dayton, OH, US) and Orbital ATK (Dulles, VA, US) toward full qualification of this material — as well as CNT-reinforced polyetherimide (PEI, e.g., Ultem), high-density polyethylene (HDPE) and nylon, for a variety of aerospace applications.

Service history in spacecraft

Spacecraft manufacturers, in fact, were early adopters of this macro-CNT technology. In 2011, raw MIRALON yarns were exposed in space for more than two years, as part of the International Space Station MISSE 8 ORMAT E-111 mission. Afterward, they were found in pristine condition except for a very thin oxide layer, similar to that formed on aluminum under similar conditions, proving they can function in the radiation, cold and corrosive atomic oxygen present in low Earth orbit (see Learn More).

Also launched in 2011, the *Juno* spacecraft, which reached Jupiter in July 2016, uses MIRALON sheet combined with M55J carbon fiber (Toray Carbon Fibers America Inc., Flower Mound, TX, US) in a composite radiation/ESD shield on the main attitude-control thrusters and as a protective EMI layer on the main engine cover (Fig. 8, p. 91). Qualified by Lockheed Martin Space Systems (Denver, CO, US) for NASA JPL (Pasadena, CA, US), MIRALON went through testing for mechanical properties, as well as rigorous space qualification procedures for vibration and radiation resistance, and endured a soak test for chemical and water resistance.

MIRALON nonwoven sheet has been used by itself as the outer layer of a laminate for satellite radiation shielding, and also as a web, processed into 100% MIRALON honeycomb for large-scale composite sandwich structures. Here, DuPont, Orbital ATK, Patz Materials and Technologies (Benicia, CA, US) and Boeing Research & Technology (R&T, Long Beach, CA, US) are key development partners. Antoinette claims MIRALON core offers a 300-500% increase in stiffness and 200-300% pick up in compression strength with less weight vs. incumbent products. »

This same combination of properties prompted a NASA flight test this year to demonstrate the use of MIRALON fiber in overwrapped propellant tanks. "It provides better hoop strength in a tighter radius than carbon fiber," claims Antoinette, "and is also able to discharge static electricity to ground."

In a 2015 NASA EDGE podcast, scientists in NASA's Game Changing Development Program explained that, using NTI products, they were able to make CNT composites with specific strength double that of carbon fiber composites. NASA senior materials scientist Mia Siochi notes that NASA actually moved away from working with powdered CNTs years ago and now focuses on continuous-format fibers and sheets.

Next-gen products

From NTI's R&D and product development labs, CW is escorted into the adjoining 2,800m^2 Phase II low-rate initial production (LRIP) area. It is empty except for an enclosed 10m by 10m production cell. Antoinette explains this is NTI's prototype next-generation fiber post-processing line. The plan is to have the entire area filled with low-rate production of MIRALON products by 2018. Although furnaces and production lines occupy less than 50% of the floor space in Phase 1, with the remainder of that space devoted to post-processing, R&D and other functions, Antoinette points out that in Phases 2 and 3, the majority of each space will be devoted to furnaces and production lines, with smaller spaces reserved for other needs, such as post-processing.

"NASA found that for certain high-strength, high-modulus fibers, like IM7 and M463, there is a significant knockdown in properties when you move from fiber to composite form," explains Antoinette. He claims that MIRALON-reinforced composites do not exhibit this knockdown. "We already have equal strain to IM7 and are almost on par with T1000 in a composite," Antoinette asserts. "We chemically treat the yarn to align the CNTs, increasing both strength and electrical properties." The challenge now is to continue boosting strength and modulus to the levels of today's highest performing fibers, while scaling production without losing MIRALON's greater strain to failure, which adds ductility to structures.

Indeed, NASA is working with NTI to optimize this next-generation fiber. Sochi believes it is possible to produce composites that are 300% stronger than anything now available. "If we can get two or three times the strength of state-of-the-art materials, it makes a mission to Mars possible."

Meanwhile, NTI is part of the Advanced Functional Fabrics of America (AFFOA) Institute consortium at the Massachusetts Institute of Technology (MIT, Cambridge, MA, US). As part of AFFOA's mission to help secure US leadership in next-generation fibers and textiles, it is developing the electrical conductivity of CNT fibers for smart structures. Antoinette shows a sample of cloth woven from MIRALON fiber that provides a flexible, yet durable textile Faraday cage. MIRALON-based materials also are being demonstrated in a multifunctional composite structure that uses electrical power to function as a heating element. "We have demonstrated we can repair the structure and restore electrical conductivity," Antoinette notes. "We are looking at a variety of heated structures and heating devices, including rapid heat blankets like those used in composite repair."

On the tour's final stop, Antoinette opens a set of doors that reveal the Merrimack facility's Phase III area, which is still in the process of build out. The goal is to have this space filled with production by 2020, which will bring the site's total annual furnace/production line capacity to 20 MT. Although Title III funding enabled NTI's move into this facility, it also demanded matching funds from non-government sources, which NTI met. The company continues to raise additional funds necessary to complete the Phase II and III expansions, while it secures commercial contracts, initially for cable and ballistic protection applications. "Though these commercial contracts are not for composites," says Antoinette, "they are enabling the increased capacity and development that will allow composites to be revolutionized by MIRALON products." Indeed, these commercial contracts differentiate it from many other nanotechnology startups, and are key to the company's long-term success. Antoinette's vision includes a facility 10 times the size of the Merrimack site, "We have only just scratched the surface of what these materials can do." CW

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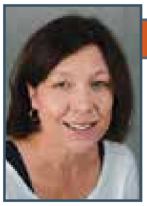

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Structural adhesives, Part II: Aerospace

New polymers join the fray, but tried-and-true epoxies still dominate, and usage increases with improved forms.

By Sara Black / Technical Editor

■ Structural adhesives: Unseen but pervasive

Despite the necessarily ubiquitous use of metallic fasteners for redundancy, structural adhesives are also necessary for many aerospace bonding applications, both for composites-only and composite-to-metal bonds, in both airframes and interiors. Adhesives also function uniquely in specialized applications as shims and surfacing films for lightning strike protection.

Source | The Boeing Co.

» As they do in automotive, marine and other industrial markets (see "Part I," via Learn More), structural adhesives play an important part in aerospace manufacturing. "The importance of adhesives in aerospace is increasing significantly with higher composites usage," says Bjorn Ballien, global business development manager development manager, aerospace adhesives, at Henkel Aerospace (Bay Point, CA, US). Historically used to bond faceskins to honeycomb core in sandwich constructions, such as flight-control surfaces and interior panels, adhesives today see increasing opportunities for use in composite primary and secondary structural assemblies.

As is true on the industrial side, the structural properties of adhesives for aerospace applications can be tailored with additives for higher or lower viscosity, greater toughness, shorter cure time, longer working time and other properties. In fact, nearly every supplier contacted says it is able to customize an adhesive solution for a customer's unique situation.

■ Tailored for tough military duty

Although few specifics are available, military aircraft, including this first Italian F-35A *Lightning II* fighter, shown here, use an abundance of structural adhesives in numerous applications.

Source | Lockheed Martin

What makes adhesive *aero*structural?

Adhesive manufacturers consider an adhesive *structural* if it can withstand a force of at least 6.9 MPa (1,000 psi) in a lap shear coupon test. But for aerospace applications, there are marked differences from industrial applications in how they are viewed and used. For one, there is a pervasive regulatory requirement for rivets and other fasteners, for redundancy, when adhesives are used to bond joints (see Learn More). That said, structural adhesives are necessary for bonding of some aerospace assemblies, both composites-only and composites-to-metal. They also function in specialized applications, as shim materials and in the form of surfacing films designed for lightning strike protection.

Adhesives for aerospace use are typically applied in the form of either a paste or a film. Pastes, with viscosities of 8,000 cps or more, tend to form thicker bond lines and, therefore, fill and bridge gaps between bonded surfaces and can offer significantly greater elongation and impact resistance. They also are used for bonding detailed parts and in more metal-intensive situations. Films, which consist of a thin layer of pre-catalyzed resin supported on a scrim or paper backing, are sold in roll or sheet form. They are used in large-area structural bonding applications in more composites-intensive constructions. Ideal for composite parts with a very high fiber content and a correspondingly low resin content, says Ballien, the film flows under application of heat to bond the faying parts.

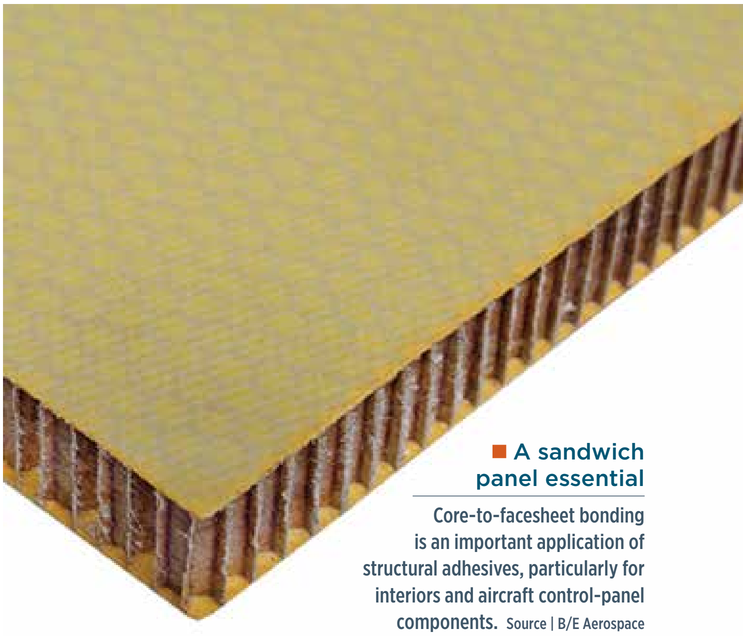
Further, when adhesives are applied to "green" (B-staged) composites and co-cured, the adhesive's chemistry actually dissolves molecules in the adherend, forming covalent chemical bonds that chemically lock the two together. Adhesives also can attach a cured part, such as a stringer, to an uncured part (a wingskin). They also are used in a secondary bonding process, where two cured composite parts, or a composite and metal part, are joined.

Historically, epoxy has been the dominant adhesive chemistry, due to its strength, stiffness, toughness and relatively high temperature performance. It remains so, but structural adhesives based on polyimide and bismaleimide (BMI) chemistries have carved out a niche. These adhesives can be processed at higher temperatures and, most importantly, be put into service at *much* higher sustained operating temperatures than epoxies.

Because suppliers are almost inevitably prevented by nondisclosure agreements (NDAs) from sharing details about contractual arrangements, *CW's* report here is short on actual aircraft/spacecraft application specifics, but catalogs and describes the intended uses for an extensive list of available aerospace-grade adhesive products from key suppliers.

Bonding aircraft structure

A leader in high-performance adhesives for bonding metal and composite aircraft structures, Cytec Solvay Group (Woodland Park, NJ, US) has supplied film adhesives for at least 30 years, says Dalip Kohli, the company's research and innovation director: "Our adhesives are used for numerous structural bonding applications for both monolithic composite and honeycomb structures." Cytec Solvay supplies films and pastes based on epoxy, phenolic, BMI and polyimide resin chemistries, along with bonding primers, core-splice adhesives and potting compounds — adhesives used to secure metal hard points or fasteners within a cored part — its well-known trademarked FM-series products. »



■ A sandwich panel essential

Core-to-facesheet bonding is an important application of structural adhesives, particularly for interiors and aircraft control-panel components. Source | B/E Aerospace

Aerospace adhesive epicenter

Epoxies, which perform at relatively high sustained operating temperatures, dominate, but other polymers, with higher upper temperature limits, are making inroads. Source | Permabond

Trzaskos and Kohli both say Cytec Solvay devotes R&D time and funds to improve the reliability of bonded composite structures, developing new multifunctional surfacing and lightning strike protection technologies as well as new adhesive forms and application technologies (including automation) to reduce overall part cost. "We have new adhesives, including FM 209-1, that are designed for both autoclave and out-of-autoclave bonding," says Kohli. Adds Trzaskos, "Our ultimate goal is to replace or reduce fasteners with bonding to save weight and cost, and to eliminate hole-drilling to improve performance of composite structures."

With a wide-ranging product portfolio, Evonik Hanse (Geesthacht, Germany) supplies many aerospace products, including additives, chemical building blocks and more for resin and adhesive matrices that are ultimately used in structural adhesives, says Dr. Stephan Sprenger, Evonik Hanse's senior market development manager: "Because a key challenge with composites is the need to reduce costs, there is a big demand for adhesives that do not require surface pretreatment. Most of our current R&D projects are aimed at developing a resin modifier that can simply be added to the adhesive formulation, to eliminate the pretreatment."

Pressure to reduce costs has created demand for adhesives that need no surface pretreatment.

Evonik products associated with structural bonding include ALBIDUR core-shell tougheners that increase adhesive toughness and significantly improve the fatigue performance of adhesive bond lines. Sprenger notes that ALBIDUR tougheners have been used in helicopter rotor blade manufacturing to bond blade skins. NANOPOX products, a family of nanosilica-containing epoxy resins, are used to improve fatigue performance and compressive strength of aerospace adhesives, particularly for carbon fiber part bonding.

Composite-to-metal, composite-to-composite

Henkel (Düsseldorf, Germany and Bay Point, CA, US) is well-known for its LOCTITE brand of epoxy chemistry, in paste and film forms, in diverse applications including bonding of composites, metals, core bonding, liquid shims and lightning strike films. Known for high-performance films in a range of thicknesses and weights, Henkel offers LOCTITE EA 9696 AERO, a toughened film adhesive for bonding composites, honeycomb core to faceskins, as well as metals, that offers 60 days of out-time, yet cures in less than 90 minutes when heat is applied (130°C). Ballien notes that all Henkel films are formulated for chemical compatibility with aerospace prepregs and offer good mechanical performance during service. An extension of film adhesives, epoxy surfacing films formulated with an embedded nonwoven fabric, such as LOCTITE EA 9845SF AERO, improve the surface quality of honeycomb-cored composite parts, reducing surface dimpling and minimizing surface prep before painting; the film is available in lightning strike configurations with meshes.

Liquid shims are another core technology for the company; Ballien explains that the products are specifically formulated paste adhesives that flow to fill gaps between two faying composite surfaces, which unlike metals, cannot be ground or milled to reduce surface undulations or waviness that result from the molding process. "The liquid shim product fills gaps up to 3 mm and can handle the bonding and fatigue stresses as well, once cured." LOCTITE EA 9377 AERO is a third-generation epoxy shim product that offers long out-time to facilitate bonding large parts, such as composite ribs to large wingskins. It also offers very high compressive strength and a coefficient of thermal expansion (CTE) matched to typical carbon composite substrates.

Given the increases in commercial aircraft build rates, Henkel offers its LOCTITE automated meter/mix and dispensing equipment alongside its paste adhesives to improve mixing reliability and speed production assembly as part of its focus on innovations that make adhesive bonding faster and more efficient.

Hexcel's (Stamford, CT, US) well-known, trademarked Redux epoxy film adhesives, a standard for years, are for customers who bond sandwich panels used in structural aerospace applications, says David Elliott, Hexcel's adhesives product manager: "Where high routine service temperature is required, up to 175°C, Redux 322 is qualified for many engine nacelle applications. Where the principal concern for load is the peel force, then Redux 319, with very high peel strength, is a good option."

Redux 319 is widely used in wing structures and flight-control panels. Film weights range from 50-400 g/m^2 and are available either supported by a carrier that aids film placement and resin flow, or in unsupported form, which can be used for the reticulation process in core-to-faceskin bonding (*reticulation* occurs when film adhesive is placed over a honeycomb core in a specialized press, then heated. This subjects the film to gas pressure, which creates bubbles over the cells that subsequently rupture. The burst adhesive bubble then retracts to form a fillet along the cell rims, which then adheres the honeycomb walls to the faceskin).

The company's film adhesive portfolio includes products as light as 50 g/m^2, which are used in space satellite programs where weight savings is obviously a necessity. The Redux adhesive films have been tested for compatibility with Hexcel's trademarked HexPly prepreg resins, and common chemistry is used for both.

Magnolia Advanced Materials (Atlanta, GA, US) is another long-term supplier of high-performance epoxy adhesives, primarily pastes and liquid shims, for aerospace structural assembly, and has been in business since 1957, says the company's R&D director Steve Peake: "We have a diverse customer base manufacturing fixed- and rotary-wing aircraft for commercial, general and military aviation. Our products excel at bonding composites, metals and dissimilar substrates." The company specializes in tailoring an adhesive specifically for a customer's application, adds Peake, noting that working time, cure time, density, mechanical performance and thixatropy all can be tailored. "These aren't off-the-shelf products. We customize to meet the customer's needs."

A well-known Magnolia product is the 6398 epoxy paste family, designed for room-temperature cure for large-component assembly, including wing boxes or large wing structures. Magnolia's technical director Greg Bunn says that 6398 provides high compressive modulus and good strength for key aircraft structures. Epoxies can be made very tough with certain additives, but one downside of that is the potential for lower service temperature. "Our products employ next-generation toughening technologies which avoid an unfavorable trade-off between toughness and T_g," he says. Liquid shim pastes, Bunn adds, are a big part of the company's sales, particularly on military aircraft platforms where bonding is more common than commercial aircraft. Says Peake, "Liquid shims are key to reducing part scrap rates by filling the gap created by mismatch in part dimensions."

Given its a long history of engineering adhesive development, Permabond (Colden, Hampshire, UK and Pottsdown, PA, US) serves virtually all markets, including aerospace, and offers a broad range of adhesive chemistries in liquid and paste form. The company's technical manager Manny Dias says, "The widespread use of adhesives in aerospace, in the interior, structure and engine area, is driven by the need for strength with weight reduction." Permabond's two-part structural epoxies ET5428 and ET5429 are designed to bond carbon fiber composites and many other substrates, including metals.

Permabond offers a line of lightweight epoxy-based honeycomb core edge fillers with very low density to help keep aircraft components as light as possible, adds Dias.

Adhesives for high temperatures

Although standard epoxies, as a rule, process at higher temperatures than other polymer adhesives, the use of adhesives in aerospace applications in close proximity to jet engine "hot zones" and in other critical applications where heat is generated has opened a market for adhesives capable of sustaining their performance properties at unprecedented operating temperatures. Permabond added a high-temperature-resistant structural epoxy adhesive to its range several years ago. Permabond ET5401 was developed to bond a variety of engineering materials, including composites, thermoplastics, metals and ceramic materials. The epoxy can survive 140°C continuously, while maintaining its performance characteristics, says Dias: "Permabond ET5401 is a toughened product, which is ideal for bonding dissimilar materials, such as metal to composite, where differential thermal expansion and contraction may occur or when good impact and vibration resistance is important."

Optimizing bonds via surface preparation

Although surface abrasion is a common, and very effective, way to ensure optimum bonding between two adhesively bonded surfaces, with composites, there is the real risk of fiber damage. Many aerospace manufacturers, therefore, prefer to use peel ply, a synthetic release fabric placed over and cured with a composite part layup. Peeled off after cure, as shown here, the fabric shears the matrix surface in a way similar to what takes place during abrasion, enhancing surface free energy and aiding bonding with less risk to fiber. Source | Henkel

However, other polymers have come into use in parallel with higher-temperature laminating resins. Renegade Materials Corp. (Miamisburg, OH, US), for example, makes structural adhesives for use with its high-temperature polyimide and bismaleimide (BMI) prepregs, says general manager Laura Gray. She points out, "High-temp adhesives are not meant to be compared with epoxy adhesives. Our materials are designed to perform in extremely severe environments, so we're not focused on 'ultra-high strength,' but rather adhesives that have enough strength to do the job at high service temperatures." Gray adds that the adhesives nevertheless do demonstrate lap shear strengths of between 14 MPa to 21 MPa at room temperature, with little or no degradation at elevated »

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temperatures. Use temperatures for the polyimide adhesives can reach 340°C, and for the BMIs, 232°C.

Renegade's adhesives are available in film and paste form: Four polyimide adhesives have been developed for use with specific polyimide prepreg resins (those resins include AFR-PE-4, MVK-14, RM-1100 and RM-1066, which is the non-methylenedianiline [MDA] replacement for legacy Skybond resin). Two BMI adhesives, RM-3007 and RM-3011, also are offered, in film or paste, with the pastes intended for core-fill applications (filling the cut edges of honeycomb core) and for bonding fasteners and metallic hard points into cored parts. Primers are available for prepping surfaces for paste products.

Gray reports that most customers use adhesive films, which bond very well to metal (typically titanium) and composites, with simple surface prep that includes cleaning and surface grit-blast: "There are very few choices for high-temperature cores, but our adhesives work very well with them, most frequently Hexcel's HRH-327 polyimide honeycomb." All of Renegade Materials' adhesive films are reportedly non-toxic and exhibit excellent tack and handling characteristics and tailorable out-time. Films are supported with a variety of lightweight scrims to enhance handling and to control bond-line thickness.

Optimizing the bond

Adhesive formulators emphasize that having the right adhesive is only part of the answer. Handling the adhesive and the *adherends* is key to success. One important way composites manufacturers can optimize adhesive bonds is by increasing the surface free energy on the mating faces of the substrates that will be bonded. A common method is to abrade the substrates' bonding surfaces, which improves chemical bonding by shearing the top layer of matrix molecules to create broken atomic bonds. But, in the case of composites, this must be done carefully to avoid damaging fibers. For that reason, many aerocomposites molders employ peel ply, a release fabric placed over the layup and cured with the part; peeling off the ply after cure shears the top layer of molecules without damage to fiber and, *ideally*, enhances surface free energy for bonding without other surface prep. In reality, peel plies have come in less-than-ideal dry and resinous or "wet" forms. The latter are preimpregnated with resin to avoid leaving behind loose fibers that contaminate the adherend surface (a problem with the former). But variations in wet peel ply fabric weaves and resin toughness also can affect subsequent bond strength. In short, dry or wet peel ply *alone* might result in weak bonds (see Learn More).

"Surface preparation is a critical component of any bonded aerospace assembly, especially in composite bonding. We don't want the adhesive interface to be the weak link," says Cytec Solvay's technical fellow Bill Trzaskos, but adds, "The entire material system, including prepreg, adhesive film and peel ply should be thoroughly studied to confirm optimum performance." Cytec Solvay recently introduced a new resinous peel ply, trademarked FM 3500 EZP, designed to work with the majority of epoxy-based prepregs and adhesives.

LOCTITE EA 9895 AERO is Henkel's resinous peel ply. Reportedly much easier to remove from the composite surface, it is said to leave behind no fiber contamination, creates a clean bonding surface that increases bond durability and improves assembly productivity. "No other mechanical or manual surface preparation is needed for bonding," asserts Ballien. "A lot of customers use peel plies, since they can generate cost savings in terms of elimination of labor and sanding hours, as well as solvent usage."

Hexcel also supplies a range of peel plies, both dry (F161) and resinous or wet (M21), with the latter generally providing a better bonding surface, says Elliott.

What's to come?

When asked about the future of adhesives in aerospace, interviewees' answers were strikingly similar to those listed in *CW*'s previous aerospace adhesives overview, almost 9 years ago: Development of better bonding systems with new chemistry — potentially, nano-technologies; reductions in the surface preparation required to optimize bonding in order to speed production; chemistry changes necessary to improve health and safety and sustainability in many products; and continuation of the trend towards application-specific products tailored to each customer.

Ballien says aerospace fabricators might begin to adopt technology now used in the automotive and industrial sectors, to increase production efficiency, including out-of-autoclave strategies. Automation of adhesive application will certainly increase, to streamline aerospace part production: "Customers want more automation, especially when dealing with larger composite parts," he notes.

"Aerospace has been slow to adopt more automated solutions," Ballien observes, but insists, "but that is changing rapidly." CW

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The emerging commercial space industry

A decade since NASA opened extraterrestrial space to potential use as a commercial industry workplace, *CW* traces the role composites have played in public/private progress toward that goal.

By Donna Dawson / Senior Writer Emeritus

Fig. 1 Commercial missions to ISS: Strong competition

Sierra Nevada Corp. (Louisville, CO, US) lost out in NASA's three-way crewed mission competition (see Fig. 2), but has more recently capitalized on future *un*crewed cargo docking assignments that will have a modified version of its *Dream Chaser* docking at the International Space Station (as depicted above) in the 2019-2024 timeframe. Sierra Nevada also has supplied NASA with hardware for 13 of its Mars missions, thus far. Source | Sierra Nevada Corp.

» Once the sole purview of NASA, a US federal agency established in 1958, and its counterpart in the former Soviet Union, the space beyond Earth's atmosphere became a hot destination in the 1960s. The resulting space race consumed the public's imagination and the scientific community's technical ingenuity. Although the Soviets launched first (*Sputnik* and cosmonaut Yuri Gagarin were both firsts), the US was said to have "won" the race when NASA's *Apollo 11* touched down on the moon, July 20, 1969, and astronaut Neil Armstrong stepped out to walk on its surface.

Moving from slide rules to computers, NASA's workforce and its contractors went on to build five Space Shuttles. Following the first launch in April 1981, they flew 135 missions. But when the aging fleet was retired after 30 years, much had

Fig. 2 Two picks for commercial crewed missions

NASA's Commercial Crew Program (CCP) competition selected The Boeing Co. (Chicago, IL, US) and Space Exploration Technologies (SpaceX, Hawthorne, CA, US) to design and build human-rated spacecraft to transport crew and cargo to the International Space Station. Boeing is in the process of building its Crew Space Transportation (CST-100) *Starliner* (top) to meet CCP requirements SpaceX is modifying its *Dragon* (bottom). Source | (top) Boeing / (bottom) SpaceX

Fig. 3 Commercial launch vehicle of the future?

United Launch Alliance's (ULA, Centennial, CO, US) launch vehicles in its *Delta* and *ATLAS* families served NASA well during the latter's efforts to reach the Moon, but ULA has a new family in process: The *Vulcan* will fly in 2019, and a replacement, the *Vulcan Aces* (Advanced Cryogenic Evolved Stage), is scheduled for first launch in 2023. Unlike predecessors, the new *Vulcan V*, shown here in graphic launch display, will typify the *Vulcan Aces* family with extensive composites use. Source | ULA

changed. No longer a competitor, post-Soviet Russia had become a NASA supplier/partner. Crews — from Russia, the US and elsewhere, sometimes together on the same flight — and cargo were transported on Russia's *Soyuz* and *Progress* spaceships, respectively, to the symbol of a new vision for *cooperative* space exploration, the International Space Station (ISS).

Composites in space: The commercial market

Meanwhile, a no less profound vision was incubating: In 2006, US government programs were established to stimulate a *commercial* space program, with NASA acting as a "financial investor without equity" and technical consultant. In short, NASA was opening its vast legacy of space technology to *private* industry. The resulting Commercial Crew & Cargo Program (C3PO) and the Commercial Orbital Transportation Services (COTS) program were aimed at giving the US the capability to deliver crews and cargo to the ISS again from its own soil.

Along the way, private industry began to have ideas of its own about commercializing space. One result is that there are some *1,300* satellites in Earth orbit. Many of them perform commercial functions: Most of us rely on them for mobile phone, TV and GPS services. Others are research-related, and gather data for universities and government programs (Fig. 7, p. 107). Further, private companies have pursued much-publicized replacements for the Space Shuttle, future space-travel exigencies, such as Moon habitats, and even spacecraft for tourists. (See Learn More.)

Kathryn Lueders, program manager for NASA's Commercial Crew Program (CCP), says that was precisely the point: "The first important goal … was to be working with industry so industry could start providing the key transportation capability to the ISS," she notes, but emphasizes, "This frees NASA resources to focus on its exploration goals. And at the same time, this enables the partnership companies to develop and market their space capabilities for commercial uses, as well." »

Fig. 4 A sense of the launch vehicle market

The primary structures for the United Launch Alliance *Vulcan* launch vehicles, which are under development by Ruag Space (Zurich, Switzerland), will make extensive use of composites. Here, manufacturing staff pose in front of one half of a wrapped-for-transport carbon fiber composite payload fairing, made in one piece, out of the autoclave.

Source | Ruag Space

CCP's second goal was to make ISS a science laboratory, and to deliver crew to the ISS to perform that scientific work. Some 15 years of ISS data is now available for research. "People will be getting their Ph.Ds off this data for many years to come," she contends, pointing out that, ultimately, this represents a substantial return on investment for the nation.

A third goal was to reap the benefits of competition: Lueders notes that when multiple companies try to solve the same problems, unique solutions are found. Significant advances have come about in material science and manufacturing as new designs are evolved. "We are all learning about the best materials for the thermal protection systems that will most safely protect the crew and the cargo in the launch environment, in operation in space and on the return through Earth's atmosphere," she says.

As private industry has begun to explore the commercial potential in space flight, the high strength- and stiffness-to-weight, thermal stability in wildly varying temperatures and exceptional producibility for large, complex shapes of composites have been an enabling technology for space excursions. Given the breadth and variety of current space-related composites applications, this *CW* overview is by no means an exhaustive study of their use in the commercial space industry. The small and large manufacturing companies that make today's composites-intensive spacecraft and other off-Earth products are simply too numerous to list, let alone credit for their work (but see Learn More). At best it's a series of snapshots — of prominent features and participants.

Cargo Resupply Services (CRS)

As part of its COTS program, the first partnership NASA opened to private industry was for Commercial Resupply Services (CRS). The goal was a US vehicle to transport to and from ISS both cargo and supplies, ranging from food, water, clothing and personal items for the crew to components necessary for science experiments. The first contracts under CRS-1 were awarded to Space Exploration Technologies' (SpaceX, Hawthorne, CA, US) and Orbital ATK (Dulles, VA, US) in December 2008, and "CRS-1 will remain active through 2018," says Daniel Huot, a public relations officer for Johnson Space Center (Houston, TX, US).

In August 2012, the SpaceX cargo ship *Dragon* became the first commercial spacecraft to dock on the ISS (see Learn More). Although the *Dragon* capsule is not reusable, it can re-enter Earth's atmosphere and make a water landing via parachute (in this case, about 250 miles off the coast of southern California, in the Pacific Ocean), and, thus, can return cargo to Earth, including material resulting from ISS science experiments. Although it is known that SpaceX does use composite materials for some parts of *Dragon*, the company did not respond to requests for information for this article.

Orbital ATK (Dulles, VA, US) fulfills its CRS-1 contract with its *Cygnus* spacecraft. Orbital's long history in space began with the world's first privately developed launch vehicle more than 25 years ago, says Orbital's Sean Wilson, director of corporate communications. Its spacecraft are in low Earth orbit (LEO), geosynchronous orbit and in deep space. Its *Antares* launch vehicle supports commercial and government payloads. The company is now working on — and fully self-funding — a Mission Extension Vehicle, designed for servicing satellites in orbit. The first test article is slated for launch in late 2018.

Orbital houses the spacecraft's avionics, electrical propulsion and communications systems in its *Cygnus* service module, which is a 12-sided structure with circular forward and aft decks. Each of the 12 panels and aft deck are aluminum honeycomb sandwich panels. Carbon composite skins are on the aft deck structure, but the 12 equipment panels have aluminum skins.

Carbon composite sandwich structures with composite skins and aluminum honeycomb core are also used to make up the main structure for Orbital's rigid solar arrays. The facesheets are first autoclave-precured, then are co-cured in an autoclave with various inserts and the core material. Other structural inserts are cold-bonded into the panel afterwards. The cured parts are then machined to final dimensions. "To be a substrate for solar cells, the electrically conductive carbon fiber is covered by an insulting material on the side to which the solar cells are bonded," Wilson explains.

SpaceX and Orbital now regularly resupply the ISS. At this writing, SpaceX had completed eight and Orbital five missions. In May 2016, ISS hosted *Dragon* and *Cygnus* at the same time. "There is room for six vehicles to be docked simultaneously," Huot explains. "And along with those two US vehicles, two Russian *Soyuz* and two Russian *Progress* ships were also moored at the station."

In January 2016, NASA awarded a CRS-2 contract to Sierra Nevada Corp. Space Systems (SNC, Louisville, CO, US). Resupply via its *Dream Chaser SpaceSystem* (*DCSS*) is scheduled for 2019-2024, with earliest launch expected in late 2019.

Like the previous Space Shuttles, *DCSS* launches vertically, lands horizontally (VTHL) and is reusable. It has been modified »

SIDE STORY

The emerging commercial space industry: Google's Lunar XPRIZE

Google (Mountain View, CA, US) and the XPRIZE Foundation (Culver City, CA, US) have partnered to create the Google Lunar XPRIZE "in order to incentivize space entrepreneurs to create a new era of affordable access to the Moon and beyond while inspiring the next generation of scientists, engineers and explorers," according to Chanda Gonzales, prize lead for the Google Lunar XPRIZE.

Andrew Barton, the competition's director of technical operations, explains that of the seven active prizes in competition now, the Google Lunar XPRIZE is the biggest. "We don't use conventional contracting methodologies," Barton says. XPRIZE instead uses the incentive prize model to encourage companies and innovators to do things that they wouldn't otherwise do. "XPRIZE guarantees that one team will win the grand prize if it is the first to complete the requirements before the termination date of the prize." Only non-governmental teams can participate.

Fig. 5 **Holding out the commercial market carrot**

Since aerocomposites pioneer Burt Rutan and Scaled Composites (Mojave, CA, US) won the first cash award from the XPRIZE Foundation (Culver City, CA, US) by sending the first privately developed, piloted spacecraft beyond Earth's atmosphere, the foundation has continued to encourage commercial space exploration. Currently, teams competing to be the first to reach the Moon and claim the Google Lunar XPRIZE include SpaceIL (Jerusalem, Israel). Its moon lander, the *Sparrow* (artist's conception pictured here), will have a number of composite components. To read more about the previous XPRIZE-inspired efforts, see Learn More, p. 108. Source | SpaceIL

The grand prize is US$20 million. It will go to the first team that, on or before Dec. 31, 2017, successfully places a robot on the moon that can travel at least 500m over the moon's surface and transmit high-definition video and images back to Earth. The second team to do so will win US$5 million. In 2013 and 2014, additional sets of milestone prizes resulted in awards totaling US$5.25 million to five teams that had made substantial technical progress on the ground in preparation for their mission.

The prize was announced in 2007, registrations closed at the end of 2010 and prize contenders must have a signed launch contract by the end of this year. Originally, Barton says, about 30 teams registered, but almost half of them have dropped out. So far, only two of the 16 remaining registered teams have verified their launch contracts: SpaceIL (Jerusalem, Israel) and Moon Express (Cape Canaveral, FL, US).

SpaceIL contracted with the co-manifesting service, Spaceflight Inc. (Seattle, WA, US.), for launch by the *Falcon 9* rocket, supplied by Space Exploration Technologies (SpaceX, Hawthorne, CA, US). SpaceIL is building a 1.5m high, 2m wide craft, "a bit larger than a standard US dishwasher," they say, named the *Sparrow*. In addition to attempting to complete the grand prize requirements, the spacecraft will carry a magnetometer, with which it will take measurements of the magnetic field on the surface of the Moon should it complete its mission.

Although the *Sparrow's* basic structure of lightweight sandwich panels will feature aluminum honeycomb between thin aluminum facesheets, aluminum embedded blocks and inserts, bonded with epoxy film adhesive and foam adhesive, its struts will be carbon fiber-reinforced polymer (CFRP) tubes with bonded aluminum end-fittings. *Sparrow's* landing gear struts will have tubes constructed from a combination of CFRP prepreg unidirectional tapes and fabric with bonded aluminum/titanium end-fittings.

Further, its antenna backing panel will be a sandwich construction of aluminum honeycomb between CFRP prepreg fabric facesheets, bonded with epoxy film adhesive with potted aluminum inserts.

Moon Express has contracted with Rocket Lab USA (Los Angeles, CA, US) for its launch. Its *MX-1* lunar lander spacecraft is described as "about the size of a large coffee table." The spacecraft main rocket engine is a dual-mode bi-propellant system that uses hydrogen peroxide and kerosene for propulsion. Rocket Lab is building an all-composite launch vehicle. Its *Electron* launch system uses additive manufacturing (3D printing) for all primary components of its Rutherford oxygen/hydrocarbon engine and carbon composite construction for its payload fairing, and first and second stage liquid oxygen propellant tanks.

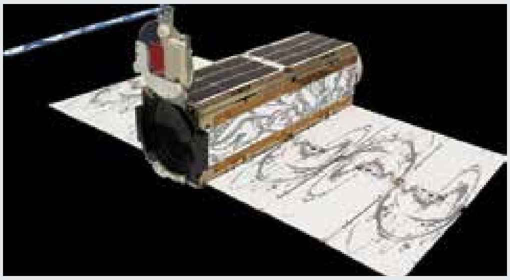
SIDE STORY

The emerging commercial space industry: Habitats and CubeSats

Although information about their methods of construction is scarce, and it is too soon, therefore, to tell if they will be big markets for composites, commercial research satellites and extraterrestrial workspaces represent great future potential. The following are three examples.

Bigelow Aerospace (Las Vegas, NV, US), has a *Federal Acquisition Regulation* (*FAR*) contract with NASA for an expandable activity module, called the *Beam*, which was successfully attached to the ISS and inflated on June 6, this year. US astronaut Jeff Williams then entered the Beam and added wireless sensors throughout the interior as a technology demonstrator to measure essential data, such as pressure, temperature, radiation and micrometeorite debris impacts. Astronauts will collect the findings on a regular basis for two years, as evidence of how well an expandable system will work in space. The *Beam* offers 16m^3 of interior space, which is available “for rent” to government or commercial tenants.

Bigelow also has developed a larger inflatable space habitat (with 340m^3 of internal space) for supporting microgravity research as well as future housing on the Moon for astronauts or space tourists — or a potential way station for missions to Mars.



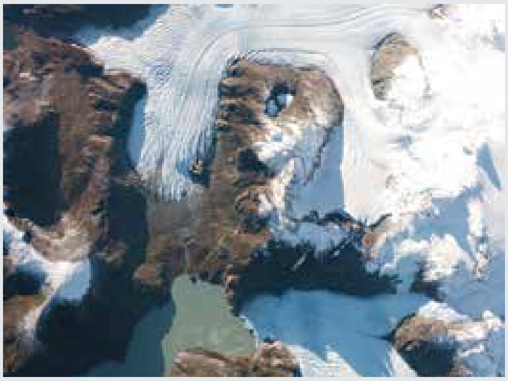


Fig. 6 The commercial CubeSat industry

Although information about their methods of construction is scarce and it is too soon, therefore, to tell if they will be big markets for composites, small commercial research satellites, called CubeSats — many not much larger than loaves of bread — are proliferating for a wide range of purposes. Pictured here is a *Dove* satellite, one of many built by Planet Labs LLC (San Francisco, Calif.) as part of an effort to capture images of the entire Earth daily (e.g., this satellite photo of a Southern Patagonia ice field). To read more about it, see Learn more, p. 108.

Source | Planet Labs LLC

The rise of CubeSats

By contrast, very small satellites, called CubeSats — not much larger than a loaf of bread — are very big business today. Founded in 2010 by a team of ex-NASA scientists, Planet Labs LLC (San Francisco, Calif.) is a leader here. “We are building a constellation of very small CubeSats, which we named *Doves*,” says the company’s communications operative Rachel Holm. “Planet is driven by a mission to image the entire Earth every day, making global changes visible, accessible and actionable,” he explains.

The company, in fact, has designed, built and now operates the world’s largest commercial fleet of Earth-imaging satellites, funded by venture capital and customers of its services.

As of mid-May, Planet had launched 133 satellites into space during a three-year period, on rockets built by SpaceX, Orbital ATK and the Japan Aerospace Exploration Agency (JAXA) to the ISS with other payloads. Planet’s CubeSats are then released from the ISS into orbit and operated from Planet’s Mission Control in San Francisco.

Holm does not reveal if composite materials are used in making the satellites, but says, “Our *Dove* satellites are designed in-house using a mix of custom-designed, space-grade materials and off-the-shelf consumer-grade electronics.”

NanoRacks LLC (Webster, TX, US) was formed in 2009 to provide commercial hardware and services for the US National Laboratory, the official designation of the US portion of the ISS, through a Space Act Agreement with NASA. Abby Dickes, marketing and communications manager, says NanoRacks’ role with composites is limited, but calls NanoRacks the market leader for access to LEO. “We have coordinated more than 350 customer payloads that have launched to the ISS, which includes 120 CubeSats deployed from our NanoRacks CubeSat Deployer on Station,” she says, adding that the company has helped push the space marketplace to its new era (Fig. 7, p. 107).

Its fleet of on-orbit hardware includes NanoLabs, MixStix (mixture tubes) a MicroPlate reader and a microscope. NanoRacks core payload hardware is its 10 cm^3 NanoLab standardized plug-and-play CubeSat research modules.

Its customers build their experiments (to discover seed or plant behavior, for example, in a microgravity, or weightless environment) into the NanoLab CubeSat for launch with other payloads to the ISS. Customers include NASA and other US government agencies, the European Space Agency (ESA), the German Space Agency (DLR), Urthecast, Space Florida, Virgin Galactic, pharmaceutical drug companies, Planet Labs, schools and more.

In 2015, NanoRacks signed a teaming agreement with Blue Origin (Kent, WA, US) to offer integration services on its *New Shepard* spacecraft. Also in 2015, an agreement was signed with Made in Space (Moffett Field, CA, US), which has developed additive manufacturing technology for use in microgravity, to build and deploy 3D printed satellites into orbit. Called Stash & Deploy, the experiment has demonstrated that a 3D printer works normally in space. NASA says testing a printer on the ISS is the first step toward establishing an on-demand machine shop in space, which would be essential for deep-space crewed missions.

Fig. 7 Signed, sealed and delivered to LEO

NanoRacks LLC (Webster, TX, US) provides commercial hardware (like this NanoRacks-JAMSS-2, Lagrange-1 device) and services to the US National Laboratory aboard the International Space Station (ISS). The company's devices deliver commercial and student payloads, including CubeSats, to the ISS, for small satellite deployment into space and/or missions, such as research materials delivery to ISS and return to Earth for further study after exposure to the space environment. For more, see Learn More, p. 108.

Source | NanoRacks LLC

for uncrewed cargo missions to meet CRS-2 requirements. The crew version has fixed wings and launches vertically on top of the launch vehicle without a fairing encasing the vehicle — a feature allowing a mission to be aborted during launch if necessary for crew safety. The uncrewed cargo spacecraft does not need this capability, so its wings fold, allowing it to be mounted in a standard 5m-diameter payload fairing. Its main propulsion system, originally included for abort capability, has been removed to make space for more cargo storage. Further, a separate cargo module has been added as well.

Dream Chaser's primary and secondary structures, including aerosurfaces and aeroshells, canted fins, cabin and bulkhead, are constructed from carbon fiber prepregged with bismaleimide (BMI) resin, in woven fabric and unidirectional tape, in a sandwich structure with a nonmetallic honeycomb core. The latest design employs extensive co-bonding in an autoclave, incorporating advanced 3D woven preform joints.

SNC's space technologies group already provides critical subsystems to NASA and to other commercial space companies throughout the world. "We have provided thousands of components, supporting over 450 space missions, including more than 70 NASA missions that have gone to seven planets in our solar system, and in the last two years have also launched 18 satellites," says John Roth, VP of business development for SNC's Space Systems. "I would say our overall vision is to continue to be an integral part of humanity's use, and exploration, of space."

Commercial Crew Program (CCP)

Established in 2010, NASA's Commercial Crew Program (CCP) selected SpaceX and The Boeing Co. (Chicago, IL, US) to design and build human-rated spacecraft to transport crew and cargo to the ISS. SpaceX is modifying its *Dragon* to meet NASA's CCP requirements and Boeing is in the process of building its Crew Space Transportation (CST-100) *Starliner*.

The test article of Boeing's *Starliner* capsule is undergoing thorough testing at Boeing's Huntington Beach, CA, US, facility. In Boeing's terms, it is being "shaked, baked and tested to the extreme." A second *Starliner*, called *Spacecraft 1*, is being assembled at NASA Kennedy in Florida. The upper and lower domes of the pressurized spacecraft are aluminum, made in a weldless spinforming process and machined into a honeycomb pattern to reduce weight. Some portions of the *Starliner* are apparently composite, but Rebecca Regan of Boeing Communications, advises, "Because of the highly competitive environment we're in with the Commercial Crew Program, we're not talking about our composite parts, materials or processes at this time."

> NASA selected SpaceX and Boeing to build human-rated spacecraft to transport crew and cargo to the ISS.

Sierra Nevada and Blue Origin (Kent, WA, US) are potential contenders for future CCP contracts. Founded by Jeff Bezos, Blue Origin is a privately funded aerospace manufacturing and spaceflight services company. Its *New Shepard* six-seat crew capsule and second stage booster rocket — named for Astronaut Alan Shepard, the first American in space — are designed for vertical takeoff and vertical landing (VTVL). The crew capsule returns via multiple parachutes for landing, and the first stage booster rocket also returns to Earth. Both are reusable. The first test flight was in April 2015. In a November 2015 flight, the capsule reached an elevation of 100,534m, and both capsule and rocket were returned safely to Earth. In January 2016, the same capsule and rocket were relaunched. The capsule reached an altitude greater than 101,500m, and again, capsule and rocket safely returned and were still fit for reuse. (The Kármán line, which is 100 km/62 miles above sea level, is considered the starting point of "outer space" above Earth's atmosphere.) »

Fig. 8 Investing in the commercial possibilities

Blue Origin (Kent, WA, US) has broken ground on its 750,000 ft^2 orbital vehicle manufacturing facility in the US state of Florida (near long-established US launch facilities at Cape Canaveral) for manufacture of its *New Shepard* reusable spaceship (artist's renderings).

Source | Blue Origin

Although Blue Origin declined to discuss the materials used in the *New Shepard* craft, Bezos revealed in-progress plans to build a 750,000 ft^2 orbital vehicle manufacturing facility at Exploration Park (Kennedy Space Center, Cape Canaveral, FL, US) "clearing the way for the production of a reusable fleet of orbital vehicles that we will launch and land, again and again." Work on all but *New Shepard's* engines is slated for the facility, which the company says will house automated composites processing equipment, clearly implying composites for its spacecraft.

Launch vehicles: To ISS and beyond

Design and assembly of launch vehicles also has been opened to private industry. SpaceX's *Falcon 9* launch vehicle pushes cargo and will ferry future crew vehicles to the ISS and other LEO missions. For its part, Orbital ATK has, thus far, used its *Antares* rocket to power its *Cygnus* on cargo delivery missions to ISS. The second stage of *Antares* features a solid rocket motor with a composite case, and all its upper stack structures — interstage, motor cone and payload fairing — are composite structures as well.

Headquartered in Centennial, CO, US, United Launch Alliance (ULA), a 50/50 joint venture between Boeing and Lockheed Martin (El Segundo, CA, US), is currently launching LEO missions via the *ATLAS V*, a version of the *ATLAS* rocket that served NASA so well during the 1960s race to the moon. Boeing, Sierra Nevada and Orbital all plan to launch their upcoming crewed cargo missions on *ATLAS V* vehicles.

The company's *Delta* and *ATLAS* families of launch vehicles will be replaced, in time, with its next generation *Vulcan* launch system, the first of which will be the *Centaur*, scheduled to fly in 2019. A replacement, the *Vulcan Aces* (Advanced Cryogenic Evolved Stage), is scheduled to fly in 2023. Cryogenic refers to the propellant, which for the *Aces* stage will be liquid oxygen and liquid hydrogen.

The primary structure of *Vulcan* makes extensive use of composites. Five major carbon fiber/epoxy composite structures will make it up: The payload fairing (5.4m diameter) is available in three lengths, 20.7m, 23.5m and 26.5m. The interstage structure (5.4m diameter) is 4.1m long. This single, tapered 360° hollow piece connects the rocket's first and second stages. It's 5.4m in diameter at its base, and it tapers toward its upward end to interface with the smaller-diameter second stage. A 5.4m-diameter heat shield at the rocket's base also will be a one-piece composite structure. Most of these structures also will have composite insulation protection on their exteriors. Mark Peller, VP of engineering, says ULA has completed its preliminary

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

Read more on two subjects noted in this feature article in online articles that provide additional background details:

"X Prize offered for first private craft to the Moon" | short.compositesworld.com/LUNARX

"NASA considers carbon nanotube mirrors for cubesat telescope" | short.gardnerweb.com/NASACube

Read about early efforts in commercial space development online in "The Private Space Race" | short.compositesworld.com/nfVqM80G

One example of commercial satellite entrepreneurship is Ames Research Center's Common Bus, a software-streamlined, modular concept that enables assembly of a variety of different composites-intensive orbital vehicles from commercial off-the-shelf parts. Read "Optimization software improves small, low-cost satellite design" | short.compositesworld.com/IdJIZ2AT

Read more online about the historic first private mission to ISS in "SpaceX *Dragon* safely returns NASA cargo from International Space Station" | short.compositesworld.com/Dragon2ISS

Read more about SNC's *Dream Chaser* development in "U.S. crew and cargo candidate takes shape with composites" | short.compositesworld.com/USCrew

Read more about composite cryotank development in "NASA/Boeing composite launch vehicle fuel tank scores firsts" | short.compositesworld.com/CCTDCryotk

Read about a NASA/Boeing cryotank "first" in "'Smart tooling' cuts time and risk for complex unitized composite structures production" | short.compositesworld.com/IM-FlutCor

Read more about the *Orion* heat-shield redesign in "*Orion* re-entry system: Composites displace metal" | short.compositesworld.com/Fwr8VO1b

Read more about the parallel all-composite *Orion* capsule in "Simulation simplifies fabrication of all-composite crew module" | short.compositesworld.com/5ml86XSF

Read more online about the genesis of Virgin Galactic's private tourism quest and its *LauncherOne* program in the following:

"Meet *VSS Unity*, Virgin Galactic's new all-composite *SpaceShipTwo*" | short.compositesworld.com/VSSUnity

"Virgin Galactic's *LauncherOne* picked for satellite launches" | short.compositesworld.com/Launcher1 design review, is working on the detailed design and already has released some orders to suppliers or to the factory floor for building rocket components. "We are partnering with Ruag Space (Zurich, Switzerland) for development and production of our composite structures," Peller says. Ruag has supplied large composite structures to ULA, as well as major European aerospace companies, for many years and will have oversight responsibility for the five major *Vulcan* composite structures — each of which will be built in *one piece*, using out of autoclave (OOA) materials, in ULA's Alabama factory. This means the *Vulcan* will be "more efficient, lighter and, hopefully, lower cost and higher quality," Peller says.

For the 5.4m diameter payload fairing, Ruag is using Toray T300 carbon fiber woven in either a carbon or carbon/glass (E- glass and S-glass fibers) prepreg. Ruag selected the (unidentified) resin from among various commercial resin systems, choosing the one best suited to its vacuum bag out-of-autoclave process, "recently implemented as a baseline process for all our products," says Matteo Rendina, manager of product engineering for Ruag Space.

The payload fairing is a sandwich structure with prepreg laminate skins and an aluminum honeycomb core. A cork thermal protection system is applied to the exterior. The cylindrical-shaped main section of the fairing is laid up in 0/90° and ±45° fiber architecture on a flat table via an automated process. When complete, the layup is transferred onto a male bonding mold by a dedicated jig. The inner skin of the ogive-shaped section at the top of the fairing is hand laid directly on the final bonding mold; the outer skin is laid up on a dummy mold and then transferred to the bonding mold, and finally draped over the honeycomb core.

A co-curing process is used to manufacture a full fairing half in one piece, including the inner and outer skins, honeycomb core and thermal protection, a manufacturing process that reduces the production time and costs, Rendina says. (The payload fairing must be made in two halves, in length, because it separates during launch.) Rendina declined to disclose any details of the proprietary curing process. He says, however, that the cure profile has been fully validated by Ruag.

All composite elements are manufactured using to the same materials and process, Rendina says, although the design details vary on the different products in terms of the laminate layup, honeycomb and thermal protection system.

Space tourism

Although Virgin Galactic (Mojave, CA, US), founded by Sir Richard Branson and abetted by aerospace composites boundary-pusher Burt Rutan, has yet to realize its much publicized space tourism enterprise, its newest rocket-powered *SpaceShipTwo (SS2)*, the *VSS* »

Unity, is in the ground-test phase, after which it will undergo extensive flight testing. Flight tests will begin with captive-carry flights attached to the *WhiteKnightTwo (WW2)* "mothership" followed by glide flights before proceeding with rocket-launched flights of increasing length. The latest version of *WW2*, the *VMS Eve*, is in routine service as a trainer aircraft. In service, the company expects that a *WW2* will ferry a fleet of ticketed-passenger-filled *SS2s* aloft, then launch them for rocket-powered flight beyond 100 km/62 miles above sea level for a short, weightless sub-orbital excursion to the Kármán line. Passengers will be returned to Earth via winged flight to a landing strip (see Learn More).

Both of these space access systems have all-composite airframes. William Pomerantz, Virgin Galactic's VP, special projects, notes that composite materials were selected largely because of their highly desirable strength-to-weight ratio, as well as their manufacturability and customization. Details of the materials and process technology are proprietary, but Pomerantz says hand layup and winding techniques are used, and parts are produced by autoclave and out-of-autoclave processes.

LauncherOne, the company's all-composite satellite launch vehicle, is now in construction and testing, and represents Virgin Galactic's commercial aspirations in the small LEO satellites realm. It will be built by Virgin's sister group, The Spaceship Co., at its design and manufacturing facility in Long Beach, CA.

NASA's quest: Humans to Mars

The burgeoning commercial space industry has, indeed, freed NASA to focus on the demanding and radical challenges of accessing and exploring deep space. NASA is building its *Orion* capsule as its space vehicle to take astronauts deep into space — even eventually to Mars — with Lockheed Martin as its prime contractor. *Orion's* original metal atmospheric-reentry heat shield has been exchanged for one designed with composites, and in a parallel program, an all-composite *Orion* capsule has been prototyped alongside the currently mainstreamed metallic version (see Learn More). NASA also is building a new Space Launch System (SLS) for missions beyond LEO. Although Boeing is its prime contractor, opportunities are also in the works for partnering with SpaceX for launches beyond LEO.

NASA has contracted with SNC, for example, to provide critical hardware for a planned 2020 mission to Mars. It will be the 13th NASA mission to that planet for which SNC has earned a contract. On one of them, SNC provided no less than the descent braking system that lowered the *Curiosity* rover to the Martian surface.

Orbital ATK also has been selected by NASA, in this case, to study the concept of a cislunar habitat (*cislunar* refers to the space lying between the Earth and the Moon, or to the Moon's orbit), with an eye on an eventual human mission to Mars. Orbital's *Cygnus* spacecraft is a strong candidate to be used as a habitat building block for these ventures, says Orbital's director of corporate communications Sean Wilson.

In addition, an important technology demonstration effort at NASA Marshall Space Flight Center (Huntsville, AL, US) is the development of a composite cryotank capable of containing liquid hydrogen or liquid oxygen rocket fuel (see Learn More). Completed in 2014 by a NASA/Boeing team, it marked a major accomplishment in NASA's Game Changing Development program under the Space Technology Mission Directorate.

John Vickers, NASA principal technologist for advanced manufacturing on the composite cryotank technologies demonstration effort explains, "It was not developed for a specific launch vehicle, but as a technology demonstrator to help us increase our capability for the mission to Mars." It would be applicable to all kinds and sizes of launch vehicles, as well as to habitats, landers, to surface vehicles — any of the logistical craft that might be needed for the mission to Mars.

About a 30% advantage is gained, in general, when composites replace metals on spacecraft. But, "when we think about the launch vehicle, it's probably 60% of the total weight of the launch vehicle," says Vickers, because the vast majority of the weight is made up of the fuel tanks.

Composites in space: Increasing mission capabilities

Vickers describes the challenge ahead in terms of launch vehicle-to-payload ratio, a comparison of the weight of the fuel and rocket compared to that of the payload the rocket is able to deliver to target. "If we are talking about going to LEO," he points out, "that would be about 20:1. That is, it would take about 20 lb of fuel and rocket to deliver 1 lb of payload to LEO." For the trip to *Mars*, however, the ratio, he points out, "is certainly greater than *600:1*." There's a huge incentive, then, for NASA and private industry alike, to close that ratio to the greatest extent possible, and Vickers contends that composites offer the best opportunity available today. Whatever goes to deep space — cryotanks, launch vehicles, crew capsules, landers, surface vehicles — needs to have the lowest possible mass. "Typical advanced composites can reduce the weight for us by about 30%," Vickers notes. "That's pretty significant. But what we are really pushing for today is to reduce the weight by 50%."

So," he sums up, "we are seeking *half* the weight and *half* the cost at *twice* the speed." CW

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Composites Events

Sept. 7-9, 2016 — Novi, MI, US
SPE Automotive Composites Conference and Exhibition (ACCE)
speautomotive.com

Sept. 12-17, 2016 — Chicago, IL, US
International Manufacturing Technology Show (IMTS) 2016
imts.com

Sept. 13-14, 2016 — Chicago, IL, US
Additive Manufacturing Conference 2016
additiveconference.com

Sept. 13-15, 2016 — Liege, Belgium
SAMPE Europe Conference & Exhibition
sampe-europe.org/conferences/liege-2016

Sept. 14-15, 2016 — Chicago, IL., US
TRAM (Trends in Advanced Machining, Manufacturing & Materials) Aerospace Conference 2016
tramconference.com

Sept. 19-21, 2016 — Toulouse, France
SpeedNews 17th Annual Industry Suppliers Conference in Toulouse
speednews.com/aviation-industry-suppliers-conference-in-toulouse

Sept. 19-22, 2016 — Williamsburg, VA, US
American Society for Composites 31st Technical Conference and ASTM Committee D30 Meeting
mech.utah.edu/ASC2016

Sept. 21-23, 2016 — Augsburg, Germany
Experience Composites
experience-composites.com/en

Sept. 26-29, 2016 — Anaheim, CA, US
CAMX – Composites and Advanced Materials Expo 2016
thecamx.org

Sept. 27-30, 2016 — Hamburg, Germany
WindEurope Summit and WindEnergy Expo
windenergyhamburg.com/en

Oct. 4-6, 2016 — Tampa, FL, US
IBEX 2016
ibexshow.com

Oct. 5-7, 2016 — Los Angeles, CA, US
Greenbuild International Conference and Expo
greenbuildexpo.com

Oct. 11-12, 2016 — Bremen, Germany
ITHEC, International Conference and Exhibition on Thermoplastic Composites
ithec.de/conference_fees

Oct. 11-13, 2016 — Hannover, Germany
GOCarbonFibre Europe 2016
gocarbonfibre.com

Oct. 12-13, 2016 — Dearnborn, MI, US
Automobility 2016: Reimagining Transportation
autonomyandmobility.com

Oct. 18-20, 2016 — Munich, Germany
eCarTec Munich 2016
ecartec.com

Oct. 19-22, 2016 — Goyang, South Korea
SAMPE Korea 2016
nasampe.org/m/event_details.asp?id=797466

Oct. 25-26, 2016 — Warwick, RI, US
AWEA Offshore WINDPOWER 2016
awea.org/events/eventv2.aspx?eventid=43770&navItemNumber=8265&navItemNumber=8237

Nov. 2-3, 2016 — Birmingham, UK
Advanced Engineering UK
advancedengineeringuk.com

CW **Nov. 9-11, 2016 — Scottsdale, AZ, US**
Carbon Fiber 2016
compositesworld.com/conferences

Nov. 14-16, 2016 — Sao Paulo, Brazil
Feiplar Composites + Feipur 2016
feiplar.com.br

Nov. 15-17, 2016 — Suntec City, Singapore
JEC Asia 2016
jeccomposites.com/events/jec-asia-2016

Nov. 28-29, 2016 — Stuttgart, Germany
2nd International Composites Congress (ICC)
www.composites-europe.com/1st_international_composites_congress_icc_28.html?

Nov. 29-Dec. 1, 2016 — Stuttgart, Germany
Composites Europe 2016
composites-europe.com

Dec. 12-14, 2016 — Düsseldorf, Germany
Wind Turbine Blade Manufacture 2016
amiplastics-na.com/events/Event.aspx?code=C756&sec=7154

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

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
jeccomposites.com

March 26-30, 2017 — New Orleans, LA, US
NACE Corrosion 2017
nacecorrosion.org

April 4-6, 2017 — Hamburg, Germany
Aircraft Interiors Expo 2017
aircraftinteriorsexpo.com

April 4-6, 2017 — Detroit, MI, US
SAE 2017 World Congress
sae.org/congress

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RAIL LINE LANDMARK RESTORATION VIA PULTRUSION

Composites' corrosion resistance prolongs handrail/fencing lifespan

Strongwell provided 564 linear meters of assembled FRP fencing and handrail for the access stairway and pedestrian footbridge along one side of the Carlisle Bridge on the historic London-to-Glasgow rail route.

Source (all photos) | Strongwell

Network Rail (London, UK) wanted a fencing/handrail product that would eliminate the previous rounds of repairs, painting and, ultimately, complete overhauls that were expected with the previous corrosion-prone steel fencing and handrail systems.

Great Britain's extensive railway network includes historic and, often, picturesque infrastructure. One example is the Carlisle Bridge in Lancaster. Set in the Lancashire region of northwestern England, the 110m bridge over the River Lune has carried rail traffic since 1847. A key element of the West Coast main line, it is part of the London-to-Glasgow rail route.

The rail bridge includes an access stairway and pedestrian footbridge along one side, which protect walkers with fencing and handrails. Previous metal fencing elements had been replaced numerous times, but given the wet climate, were badly rusted again. Network Rail (London, UK), the entity responsible for maintaining the railway, wanted a fencing/handrail product that would combine a suitable aesthetic with high strength at low weight to avoid adding more mass to the bridge. Most importantly, planners wanted corrosion resistance, to eliminate the previous rounds of costly maintenance — repairs, painting and, ultimately, complete overhauls.

Network Rail selected Pipex px (Roborough, Plymouth, UK), a British manufacturing, engineering and design firm, to develop a composite solution that would replace the corroded metal footbridge and stairway railings. Pipex px, a distributor for pultruder Strongwell (Bristol, VA, US), specified Strongwell's trademarked EXTREN Series 525 pultruded glass/polyester structural shapes in slate gray color, including I-beams, square tubes and round tubes, as well as flat plates for attaching the railing system to the bridge parapets. Series 525 incorporates fire-retardant additives and an ultraviolet (UV) inhibitor. The fencing and handrail system ranges from 1.07m to 2.44m high, and was assembled offsite, then installed along both sides of the rail bridge and the stairways by Story Contracting (Carlisle, UK).

In total, 564 linear meters of assembled FRP fencing was installed. Reportedly, both the installers and end-users are delighted with the outcome of the completed refurbishment project. The composite fencing and handrail at Carlisle Bridge is anticipated to last more than 60 years in continuous service. CW

The corroded steel fencing and handrail system (above) was replaced with Strongwell's trademarked EXTREN Series 525 pultruded glass/polyester structural shapes in slate gray color (at right).

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3D printed composite parts provide solution for UAV

New technology uses long carbon fibers to boost strength and stiffness for small yet high-performance aircraft.

By Ginger Gardiner / Senior Editor

» Aurora Flight Sciences (Manassas, VA, US) is a well-known Tier 1 supplier of advanced aerospace components, such as the composite fuselage for the *Global Hawk* unmanned aerial vehicle (UAV). It is also a manufacturer of UAV platforms, including the line of small vertical takeoff and lift (VTOL) UAVs named *GoldenEye*; the *Orion* medium-altitude, long-endurance UAV; and the *Skate*, a family of small UAVs tailored for use in urban or crowded environments. In 2016, Aurora was selected by the Defense Advanced Research Projects Agency (DARPA, Arlington, VA, US) to develop the Vertical Take-Off and Landing Experimental Aircraft (VTOL X-Plane), which will be the first aircraft in history to demonstrate distributed hybrid-electric propulsion ducted fans, both tilt wing and canard, for VTOL and high efficiency in both hover and high-speed forward flight.

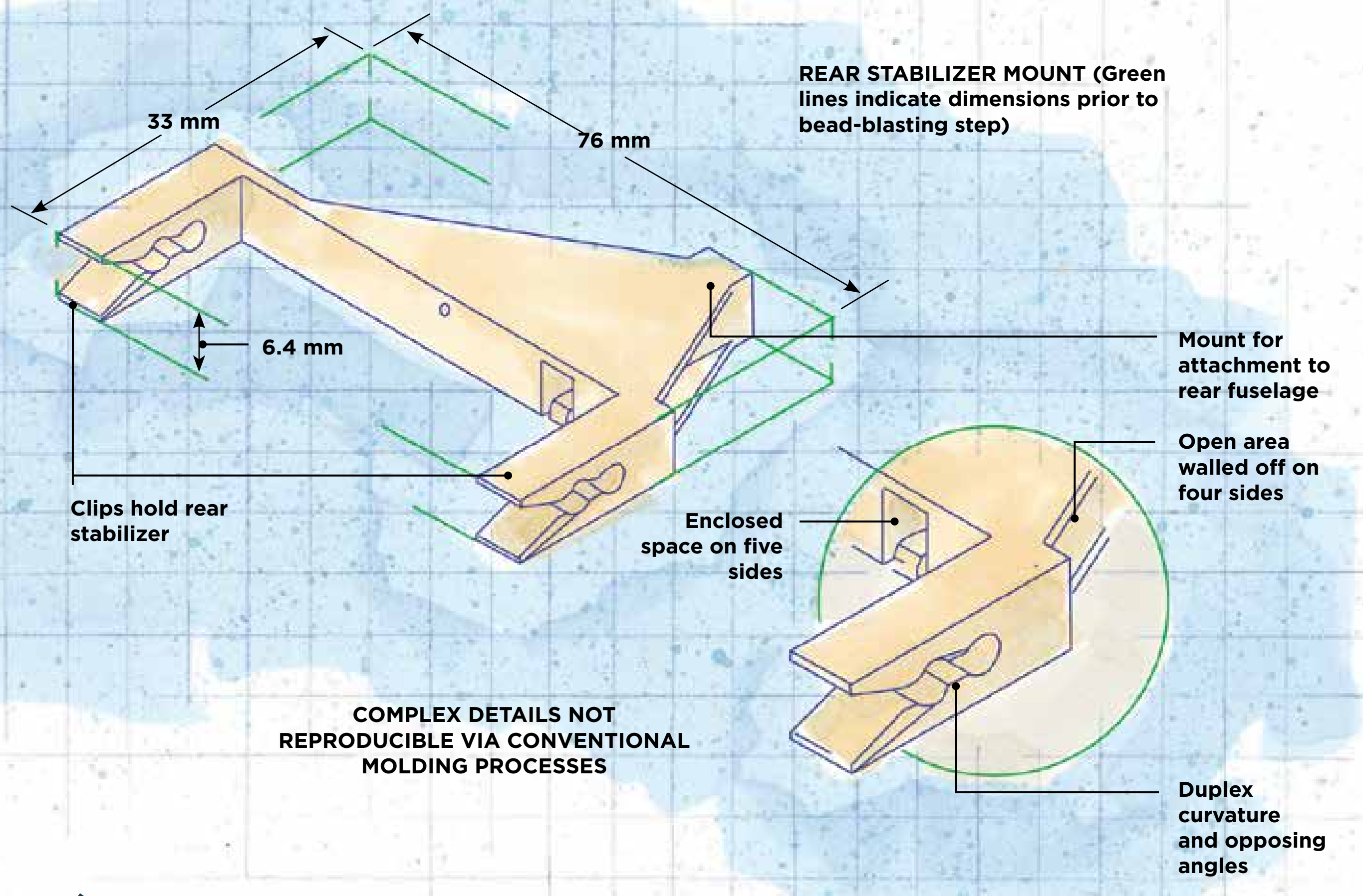
Aurora also is a pioneer in the use of 3D printing in aerospace systems. In November 2015, it worked with Stratasys (Eden Prairie, MN, US) to produce the world's first jet-powered, 3D-printed UAV, using fused deposition modeling (FDM) and ULTEM 9085 polyetherimide (PEI) resin from SABIC (Pittsfield, MA, US) for 80% of its parts. According to Dan Campbell, structures research group lead at Aurora Flight Sciences R&D in Cambridge, MA, US, this project demonstrated "just how quickly you can go from designing to building to flying a 3D printed jet-powered aircraft." Campbell adds that the overall design and build time for the 15-kg aircraft, which has a 3m wingspan, and can fly at speeds up to 240 kph, was reduced by 50% vs. conventional manufacturing methods.

Aurora continues to work with a variety of 3D printing technologies, and recently pioneered the use of 3D-printed *composite* parts reinforced with 25.4-mm-long carbon fibers for a new-development UAV. Although that aircraft cannot be detailed here, its 76-mm by 38-mm rear stabilizer mount, which exploited the composites-based additive manufacturing (CBAM) technology developed by Impossible Objects (Northbrook, IL, US), provides an interesting study in what long-fiber reinforcement can provide in 3D-printed structures.

Aurora Flight Sciences used Impossible Objects' CBAM technology to 3D print — using 25.4-mm-long carbon fibers in an HDPE matrix — a 76-mm by 38-mm rear stabilizer mount (lower left in photo) for a developmental UAV similar in size to the *Skate* shown above, part of an Aurora-developed family of small UAVs.

Source (photo at left) | Impossible Objects

Source (photo at top of page) | Aurora Flight Sciences



DESIGN RESULTS | **Aurora Flight Sciences' 3D Printed UAV Rear Stabilizer Mount**

- Delivered increased strength vs. 3D printed, unreinforced polymer parts, yet met a tight schedule and maintained reduced cost.
- Achieved geometric complexity not possible with conventional manufacturing methods for a low-volume, prototype part.
- Provided high strength at low weight, important for achieving the desired performance in the unmanned aerial vehicle.

Illustration / **Karl Reque**

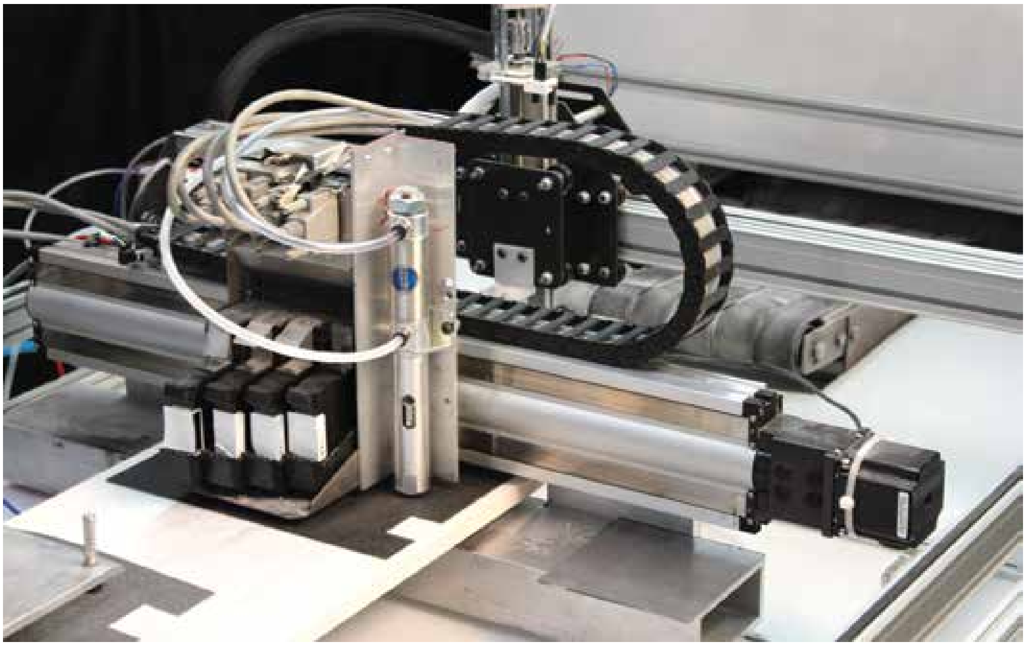
Fiber for higher strength

"This part sits below the tail at the rear of the aircraft," explains Campbell. "The single projection mounts into the aircraft fuselage and the clothespin-shaped prongs or clips hold the stabilizer." The part is an interior structure, not visible on the aircraft's exterior.

Impossible Objects' chief commercial officer Jeff DeGrange had worked with Aurora Flight Sciences in his previous tenure at Stratasys, and was in communication with Campbell's team when they began having difficulty with this part. "The 3D printed unreinforced plastic parts they had been using were breaking," recalls DeGrange. These parts were printed using selective laser sintering (SLS) and nylon resin. "This aircraft does not have landing gear," explains Dan Campbell, "so when it lands on its belly, as it is designed to, the stabilizer receives a fair amount of loading, which would snap the prongs on the purely plastic parts." DeGrange thought Impossible Objects' CBAM technology could provide a solution.

"The part needed to be stronger," recalls DeGrange, "but also lightweight." This, indeed, is what CBAM offers because, as a 3D printing method, it departs from the ordinary with a rather uniquely designed process. It begins with *nonwoven fabrics*. Not only stronger than unreinforced plastics, the fabrics can accommodate a fiber length much longer than the milled/chopped fibers used in most commercially available "carbon fiber" FDM filaments.

"3D printing was obviously the quickest path to producing this part," explains Impossible Objects CEO Larry Kaplan. He notes that the UAV rear stabilizer mount's complex geometry could not have been easily injection molded or machined, "especially as an integrated, unitary part." While most 3D printing processes enable rapid manufacture of low-volume, complex parts without tooling or significant subtractive metal parts-type machining, he adds, "ours was the only such technology that could provide a solution in this situation." »



The CBAM process begins with a printer, which applies a water-based solution followed by a powdered thermoplastic matrix on successive, extremely thin layers of carbon fiber felt. Only the part shape is printed with the solution, layer by layer, so the thermoplastic powder only adheres to the felt where the sheet is wet from printing when excess powder is vacuumed away between layer depositions.

Source | Impossible Objects

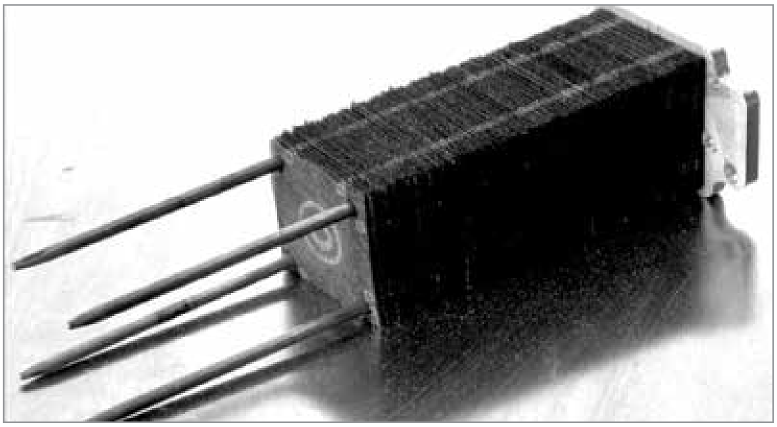
Printing a CBAM part

Production of the part began with Impossible Objects' review of the CAD-generated STL file supplied by Aurora Flight Sciences. (STL comes from STereoLithography, and is the standard software language for 3D printing.) "Sometimes the designs need to be refined for a layer-based manufacturing process like 3D printing," explains Kaplan. He notes it is also important to look at where the part has its maximum and minimum strengths. "Our process achieves maximum strength in the plane of the fabric, so we collaborate with customers to maximize this per the part's requirements," he notes. Wall thicknesses also might need to be examined and, depending on the part design, increased for additional strength or even beneficially decreased to take advantage of the strength-to-weight ratio offered by a part printed with long fiber reinforcement.

In this case, however, no adjustments were needed. Thus, Impossible Objects processed the design through its in-house software, slicing it into horizontal layers 0.05-0.08 mm thick, which were then sent to its printing equipment. "We then fed in the fabrics," says Kaplan. For the rear stabilizer mount, the fabric was an isotropic nonwoven sheet made of carbon fibers chopped to nominal 25.4-mm length, held together with a binder. Sheets are processed individually, from the part bottom to its top.

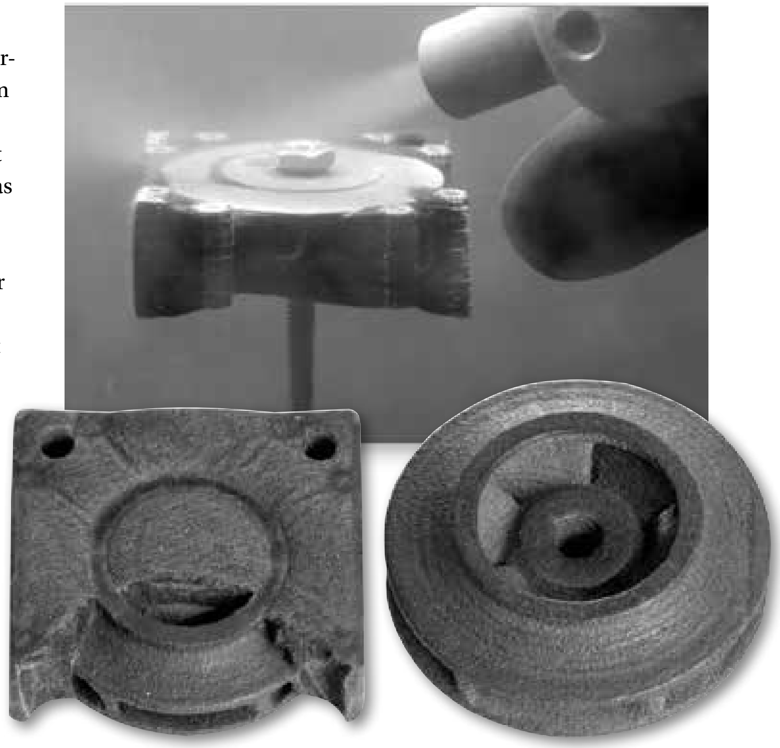
"Our printer applies a water-based solution to the sheet and then a powderized thermoplastic matrix," says Kaplan, noting the mechanism is similar to a toner-based copier. This part used a high-density polyethylene (HDPE) powdered matrix. The powder adheres where the sheet is wet from printing. Only the part's shape, layer by layer, is printed with the solution. Left dry are the areas of each layer where no material is needed for the final part.

Each powder-coated sheet then passes beneath a vacuum, which removes the non-wetted powder for reuse. The sheet is then stacked onto a processing bed fitted with upper and lower press platens. The next sheet is printed, powdered, vacuumed and stacked on top, followed by all the layers required for the part. Mechanical pins in the processing bed



Printed, powdered and vacuumed sheets for a different part are shown here, stacked. Sheet alignment is maintained via pins inserted through holes punched during printing. During processing, this stack is built on the lower platen of a press. When built, it is heated to the printed thermoplastic's melt temperature and then consolidated in the press.

Source | Impossible Objects



Bead blasting removes the excess, uncoated fibers leaving the final, fiber-reinforced, 3D-printed part, as shown here with a small impeller.

Source | Impossible Objects

are used for registration of the layers. Holes for these pins are punched during the print process. “This produces very tight tolerances in the sheet positioning,” says Kaplan, “to within 0.025 mm or tighter.”

When all of the sheets are stacked, they are heated to the melt temperature of the thermoplastic polymer, which in this case was roughly 135°C. The processing bed’s platens compress the stack to final part thickness — under the resulting heat and pressure, the carbon fibers are encapsulated in the thermoplastic polymer matrix. At this point, however, the now-consolidated reinforced polymer is still surrounded by the portion of the fiber layers that were previously vacuumed free of thermoplastic powder. “We then use bead blasting to remove the excess, uncoated fibers,” explains Kaplan, “leaving the final part.”

At the time the rear stabilizer mount was first built with CBAM, more than 18 months ago, production took about 30 minutes, on average, per part batch. “Today, we can do this part in an average of 15 minutes,” says Kaplan. “We have drastically improved our processing times and we batch process so that heat and press time is shared between multiple parts.” Impossible Objects also is working on additional improvements, which it claims will ultimately reduce the part’s processing time to several minutes or even less.

“Another key benefit of the Impossible Objects process is that it is based on existing fiber materials and polymers,” Kaplan points out. “This was important for this project because of time constraints.” Since then, Kaplan’s team has proven that the system can work with nylon (PA12) and polyetheretherketone (PEEK), which offers new end-uses. Glass and aramid fiber materials also can be processed.

Stronger, faster and multifunctional

Impossible Objects has tested CF/HDPE flat specimens, which Kaplan says are made in the same way and at the same speed as the production UAV parts, so they indeed reflect printed part quality, and obtained tensile strengths of 150 MPa and tensile modulus of 10 GPa. For CF/PEEK test specimens, it has measured tensile strength of 205 MPa and modulus of 12 GPa. “Compared to published properties of standard, unreinforced 3D-printed nylon and HDPE parts, we’re up to 10 times stronger,” Kaplan asserts. “Parts printed from Ultem [PEI] are the closest in properties, but are still less than half of what we can produce using CBAM.”

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Although this project achieved success in a low-volume, functional part application, Kaplan says Impossible Objects is headed toward serial production of parts in aircraft, automobiles, medical devices/implants and high-performance sporting goods. “Our technology offers advantages in both speed and material properties vs. other 3D printing,” he contends. “We can also use a wide range of materials, for example nonwovens with metals or coated fibers.” This ability to integrate augmented electrical conductivity opens up applications like electromagnetic interference (EMI) shielding for electronics. “There is a huge market in EMI shields where you can tailor the properties,” says Kaplan. He adds that with CBAM, it is possible to alternate layers of glass and carbon fiber, “so you now have insulating and conducting layers within the same part.” For Aurora’s Campbell, this part was a demonstration of what carbon fiber can offer in 3D printed parts. But it also points the way for progress in the future. “Continuous carbon fiber is a must in modern day aircraft,” he contends. “You really cannot beat the properties it offers for the weight.” He says the ultimate goal, then, is to use 3D printing to fabricate primary structures, using continuous carbon fiber. “It’s definitely where we want to end up.” CW

ABOUT THE AUTHOR

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