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# CW CompositesWorld

## Automated Workcells:

# ROBOTS "CLIP" CYCLE TIME

MAY 2015

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## COLUMNS







## FEATURES



## » DEPARTMENTS



## » ON THE COVER

A thermoplastic composite fuselage clip for the Airbus A350 XWB is robotically transferred from a tool in a 125-MT thermoforming press to a trimming station at Premium Aerotec's fully automated clip manufcturing operation in Bremen, Germany. The facility produces more than 3,000 unique clip designs, and turns out about 150,000 total clips per year. Learn more on p. 66.

Source / Premium Aerotec

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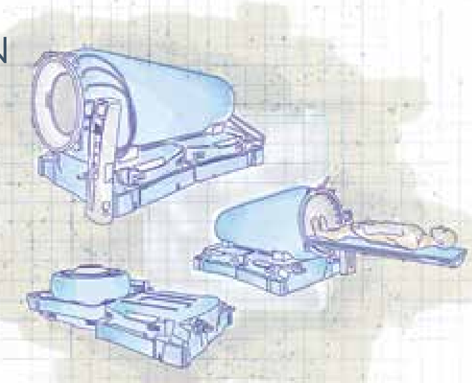



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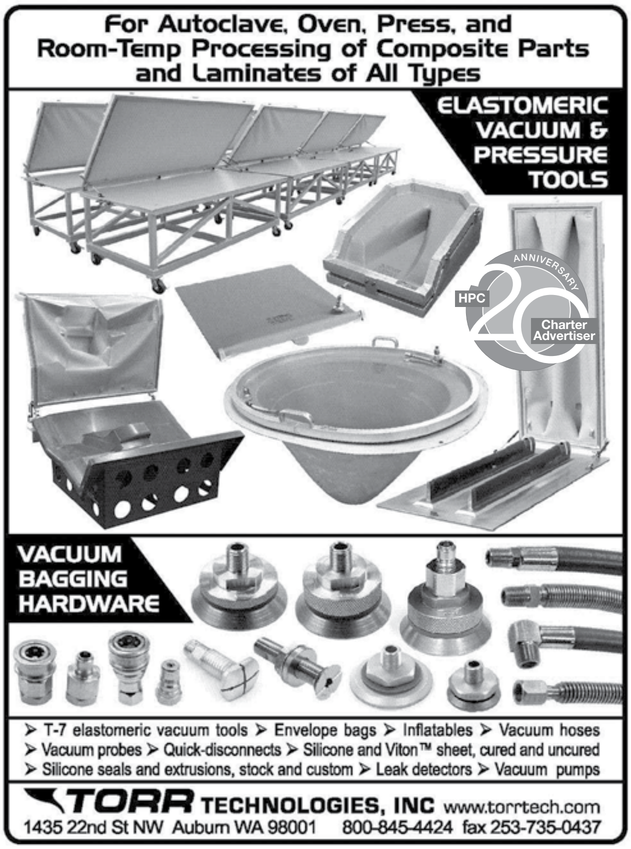





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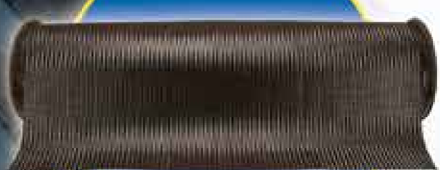

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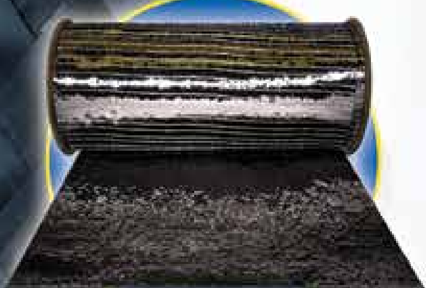

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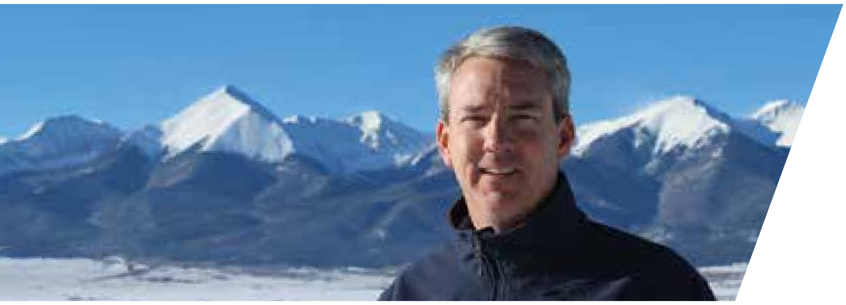

Earlier this year, we connected with composites veteran Rob Sjostedt, CEO of VectorSum Inc. (Irvine, CA, US) and a former associate of legendary composites innovator Brandt Goldsworthy of Goldsworthy Engineering (Torrance, CA). Rob wrote a CW: Past, Present & Future column for us in the April issue. There, he talked about the composites fabrication technologies that were developed at Goldsworthy Engineering — some of which have panned out and some of which haven't. Among the winners, Rob mentioned automated tape laying (ATL).

What is the genesis of automated tape laying technology?

This got me to wondering about the history of fiber and tape placement. Which came first, and when? It seemed likely to me that tape laying preceded fiber placement, but what was its genesis? Where and when was the first ATL conceived?

This sent me to our senior writer emeritus, Donna Dawson, who spent more than 20 years working with Brandt Goldsworthy and had a front-row seat for many of his company's technological developments. She dug through her voluminous notes and records and suggested I try to find a 1969 (!) SAMPE paper, authored by Goldsworthy engineering sales manager Ethridge "E.E." Hardesty, titled, "Advanced Composite, High-Modulus Tape Placement Machines." Off to SAMPE I went, where a very helpful Robert Garcia dug up the paper for me. It was presented at the SAMPE 15th National Conference in Los Angeles.

Hardesty's paper is remarkable for a couple of reasons. First, it outlines not what was being done to develop ATL, but what *must* be done. Second, it presents a well-crafted snapshot of what was then the state of the industry's art. Hardesty notes, for example, "With the advent of company-sponsored — often with Air Force assistance — flightworthy and flight-tested structures, it is immediately evident that filament and tape placement techniques and processes thus far developed, mostly involving hand layup methods, are now in need of being transposed into First Generation production machines."

Hardesty goes on to describe his (and, presumably, Goldsworthy's) vision of the first three generations of tape placement machines, which he predicted would evolve through 1974. The first-generation machine would place 3-inch wide tape with a gantry-type machine, with distances dialed-in with digital thumbwheels. The second-generation machine, owing to the need to place fiber on compound curvatures, would apply 3-inch tape slit into 24 1/8-inch tows, with X-Y, X-Z and Y-Z movement capabilities. The third-generation machine would be able to reach into "any spot on any surface and begin laying tape, progress in any direction over that surface and terminate its applied tape band at any other spot on the surface. All automatically."

So, what happened? Well, Hardesty's prescription was not just a well-calculated shot in the dark. Indeed, on Nov. 27, 1973, the US Patent Office issued to Harald Karlson and Ethridge Hardesty, both of Goldsworthy Engineering Inc., patent number 3,775,219 for a "Composite-Tape Placement Head." It would, according to the patent, comprise "an integrally complete composite-tape placement head for direct attachment to a host gantry type of machine, which tape placement head is designed to precisely apply preimpregnated fiber reinforced tape to a work piece."

The patent focuses primarily on the tape placement head, its design and features, including "tape forwarding, tape-placement, backing-film retrieval, and tape cut-off mechanical and drive functions." It suggests the use of several fiber types — "fiberglass, lithium, boron, quartz or grown whisker crystals, etc." — but not carbon fiber. It also suggests the use of several resin systems, including polypropylene, polycarbonate and polyester, as well as phenolics and epoxies.

Thus, it appears, automated tape placement was launched. If only Mssrs. Goldsworthy, Karlson and Hardesty could see, today, what's become of the technology they created.

JEFF SLOAN — Editor-In-Chief


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# Why South Carolina? Why now?

» The news was a logical extension of prior announcements, but it still made many business people pause and wonder: On July 30, 2014, Boeing announced that final assembly of the 787-10, the newest and longest member of the 787 *Dreamliner* family of airplanes, will take place *exclusively* in North Charleston, SC, US. Larry Loftis, VP & GM, 787 Program, Boeing Commercial Airplanes (Seattle, WA, US), went on to say, "We're happy with our growth and success in South Carolina …."

Not long before, in February 2014, Toray Industries (Tokyo, Japan) announced it had purchased about 400 acres of commercial land in Greer, SC, where it plans to build a facility for the manufacture of precursor and TORAYCA carbon fiber.

This brought back memories from 1992, when Toray Composites America (TCA, Tacoma, WA, US) built a prepreg facility across the street from Boeing's 777 assembly plant in Frederickson, WA. It was a key strategic element in becoming part of Boeing's supply chain. More importantly, it set a standard that others are now starting to follow — namely, that you need to be a responsive and *geographically well-sited* supply member.

> We might look back on South Carolina as the first of *several* states that recognized the … potential offered by our industry.

I suspect that Toray patiently waited many years before prepreg sales from Frederickson made *financial* sense, and they were forced, in the interim, to find other markets, recreational and industrial, for their prepreg during the aerospace slowdown. More important, it underscored the patience and sense of shared responsibility that have been hallmarks of this Japanese company.

Toray is neither the first nor will it be the last to move to South Carolina. More recently, we heard that Sigmatex High Technology Fabrics, a strong, UK-based carbon fiber weaver with US operations in Benicia, CA, had announced in October 2014 that it will invest US$12 million in a 7,000m$^2$ facility on 20 acres in Orangeburg County, SC. A mid-2015 opening is expected, and it has options to expand to 13,935m$^2$, and as much as 41,800m$^2$.

The Carolinas already have a strong collection of aero-qualified weavers, particularly BGF's Cheraw, SC, site, Chomarat's Anderson, SC, plant and the SAERTEX USA plant in Huntersville, NC. Other weavers, such as JPS (Anderson, SC), Barrday (Charlotte, NC), Pharr Mfg. (McAdenville, NC) and CFA (Taylorsville, NC) have found specialty niches in composites. Fiber producers such as Cytec Industries in Piedmont and Rock Hill, SC, along with Innegra Technologies (Greenville, SC) continue to grow. All of these investments take time, money and patience — especially for aerospace qualifications.

South Carolina's Governor, Nikki Haley, inherited highly successful efforts begun in the late 1980s to recruit business to the state, and she is prominently front and center at many ribbon cuttings. The South Carolina Research Authority (SCRA, Columbia, SC) uses its Advanced Technology International (ATI) affiliate to manage research programs, and The Composites Consortium (TCC) has 37 member companies that actively participate in research. SCRA has helped transform South Carolina from a former textile capital to a knowledge economy.

Finally, like it or not, South Carolina is a right-to-work state, unburdened by labor unions and the potential work stoppages they can initiate.

Perhaps the famous advice credited to Horace Greeley, "Go West, young man," was premature. Yes, the gold rush of 1849 brought banks to San Francisco, and helped establish railroads throughout the West. But from this Californian's viewpoint, the importance of being close to your supply chain has many executives scrambling to reassess *location* as a crucial element of their business models.

It remains to be seen how such regionalization in the composites industry plays out. Until now, composites businesses in the US have clustered around customers and end-markets without much direct intervention from state or local governments. I'm reminded of Boeing's impact on Seattle; Brandt Goldsworthy's influence on Southern California; Hercules and Thiokol stimulating composites in Salt Lake City, UT, US; the impact of General Dynamics's F-16 in Ft. Worth, TX, US; and Wright Patterson AFB's presence in Dayton, OH, US. South Carolina has clearly benefited from Boeing's decision to locate its second 787 assembly plant there, but the state also has strategically targeted the composites supply chain to help grow its economy and employment.

If, as we hope, the composites industry will enjoy many more years of growth, we might look back on South Carolina as the first of *several* states that recognized the value and potential offered by our industry. CW

**ABOUT THE AUTHOR**

Tom Lemire, president of T.F. Lemire Consulting Inc. (Irvine, CA, US), brings to his current consulting role 45 years of active duty in sales, market development and management at three major, technology-driven global operations that supply materials to the composites industry: Toho Tenax (Rockwood, TN, US), BASF Structural Materials (Charlotte, NC, US) and Owens Corning (Toledo, OH, US). Lemire also served as cochair of the *CompositesWorld* Carbon Fiber Conferences held in 2009 and 2010 and was a panel moderator or speaker at SAMPE conferences in 2010, 2011 and 2012. He received his BA from Brown University and holds an MBA from Northwestern University's Kellogg School of Management.

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# US wind energy: Parity with fossil fuels is getting closer

» Several times each year, I make the three-hour drive from my home in Indianapolis to visit Chicago. About halfway in the trip, the Meadow Lake Wind Farm (IN, US) appears and stretches for miles in each direction off Interstate 65. It's a mesmerizing sight, these very long rows of large, white turbines (1.5 to 2.1 MW each), rotating in unison as they harvest the Midwest breeze. There are 303 turbines and 500 MW of capacity. Plans are to double capacity to more than 1 GW in the coming years. Beneath the graceful turbines, the local farmers sow and harvest their crops as they have always done. Some things in Indiana remain constant, even as new technology advances.

> A recent report issued by the US DoE offers reasons for optimism even without the stimulus from the PTC.

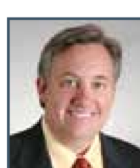
The planned expansion at Meadow Lake will depend, however, on a number of factors, one of which could be the nonrenewal of the Production Tax Credit (PTC) by the U.S. Congress. The PTC expired at the end of 2012, was temporarily renewed in 2013, and then expired at the end of 2013, only to be retroactively renewed for 2014 with two weeks to go in the year. The PTC provides a tax credit of $0.023 per kW/hr, enabling wind energy to be more competitive with electricity generated by fossil fuels. According to the American Wind Energy Assn. (Washington, DC, US), US wind energy capacity increased by a record 13 GW in 2012, but the annual increase dropped to only 1.1 GW in 2013, recovering only a little in 2014 to around 5 GW. The current belief is that the PTC will not be renewed for the foreseeable future. By contrast, European and Asian governments have much more stable energy policies concerning wind power, and installations in those regions have been fairly steady over these same years.

So is the wind energy industry in the U.S. headed for extinction? A recent report, *Wind Vision: A New Era for Wind Power in the United States,* issued by the Wind and Water Power Technologies Office of the US Department of Energy (DoE), offers reasons for optimism, even without the stimulus provided by the PTC. The report notes that wind energy provided 4.5% of US energy demand in 2013, up from only 1.5% in 2008. Both Iowa and South Dakota now generate more than 25% of their needed electricity from wind. Improved designs and larger rotors have reduced generation costs from $0.071 per kWh in 2008 to $0.045 per kWh in 2013 for regions where wind speeds are reliable. The report projects a further 24% reduction by 2020 and 33% by 2030 based on improvements in turbine technology and operations. These kinds of improvements might give natural gas, even with its current low market price, a real challenge. The DoE envisions that wind will meet 10% of U.S. demand for electricity by 2020, 20% by 2030 and 35% by 2050. These are some pretty aggressive targets.

Readers of this magazine know that builders of wind turbine blades are substantial users of composite materials, so this level of growth bodes well — *if* it happens. I visited a major wind blade factory in February, getting the in-depth tour engineers crave. I was able to witness every step of the manufacturing process for blades that exceed 50m in length, so we are talking large tools and very large parts. Having visited factories making large carbon fiber aircraft components and high-volume SMC automotive parts, I was immediately struck by how different the manufacturing process is for turbine blades. Teams of people move from mold to mold, laying fabric and core by hand, then bagging the part for resin infusion. Adhesives are applied manually rather than robotically. Tolerances for fiber angle and bond thickness are much more lenient than in aerospace. Nonetheless, what comes out of the factory is a very robust, durable product that is designed to operate for 25 years or more. While one might think automated fabric layup and adhesive application would be a natural fit, cost analysis has determined that such machines would have to lay up well over 1 MT per hour to be competitive with manual labor.

So what *is* likely to drive the costs of wind energy down? From the blade perspective, several technologies have promise: Building longer but *segmented* blades (to overcome current transport limitations) and joining them at the installation site; low-cost, high-volume carbon fiber for critical stiffening elements, such as spar caps, especially as blades get longer; improved modeling and simulation to optimize design and reduce material usage yet maximize performance; and the use of high-speed NDE techniques to ensure quality.

As it turns out, cost (especially that of carbon fiber), modeling, simulation and NDE are basically the same issues aerospace and automotive engineers face. Maybe not so different after all? CW



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Dale Brosius is the head of his own consulting company, which serves clients in the composites industry worldwide. Services include strategic planning, market analysis, assistance in mergers and acquisitions activities and technical support. 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. For three years he also served as the general chair of the Society of Plastics Engineers' annual Automotive Composites Conference and Exhibition. Brosius has a BS in chemical engineering from Texas A&M University and an MBA.

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# Virtual process chain + online process monitoring = first-time-right manufacturing

» The big challenge of composite design is to develop a part that will satisfy geometric tolerances and performance requirements (e.g., weight, thermal and mechanical behaviors). Today, even if sizing of composite structures can rely on predictive models and accurate large-scale, nonlinear analyses — including damage as demonstrated in industrial applications[1,2] — composites fabrication is still considered an art. However, manufacturing simulation tools can be used to guide manufacturing process development. The benefits of this approach are discussed here using resin transfer molding (RTM) as a reference.

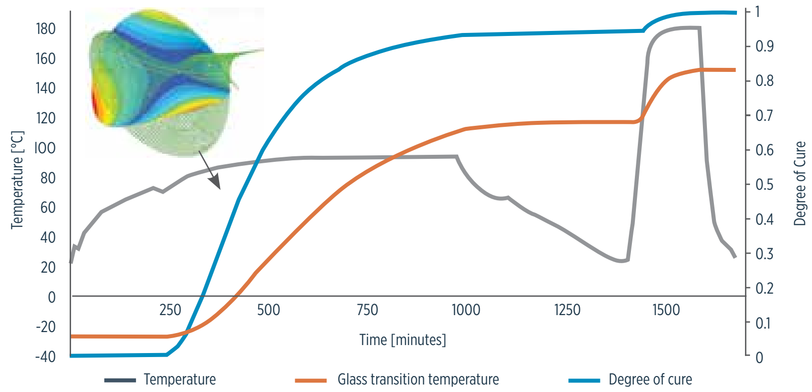



**FIG. 1**

Evolution of the relevant properties from the curing simulation, using LMS Samtech Samcef software. Source | Siemens PLM Software

## RTM process simulation

RTM is used in the aerospace industry and also as a solution for process automation in the automotive sector because this closed-molding process offers possibly fast cure cycles and good mechanical properties in the resulting part: Bonded or stitched layers of dry fibers (the preform) are laid in the mold; the mold is closed; a (typically) thermoset resin is injected and cure is accelerated through a temperature increase as consolidation pressure is applied. The cured part and mold are cooled and the part is demolded.

The manufacturing process, however, induces defects in the composite part. Residual stresses develop during cure and usually lead to geometric defects, such as *spring-in* (closing angle of corners) and *warp* (distortion of initially flat surfaces). Amplified by the anisotropy and the inhomogeneity of the layup, these unwanted effects come from the thermal strains and chemical shrinkage during cure, caused by the temperature change and the resin's phase transition from liquid to rubbery and, finally, to glassy state.

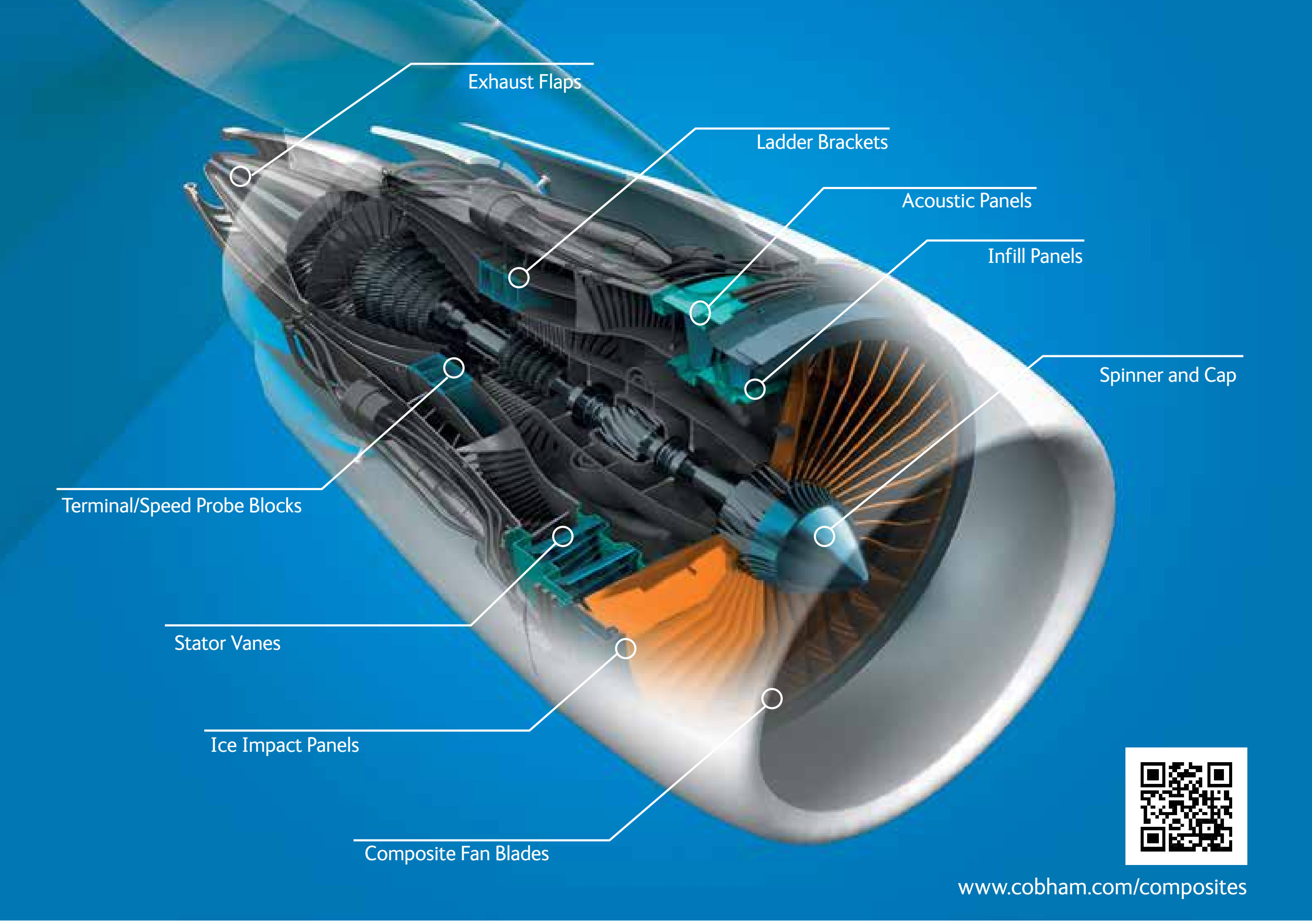
> Today's manufacturing process simulation tools … have reached a high degree of maturity.

Of the principal sources of process-induced stresses and distortions, high cure temperature is the greatest. The second is chemically induced resin shrinkage. The manufacturing process and resulting part quality are driven by parameters such as mold geometry and material and process time and temperature (i.e., cure cycle). Moreover, where warpage is concerned, factors that can influence the symmetry conditions of the layup are critical. Some of these factors can be related to the preforming stage (e.g., fiber-angle and ply-contour errors, undulation, gaps and overlaps), as well as to curing-control or resin-flow problems. Developing the manufacturing strategy and specifications to address all of these is an iterative process: Process parameters are tuned and mold geometry is modified, typically by trial-and-error. This is time-consuming and costly because it requires the iterative production of a succession of different physical molds and parts.

Today's manufacturing process simulation tools, however, have reached a high degree of maturity. State-of-the-art algorithms, such as those proposed in Fibersim, are used to develop efficient draping strategies for unidirectional plies and fabrics and help the user understand the behavior of the material laid on the mold. A bi-directional link between CAD and CAE programs enables flawless information exchanges between designer and analyst, which speeds and improves the interactions between the different disciplines, such as design, sizing and manufacturing process analyses. In addition to the preforming simulations, accurate cure kinetics models now can be comprehensively implemented in the finite element package (e.g., LMS Samtech Samcef), which can be used to conduct thermo-chemical-mechanical analyses.

Typically, thermal boundary conditions for the RTM simulation are defined in the finite element model of the composite part, knowing that to be more accurate, a high-fidelity model of the mold also must be developed. The thermo-mechanical analysis — taking into account the exothermic aspect of cure — provides the distribution and evolution of the temperature, the glass transition temperature and the degree of cure in the part during the whole cure cycle. The mechanical analysis is then run with this information to get the effect of the phase transformation of the resin on the resulting viscoelastic properties of the matrix.

The objective is to obtain the equivalent properties of the plies and predict the residual stresses during the process simulation, »

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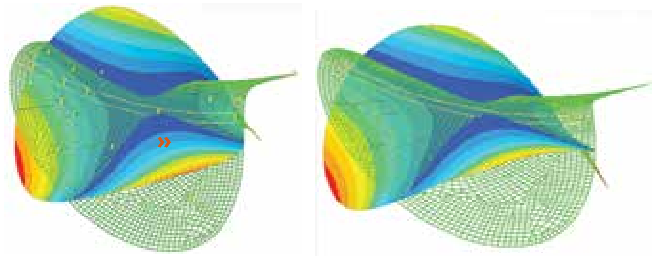

**FIG. 2**

This LMS Samtech Samcef simulation shows a 13% difference in the process-induced deformations between the "as-planned" (left) and the "as-built" (right) configurations. Source | Siemens PLM Software

together with the final shape distortion. Finally, a structural analysis can be conducted to evaluate the mechanical performance of the composite part. These advanced thermo-chemical-mechanical analyses can be performed with cure kinetics model parameters determined from well-identified, specific tests, and a good agreement has been observed between the obtained numerical solution and experimental results.[3,4] Further, a consistent simulation chain can support the development of the manufacturing process by evaluating the sensitivity of the part quality to the process parameters. Then, the geometric tolerance requirements of the part can be reached by applying mold compensation to the virtual prototype. This consists of modifying the geometry of the parameterized mold model, using either mathematical optimization algorithms or the opposite of the nodal displacements computed during the distortion analysis, both iterative processes.

### Analyzing the "as-built" configuration

Relying on simulation is a great advantage for the development of the manufacturing process. It can be used to develop the right mold geometry and determine the range of process parameters that will control the shape distortion and, finally, provide a part that satisfies geometric tolerances. However, the world is not perfect, and analyzing the structural performances on the "as-planned" (sometimes called "as-designed") configuration might be inadequate. Given the nature of composites manufacturing processes, many variations are possible, and it is essential to analyze the "as-built" (sometimes called "as-manufactured") configuration as well, in order to study the effects of deviation from the "as-planned" configuration in an early stage of the development process. This idea was developed in the ECOMISE project[5], and the virtual process chain is combined with an online monitoring system for preforming, injection and curing, providing a feedback loop from the real world to the virtual prototype. One of the important feedback concerns »

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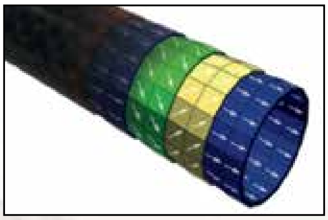

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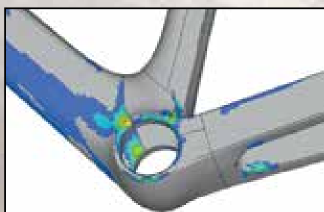

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includes the deviations and variations during the draping or preforming of the textile plies. These include incorrect ply positioning, unexpected gaps, overlaps, fiber deviation, thickness variations or foreign objects in the mold. The effect of these variations might be critical if they influence the infusion behavior and create asymmetrical conditions that induce shape distortions.

These defects may be detected by image-analysis devices during preforming or by adapted sensor strategies during the injection and curing phases. This information is reported to the model. Then the effect of the defects can be analyzed along with the virtual prototype, their impact on its structural performance estimated, and adjustments for an efficient manufacturing process can be proposed. When a doubly curved composite part is manufactured, for example, the goal is to identify the error in the ply positioning with the image analysis measurement system. This information is then reported to the virtual model, where the draping simulation is carried out, taking into account the "as-positioned" ply (Fig. 1, p. 10). The curing is simulated, and the resulting shape distortion is evaluated and compared to the "as-planned" configuration (Fig. 2, p. 12). More information and results are available from Brauner, et al.[6] This interaction between real-world and simulation, together with the feedback loop for the manufacturing process adjustment, is an essential ingredient for reducing production time and cost, as well as related material and energy consumptions. CW

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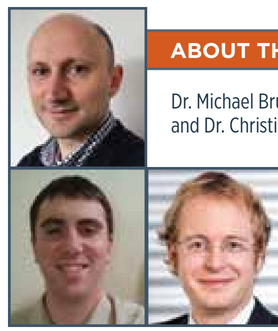

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# CW Business Index at 52.6 – Fastest growth since June 2014

» An overall reading of 52.6 in the March 2015 CompositesWorld Business Index showed that the US composites industry expanded for the fifth straight month. And, the Index reached its highest level since June 2014. However, compared with one year earlier, the Index had contracted for three months. So, although the industry had been growing and the growth rate was picking up, according to the March index, the industry was growing at a slower rate than it had during the same period in 2014.

New orders in the US increased for the 16th consecutive month. That subindex had increased steadily since July 2014 and had reached its highest level since June 2014. Production expanded for the 15th month in a row in March. The rate of expansion had increased dramatically since November 2014. Backlogs contracted for a third straight month and for the ninth time in the preceding 10 months. Compared with one year earlier, backlogs had contracted for three straight months. The annual trend indicated that capacity utilization had peaked. However, the trend in backlogs could soon change. In March, employment had increased for 25 consecutive months and the rate of increase had been accelerating since May 2014. Exports continued to contract due to the relatively strong dollar. Supplier deliveries continued to lengthen, but they did so at nearly their slowest rate in 15 months.

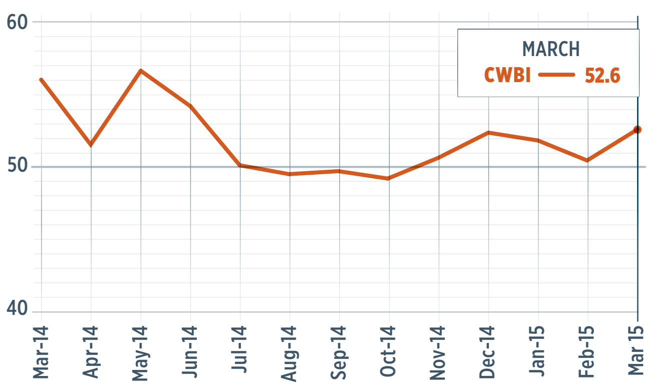
While US material prices were still increasing in March, the rate of increase had declined dramatically since May 2014. In fact, the rate of increase was at its slowest since July 2012. On the other hand, prices received had been increasing at a generally accelerating rate since November 2014. The net effect, going forward, should be improved profitability at composites fabricating facilities. Future business expectations in March were down from February, but the general trend in expectations had been up significantly since August 2014.

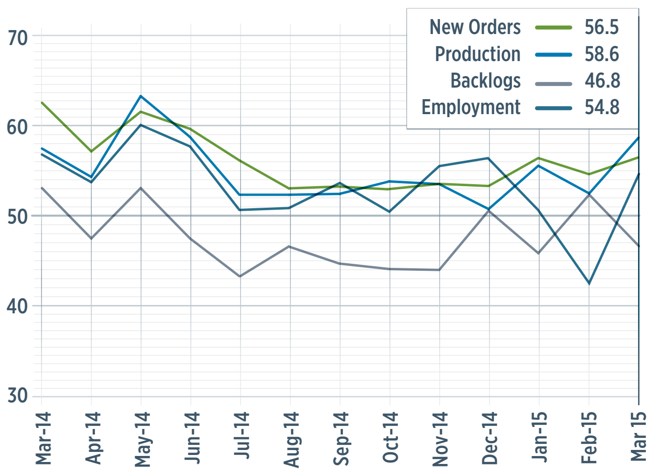
As a group, US-based composites fabrication plants with 20 or more employees saw improved business conditions in March. Plants with 100-249 employees had the most dramatic improvement as their subindex jumped to 63.0 from 50.1. Facilities with 20-49 employees improved to 55.1 from 47.1, while plants with 50-99 employees also moved to expansion from contraction, although the increase was much smaller. Facilities with 19-or-fewer employees contracted for the ninth time in 10 months.

Regionally, The US Northeast and North Central – East expanded at significant rates in March after contracting the previous month. The North Central – West expanded for the fourth month in a row, but the rate of expansion was quite modest in March. The West region contracted for the first time since August 2013.

Compared with one year earlier, future capital spending plans contracted for the seventh time in nine months. In March, the rate of change resulted in the fastest contraction since the CW Business Index was first recorded in December 2011. The annual rate of change itself had contracted, by April 1, in three of the four preceding months. CW

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




## ABOUT THE AUTHOR

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**Not one but two 60-second epoxies and innovative glass/epoxy-based and carbon overbraided transportation suspension systems head the list of composites trends and trendsetters.**

AUTOMOTIVE

## Hexion is Hexion again, with a 60-second epoxy in hand

Resins manufacturer Hexion (Columbus, OH, US), which has spent the past few years going by the name Momentive, is back to being called Hexion. But Hexion's leadership points out that although the name has changed, the corporate mission remains the same. At JEC Europe, this was nowhere more evident than in several displays that focused on developed capabilities in the automotive sector. Specifically, Hexion is working on materials for resin transfer molding (RTM) and liquid compression molding (LCM). New at the show was EPIKOTE TRAC 06170 epoxy combined with EPIKURE TRAC 06170 curing agent system (see New Products, p. 86). Hexion officials at the show said the material offers a 20-second injection phase (RTM or LCM) followed by 40-second cure, for a total cycle time of 60 seconds. The material's optimized $T_g$, says Hexion, makes this possible.


Also on the Hexion stand was a unique composite suspension coil (see photo at top left), made with EPIKOTE epoxy and developed in cooperation with Sogefi (Milan, Italy) and Audi AG (Zwickau, Germany). This filament wound drop-in replacement for metallic springs trims 4.4 kg from Audi's *A6 Avant 2.0 TDI ultra*.

The company also exhibited a Bakelite phenolic cam carrier (see photo, lower left) for Ford Motor Co. (Dearborn, MI, US) as part of the multi-material lightweight vehicle (MMLV) program supported by the US Department of Energy. Typically made with aluminum, it was developed by WGS Global Services (Flint, MI, US) and uses chopped carbon fiber in an injection molding process. The composite material maintains dimensional properties at 200°C and reduces weight by 30%. The application is developmental, for now, but Hexion hopes Ford will adopt it into production.

Finally, Hexion exhibited something relatively unusual: a compact, all-in-one composites molding machine. Dubbed the Autonomous Tooling Solution (photo, top right), it features a mold chamber on top and side-mounted controls. It reportedly molds preformed prepregs or infuses preformed dry fibers and offers 100% vacuum capability, a 100-pull silicone bag, cure and temperature sensors and full PLC control. The machine at JEC was a prototype, designed to test marketability.

Source (all photos) | Hexion

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AUTOMOTIVE

## Dow: 60-second epoxy is in range with liquid compression molding

Dow Automotive Systems (Horgen, Switzerland) made big news at JEC Europe 2014 with the introduction of VORAFORCE, its ultralow-viscosity, fast-cure epoxy for automotive molding. Since then, says Peter Cate, global strategic marketing manager, composite structures, the company has made much progress evaluating processing of the material. Particularly promising, he says, is the wet, or liquid, compression molding (LCM) process, whereby a dry fiber reinforcement is placed in a mold, resin is applied atop the fiber, the mold is transferred to a compression machine, and then the resin is infused into the fabric via the compression process. Working with KraussMaffei (Munich, Germany) and Cannon SpA (Peschiera, Italy), Dow has developed a process that, Cate says, takes 15-20 seconds for resin application and only 30 seconds for cure, for a total manufacturing time of less than 60 seconds.

Further, says Cate, use of multiple molds in coordination with one compression machine would enable the molder to dispense resin onto one mold while another is in the press, increasing throughput considerably.

A limiting factor of the technology, Cate admits, is part complexity. It's most suitable for relatively flat or slightly contoured parts. Complex parts, Cate says, might not provide a tooling surface suitable for containment of the applied resin. In such cases, Cate says, RTM is the next best alternative. Dow is working with DowAksa (Istanbul, Turkey) fabrics and hopes, he says, to implement the technology for a Tier 1 automaker before 2020.

## SAMPE 2015 returns to Baltimore

SAMPE returns to Baltimore, MD, US, in 2015 at the Baltimore Convention Center, May 18-21. It features, as usual, conferences throughout all four days, with the exhibition May 19-21. The conference offers 200 presentations, covering design, analysis, manufacturing, materials and

new applications. The keynote, on the morning of May 19, will feature a speaker from the Defense Advanced Research Projects Agency (DARPA). For more information and to register, visit nasampe.org.

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WPT

# Trends in automation: ATL and AFP technologies increase speed, flexibilty

Source | MTorres

Source | Ingersoll Machine Tools

Many automated production solutions were on offer at JEC Europe 2015, and several companies made announcements. North Thin Ply Technology (NTPT, Penthalaz-Cossonay, Switzerland), known for its ultra-thin ThinPreg multiaxial prepregs, made in an automated process involving proprietary fiber spreading paired with automated tape laying (ATL) technology, can produce tapes with areal weight as low as 17 g/m$^2$. At the show, NTPT announced a "drastically" increased production capacity with a new ATL machine (designed and developed in-house) at its facility in Poland. NTPT tapes were used to create the wings of the *Solar Impulse* aircraft currently attempting an around-the-world solar-powered flight (p. 30).

MTorres (Torres de Elorz, Navarra, Spain) revealed a huge new automated ATL head, called The Harvester (photo, top left), for massive production of flat (2D) or slightly curved parts at a rate of 250m$^2$/hr — reportedly two to three times the normal rate for current ATL heads. Intended to decrease material costs and cycle times, the head features a patented multi-tape design that holds four 150-mm-wide tapes, creating a 600-mm bandwidth.

The concept eliminates the need for (and the cost of) pre-slit tapes, and reportedly reduces scrap rates significantly, because laydown can be reduced to one tape at the end of a course. Machines equipped with these heads are already in use by aircraft OEMs for flying part production. MTorres told *CW* that it is also actively developing materials and high-rate automated processing for several unnamed automotive OEMs, which are interested in developing carbon fiber material technology to replace high-strength steel parts.

Ingersoll Machine Tools Inc. (Rockford, IL, US) called attention to its work with The Robert E. McNair Center for Aerospace Innovation and Research at the University of South Carolina (Columbia, SC, US) and with Hexcel Corp. (Stamford, CT, US) to further develop the dry fiber placement process for aerospace production. Ingersoll is the first U.S.-based automated fiber placement (AFP) supplier to work with Hexcel's HiTape dry fiber product. An Ingersoll-built Lynx AFP machine (photo, top right) at The McNair Center will produce layups for infusion to investigate fiber steering and buildup of thick structures. Martin Keaney, the lab's executive director, says it was designed for "open and proprietary research. It was built with industry in mind, to provide a controlled, secure environment." Doing a lot of the work in the McNair lab will be Michel JL van Tooren, professor, aerospace systems design and structures, late of Fokker Aerostructures (Hoogeveen, The Netherlands), who helped develop that company's thermoplastic bonding systems. He brings that expertise to the lab and will work on indirect induction welding and ultrasonic welding technologies. "The goal," he says, "is to get rid of mechanical fasteners."

The Fraunhofer Institute for Production Technology (Aachen, Germany) introduced a robotic fiber placement system, dubbed the Multi-Material-Head, to process all standard, unidirectional semi-finished fiber composite materials automatically (e.g., thermoplastic tapes, thermoset prepreg towpreg, dry fiber rovings). The modular head is reportedly easy to customize to the material, heat sources (laser, hot air or infrared) can be exchanged easily, and the flexible system is aimed at small batch production or R&D.


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## CW MONTH IN REVIEW

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**Teijin reorganizes its automotive CFRP business**
In addition, the company's R&D center for Sereebo CFRTP Technology receives ISO/IEC 17025 accreditation.
04/13/15 | short.compositesworld.com/TeijinCFRP

**Fokker and NLR open composites manufacturing plant in The Netherlands**
The Automated Composite Manufacturing pilot plant will produce composite landing gear components.
04/13/15 | short.compositesworld.com/FokkerNLR

**NASA establishes partnership to accelerate aircraft composites**
The public-private partnership will work to advance knowledge about composite materials that could improve the performance of future aircraft.
04/06/15 | short.compositesworld.com/NASA-ACC

**US Department of Energy funds development of larger wind blades**
The DoE's US$1.8 million will support R&D of blades longer than 60m to harness an additional 1 million square miles of US wind resources.
04/06/15 | short.compositesworld.com/DoEblades

***HondaJet* receives provisional type certification from FAA**
New bizjet with composite fuselage nears final certification with 12 aircraft in assembly line and five more entering production flow.
04/06/15 | short.compositesworld.com/HondaJetPC

**Airbus to locate major engineering center at Wichita State University**
Airbus America will relocate its Wichita engineering office to WSU's new Innovation Campus with a focus on developing additional partnerships.
03/30/15 | short.compositesworld.com/AirbusWSU

**Bombardier pushes *CSeries* entry into service to early 2016**
After a May 2014 engine fire, the composites-intensive *CSeries* was grounded and delayed to late 2015, but now is expected in early 2016.
03/30/15 | short.compositesworld.com/CSeries16

**Sandvik Coromant, Mitis develop vibration-assisted drilling**
The cutting tool specialist has teamed with the drilling equipment specialist to develop a vibration-assisted drilling process for stacked composites.
03/30/15 | short.compositesworld.com/Sand-Mitis

**Data centers prime target for composite access covers**
Fibrelite (Skipton, North Yorkshire, UK) reports that lightweight, easy-to-handle composite access covers are in demand to help manage cabling operations.
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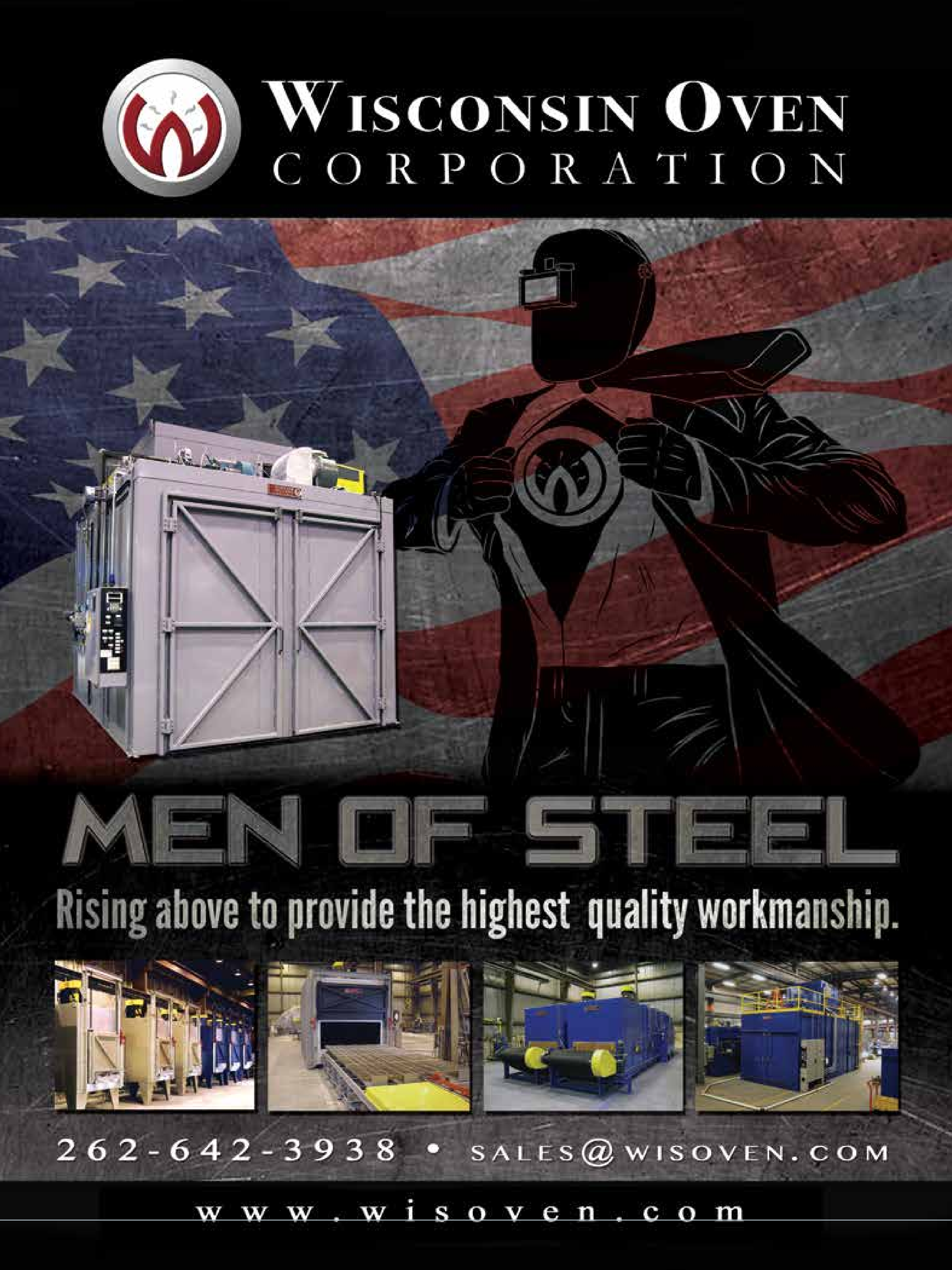

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AEROSPACE

## Trent jet engines: Rolls-Royce increases blade R&D, begins work with FACC

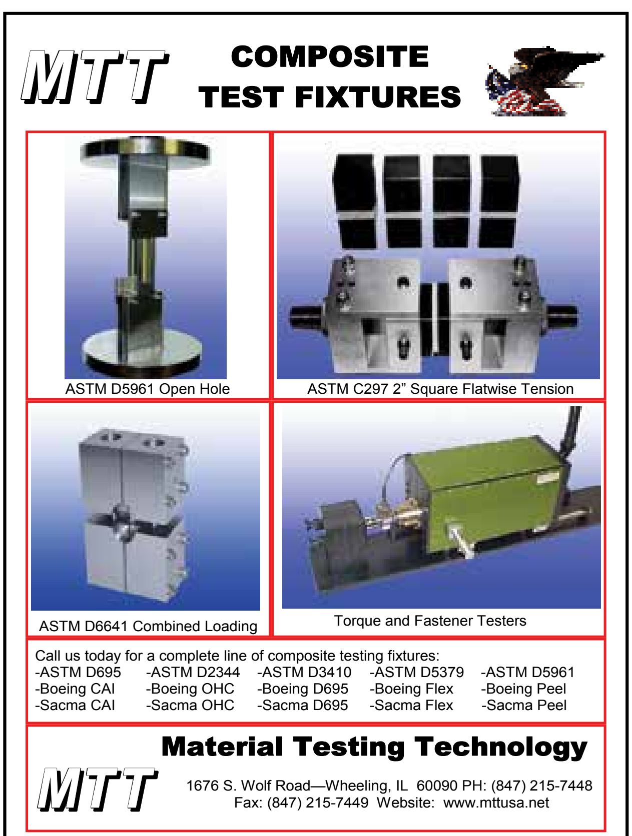
Rolls-Royce (London, UK) showed signs that it's serious about composites development in a recent report that Bristol, UK, will be the location of a composite technology center for advanced commercial jet-engine fan systems. The company says the facility will be at the forefront as Rolls-Royce develops next-generation fan blades and fan cases made with carbon fiber composites for future aeroengines.


Source | FACC

Rolls-Royce's CTi (carbon/titanium) blades are a key feature of the new Advance engine design, unveiled last year, which will reportedly burn at least 20% less fuel and emit an equally smaller quantity of $CO_2$ emissions than its first-generation Trent aeroengine. The blades and associated composite casings will form part of the new CTi fan system that could reduce engine weight by as much as 680 kg per aircraft — the equivalent of carrying seven more passengers and their luggage.

The pre-production facility will be housed within an existing building alongside Rolls-Royce's new facility for carbon fiber electrical harness rafts, currently under construction on the Bristol site by Rolls-Royce in partnership with the National Composites Centre (NCC), backed by research conducted at the Rolls-Royce University Technology Centre at the University of Bristol. Existing CTi manufacturing operations will be transferred from the Isle of Wight, UK, to Bristol, during 2017.

The CTi blade is layed up with carbon fiber/epoxy prepreg, using automated fiber placement technology. Cured blades are machined




and coated before titanium sheathes are bonded to the leading edges. Finished components are inspected and measured via ultrasound and subjected to mechanical testing.

A set of the CTi fan blades, incorporated into a Trent 1000 donor engine, successfully completed a full flight-test program on a Rolls-Royce 747 flying testbed at Tucson, AZ, US, in December 2014. A testing program for the complete fan set will continue throughout 2015.

Meanwhile, aerocomposites manufacturer FACC (Ried im Innkreis, Austria) has begun series production of composite parts for the Rolls-Royce Trent XWB engine. At rate production in 2017, FACC will deliver four ship-sets per week of composite fan track liners, rear case liners, bifurcation linings and anti-fluid panels used on the Airbus (Toulouse, France) A350 XWB powerplants.

FACC is responsible for development and production of the engine composites as part of a life-of-program contract for the Trent XWB engine, a fuel-efficient power system that entered service at the end of 2014, following delivery of the first A350 XWB to launch customer Qatar Airways.

Rolls-Royce awarded the contract to FACC in 2012. Currently, the engine maker envisages a total order volume of approximately US$300 million and foresees deliveries through 2028.

## Coriolis celebrates aerospace history, anticipates automotive future, at JEC

Coriolis Composites (Queven, France) held a press event at its stand to celebrate its 15th year at the JEC Europe event. Company president Clementine Hamlyn spoke about the company's journey from its first, small JEC stand with a prototype robotic arm, to its current size of 120 people, six additional locations throughout the world, and €14 million (US$15.15 million) annual turnover. "We started the company while at technical school" — the Université de Technologie de Belfort-Montbéliard — "and have crossed three 'valleys of death,'" quipped Hamlyn. Those challenges were to find investors willing to fund the enterprise, to find a launch customer to buy a machine and, lastly, to develop from a research laboratory into a commercial entity capable of producing equipment for timely customer delivery. As it turned out no less than Airbus (Toulouse, France) bought that first machine and, today, Coriolis boasts an impressive customer list. In the near term, customers will produce (among other parts), A350 XWB fuselage panels for Airbus, Safran engine nacelles and parts for Bombardier and many more. Hamlyn added that Coriolis also has developed and is selling machine-control software, called CAT Fiber and CAD Fiber, which can work on any robotic machine. "Our next big challenge is the automotive industry," she concluded, and hinted that some big announcements are on the horizon.

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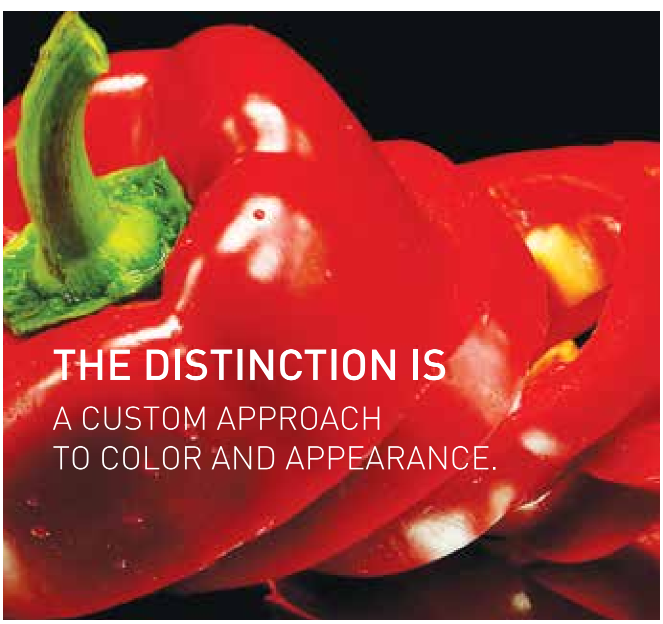
AEROSPACE

## Core collaboration for Solvay and 3A

Thermoplastics specialist Solvay (Brussels, Belgium) and core materials supplier 3A Composites (Sins, Switzerland) announced at JEC Europe a collaborative effort to develop and manufacture specialty foams and sandwich materials for lightweighting in the advanced transportation market.

Dr. Armin Klesing, global business development manager, aerospace & composites, at Solvay, and Roman Thomassin, CEO, 3A Composites Core Materials, sat down with *CW* to discuss the alliance. Klesing says the goal of the collaboration is to combine the strengths of the two companies, noting that 3A's expertise is in providing a range of industrial processes to manufacture foams, while Solvay's expertise is in formulating the broadest portfolio of specialty polymers to desired performance attributes in highly demanding applications — what Klesing called "before the extruder."

The collaboration includes personnel and capital from both companies and it will pursue challenging applications that are ripe for highly engineered core solutions. The alliance's first product, Radel PPSU foam, is already on the market in an interior application for Airbus (Toulouse, France) A350 XWB commercial aircraft. Thomassin says thermoplastics will be the base material of the products the collaboration provides. He adds that the alliance's success could lead to a more in-depth relationship with Solvay.



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AEROSPACE

## Round-the-world flight progress: *Solar Impulse 2*

Energized only by sunlight taken in by the solar panels arrayed on its horizontal surfaces, the electric-prop-driven, all-composite-airframed *Solar Impulse (Si2)* aircraft had completed nearly one-half of its much publicized 'round-the-world trip as *CW's* May issue went to press. It took off the morning of March 9 on the first leg from Abu Dhabi, UAE, under the watchful eyes of the *Solar Impulse* team there and its Mission Control Center in Monaco. André Borschberg lifted off in *Si2* at 7:12 a.m. (GMT +4) on Monday, carrying no backup fuel supply or alternative means of propulsion, headed for Muscat (Oman) before crossing the Arabian Sea to Ahmedabad (India) on the first leg of what is intended to be a round-the-world flight. Borschberg's partner and the aircraft's co-developer, Bertrand Piccard, took the controls in Oman and continued on to Ahmedabad. Piccard and Borschberg have since alternated as pilots of the single-seater experimental solar aircraft, completing three additional legs of its world tour. *Si2* took off for its fourth flight on March 18, piloted by Piccard, from Varanasi (Lal Bahadur Shastri Airport) in the Republic of India, to Mandalay International Airport in the Republic of the Union of Myanmar, landing at 23:52 UTC (see photo). Piccard flew the airplane about 1,408 km for about 20 hours.

Source | Solar Impulse / Photo © 2015 Solar Impulse

At *CW* press time, the *Si2* Team was about to embark on leg 6, from Chongqing, China to Nanjing, China, which had been delayed by poor weather. Assuming a successful flight to Nanjing, the next leg is a much more ambitious, nonstop flight from China to Hawaii.

The Solar Impulse company noted, on the occasion of the event, that it has taken 12 years for Piccard (the development program's initiator and chairman) and Borschberg (founder and CEO), to reach the point where they could demonstrate in such a fashion the importance of renewable energy.

Capable of flying over oceans for several days and nights in a row, *Solar Impulse* is scheduled, during the RTW trip, to travel a total of 35,000 km in 25 days over the course of roughly five months. Piccard and Borschberg are required to demonstrate extraordinary endurance in a $3.8m^3$ unpressurized, unheated cockpit, with external temperatures ranging from -40°C to +40°C. *Si2* has successfully passed over the Arabian Sea, India and Myanmar. After

reaching China and negotiating the Pacific Ocean with a stopover in Hawaii and an Americas leg, it will cross the Atlantic Ocean — the lengthy ocean crossings are expected to be the technology's greatest tests and the adventure's highlights. The final legs include a stopover in Southern Europe or North Africa before completing the round-the-world flight at its final destination in Abu Dhabi, *Solar Impulse's* official host city. During scheduled stops, the *Solar Impulse* team and its partners have held and will hold public events.

Supported by Prince Albert of Monaco, UAE Minister of State and Chairman of Masdar H.E. Dr. Sultan Al Jaber, Richard Branson and Al Gore, the #FutureIsClean initiative has been launched on **www.solarimpulse.com** to recruit support for the adoption of clean technologies worldwide. Of the challenge, Piccard and Borschberg have said: "We are very ambitious in our goal, but modest, given the magnitude of the challenge. This is an attempt, and only time will tell if we can overcome the numerous weather, technical, human and administrative issues."

*Solar Impulse* is an airborne laboratory, made from technological solutions developed by a team of 80 specialists and more than 100 partners and consultants. *Si2* is the largest aircraft ever built with such a low weight, equivalent to that of a small car. With a wing larger than that of a Boeing 747 covered by more than 17,000 solar cells, the plane can fly up to an altitude of 8,500m at 50-100 kmh.

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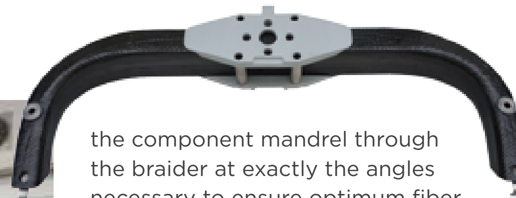
AUTOMOTIVE

## Carbon/epoxy overbraided, RTM'd spring carrier beam



Source (both photos) | Munich Composites

Munich Composites (Ottobrunn, Germany) won a JEC Innovation award in the Transportation Category for its carbon fiber air spring carrier part, produced in partnership with transportation giant MAN Truck and Bus AG (Munich, Germany). The project's goal was to cut suspension weight by using a composite in place of steel.

The air spring carrier beams are attached to the air spring suspension bags, which support the weight of the bus. Each rear axle has two air spring carriers, each weighing 83 kg, and the structure that supports those carriers weighs 53 kg, in a metal design.

Munich Composites developed a prototype replacement carrier beam made by radially overbraiding carbon fiber on a reusable inflatable mandrel. The overbraiding process is robotic, and several robots work together to pull the component mandrel through the braider at exactly the angles necessary to ensure optimum fiber alignment for complex geometries. As it does so, it generates virtually no scrap.

After layup, beams are resin transfer molded, using epoxy, in a fully automated process that results in very low void content, says Martin Stoppel, commercial director for Munich Composites. The resulting hollow, curved 1.6m-long carrier beam weighs less than 16 kg — about 70% lighter than the metal version — allowing an increase in the bus payload of one passenger.

The prototype part is currently undergoing tests on MAN buses to prove its capability and reliability. Stoppel says that the project has resulted in a highly automated and fast process that is scaleable to produce cost-effective carbon-fiber-reinforced transportation parts.


## Jushi initiates, AGY expands, US-based glass capacity

Two of the biggest names in fiberglass manufacturing made big announcements at JEC Europe 2015.

The world's largest manufacturer of glass fiber, Jushi Group Co. Ltd. (Tongxiang, Zhejiang, China), made the biggest ripples, saying it is expanding its production capacity in Egypt *and* building a new facility in the United States.

Jushi's Egyptian plant opened in 2013 with 80,000 MT of nameplate capacity. The expansion will double that. The additional 80,000 MT of capacity will come on line in 2016, followed in 2017 by a new 40,000-MT furnace for the manufacture of specialty glass fibers.

Notably, in Richland, SC, US, Jushi will erect a new facility that will *copy the Egyptian plant in capacity and capability.* Phase I of that plant (80,000 MT) is expected to open in first-quarter 2017, with the second 80,000 MT and 40,000 MT of specialty glass to follow. Company officials say the US plant will employ 600-700 people initially, and up to 1,000, eventually. Jushi also reported that global glass fiber capacity is about 4.7 million MT, 32% of which is used with thermoplastic materials.

For its part, AGY (Aiken, SC, US) told *CW* that it is in the midst of "aggressive expansion" of its S-2 and L glass capacity. Iain Montgomery, global manager, new business development, says Phase 1 of its S-2 expansion came online in January 2015, to be followed by Phase 2 in mid-2015.

Montgomery says AGY doesn't release exact capacity figures, but he did say the expansion increases its S-2 production capability by 30%. Moreover, AGY's specialty L-glass product, for PCB boards and electronics applications, will expand by *200%* by the end of 2015. Montgomery says that growth, from a relatively small capacity now, is fueled in part by the material's low signal decay properties, which has made it highly attractive to electronics manufacturers.

In 2014, AGY also acquired Owens Corning's (Toledo, OH, US) S-glass product line and has been selling product from acquired stock. Montgomery says AGY will soon officially add the S-glass product to its portfolio and establish production plans.

### JEC EUROPE BRIEFS:

The strength of both the carbon fiber and the overall composites markets was reinforced by **Hexcel's** (Stamford, CT, US) president Nick Stanage, who spoke at a press briefing during JEC. After presenting financial figures for the company, including a 2014 sales figure of US$1.9 billion, Stanage said that the company foresees 17% annual growth in commercial aerospace, which makes up 67% of Hexcel's business, and that each Airbus A350 XWB built includes up to US$5 million of Hexcel materials. He went on to state a company goal of US$3 billion in sales by 2020 and 10% company growth. Hexcel will break ground on its two new plants (one for PAN and the second for carbon fiber) in Roussillon, France, on May 21.

Markus Majoor, global market segment leader, thermosets & acrylics at **AkzoNobel** (Amerfoort, The Netherlands), reported to *CW* that the company has been doing interesting work with its cobalt-free NOURYACT brand of accelerators for polyesters. AkzoNobel has discovered, says Majoor, that the accelerator is moisture insensitive, which means that fabricators who process natural fibers are not required to dry the fiber reinforcement before infusion. AkzoNobel would like to do more research on the material and is looking for fabricators of bio-fibers with whom to partner.

At **Ashland Performance Materials'** (Columbus, OH, US) stand, Thom Johnson, marketing manager, specialty resins, related some of the product development details behind Epitome, a composite home foundation system manufactured by **Composite Panel System LLC** (CPS, Eagle River, WI, US). Designed to replace time-consuming and laborious concrete foundations, Epitome comprises composite panels, integrated attachment points and electrical and other hardware. They can be installed in as quickly as 90 minutes, says Johnson, which greatly speeds overall home construction. Johnson says Epitome is gaining traction in Wisconsin where CPS is based, but the next step is to move it into larger metropolitan areas. He concludes, "This project has singularly changed how Ashland pursues innovation in the market."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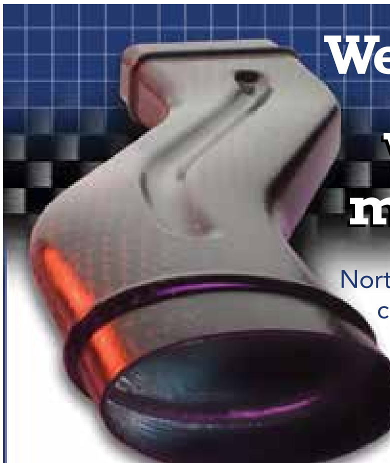

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AUTOMOTIVE

## Glass/epoxy RTM process yields "four-in-one" auto suspension blade

Hutchison (Levallois-Perret, France) caused a stir at JEC Europe with its Trifunctional Auto Suspension, made of glass/epoxy in a resin transfer molding (RTM) process. Hutchinson's technical director of the Centre Technique Composite (CTeC), Bertrand Florentz, told *CW* that the composite "suspension blade" combines four front suspension functions in one part: It eliminates the need for helical springs, wishbones, ball joints, and the need for an anti-roll stabilizing bar and, lastly, it damps or "filters" road noise caused by the frequencies generated by the tires. This approach reduces vehicle weight by 13.6 kg compared to steel-centric suspension, and saves labor and assembly time. The new unit — a design actually envisioned 20 years ago — will be used on a new hybrid European car model. The part reportedly enables a one-step assembly process, instead of the usual 12 steps involved with suspension builds.

## Zoltek's Hungarian plant to add carbon fiber production capacity

In the wake of its recent buyout by Toray Industries (Tokyo, Japan), industrial-grade carbon fiber manufacturer Zoltek Corp. (St. Louis, MO, US) has worked out a deal with the Hungarian government to expand capacity by an unspecified quantity at Zoltek's plant in Nyergesújfalu, Hungary. Zoltek reports that the plant is already the largest carbon fiber factory in the world and manufactures materials for use in the wind energy, aerospace and automotive industries. The expansion is expected to create 100 new jobs immediately and another 200-300 over the next few years. In addition to the cooperation agreement, Zoltek also has signed an agreement with the Budapest University of Technology and Economics to help educate the next generation of carbon fiber professionals.

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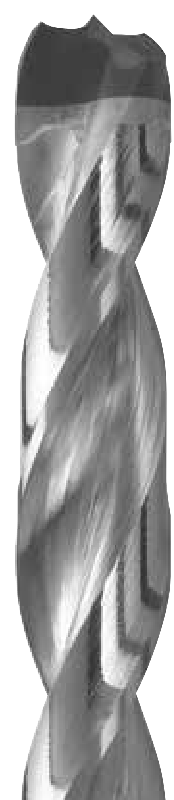

## On display at JEC Europe 2015


Arkema (King of Prussia, PA, US) exhibited this bow of a lateral float from the *Arkema* trimaran. It was manufactured via vacuum-assisted infusion using Arkema's liquid thermoplastic Elium and Luperox organic peroxide at room temperature. The structure is composed of a 1.6-mm thick carbon fiber laminate surrounding a PET-based core. Bonding is provided by a methacrylate provided by Arkema's AEC Polymers group.


Automotive parts manufacturer ARRK (Osaka, Japan) exhibited this tailgate for the Renault *Clio*. It's an all-thermoplastic, four-component structure engineered and developed by ARRK at its Flins, France, facility.


Axson Technologies (St. Ouen l'Aumône, France) exhibited on its JEC stand a new car from automaker Ligier (Abrest, France). The two-door compact, which is manufactured at volumes of 10,000 units per year, features a metallic frame with body panels made from SMC and ABS, provided by Axson.

Source (all photos) | *CW* / Photographer | Heather Caliendo

### JEC moving, renaming Paris show

JEC Group (Paris, France), the organizer of the JEC Europe tradeshow, announced at the 2015 exhibition that, starting in 2016, the event will move to a new location, at the Paris Nord Villepinte fairgrounds, just north of Paris, near the Charles de Gaulle airport. The new facility is larger (62,000m$^2$) than the Paris Expo and will allow the show to be located on one level (the 2014 and 2015 shows were on two levels). In addition, the JEC Europe show has been renamed JEC World. JEC World 2016 will be held March 8-10, 2016.

AEROSPACE

## Exelis wins center wingbox strut contract for Airbus A350-1000

Aerospace composites fabricator Exelis (Salt Lake City, UT, US) recently won a multimillion-dollar contract from Airbus (Toulouse, France) to produce composite center wingbox struts for the A350-1000. It marks the second award for the new Exelis STaR (Struts, Tubes and Rods) product line following the A380 award announcement last year. Deliveries are set for 2016 through 2020.

The struts help distribute loads from the wings and fuselage into the center wing box, providing structural support for the airframe. Exelis STaR products, through the use of patented manufacturing technology licensed from Bodair SA (Oupeye, Belgium), and a unique strut design, provide a high strength-to-weight ratio alternative to metallic struts and deliver greater weight savings compared with competing composite production methods.

Read more about Exelis and STaR online | short.compositesworld.com/ExelisTour




AUTOMOTIVE

## Fraunhofer develops FRP cylinder casing

An experimental engine with a lightweight composite cylinder casing has been developed by the Fraunhofer project group for new drive systems at the Fraunhofer Institute for Chemical Technology (ICT, Pfinztal, Germany), in collaboration with SBHPP, the plastics business unit of Sumitomo Bakelite Co. (Tokyo, Japan). "We used a fiber-reinforced composite to build a cylinder casing for a one-cylinder research engine," said Lars-Fredrik Berg, the group's project leader and manager of lightweight powertrain design. "The cylinder casing weighs around 20% less than the equivalent aluminum component, and costs the same."

Berg said that the group used metal inserts to strengthen the wear resistance of a glass-fiber-reinforced phenolic composite developed by SBHPP, which is sufficiently hard and rigid, resistant to oil, gasoline and glycol in the cooling water, and also demonstrates good adhesion to the metal inserts and does not have a higher thermal expansion coefficient than the metal, to guard against disbonding. The 55% fibers and 45% resin thermoset compound is reportedly injection molded. The process is said to be compatible with mass production scenarios.

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# FRP challenges conventional frame-and-drywall construction

## A multinational builder and a machinery manufacturer join forces to bring an automated composite panel molding system to the residential construction market.

**By Michael R. LeGault** / Contributing Writer

**Key component**

Magnum Venus Products (MVP, Kent, WA, US) partnered with a Brazil-based fabricator of composite sandwich panels to design and install a production line based on MVP's roller impregnator, pictured here. During impregnator operation, glass fabric is fed vertically into the impregnator where it is wetted with a specially formulated epoxy resin and then into a mold, which passes below it at a corresponding speed on a conveyor.

Source | MVP

» Although composites are more costly than wood, concrete and aluminum, their greater strength-to-weight ratio, superior thermal properties and humidity-, corrosion- and insect-resistance can provide contractors in the building construction industry and their customers with benefits that are difficult to match. In applications such as decking, in fact, the appeal of a long-lived, maintenance-free product have so outweighed conventional alternatives that consumers are willing to pay the composites' cost surcharge. However, despite the performance premium, composites have generally not been able to overcome the price-point disparity in mainstream applications, such as house/building framing and wall construction, where contractors bid almost exclusively on cost. However, an *automated* manufacturing system geared for this market might change that cost/benefit equation.

A manufacturer of composites fabricating equipment and systems, Magnum Venus Products (MVP, Kent, WA, US) has designed, built and installed a composite-panel manufacturing system for a multinational (but unidentified) construction and fabrication company in Brazil. The custom-built manufacturing cell reportedly has narrowed the cost differential between composites and lumber, drywall and other conventional materials in the housing market, and has the potential to narrow the gap further. The fabricator customer is using the equipment to make large, 12m by 2.5m composite sandwich panels, which are then CNC-machined into various interior and exterior wall sections and components; in the process, the fabricator incorporates windows, doors and other features, and packages the parts into kits for onsite assembly that requires small construction crews and little heavy equipment.

> The custom-built manufacturing cell .... has narrowed the cost differential between composites and lumber ....

Joe Jansen, MVP's advanced equipment sales engineer, says the machinery maker partnered with its customers and construction companies to design and build a complete manufacturing cell for commercial production of the composite building system. "We work with our customers to make ideas commercially viable," says Jansen. »


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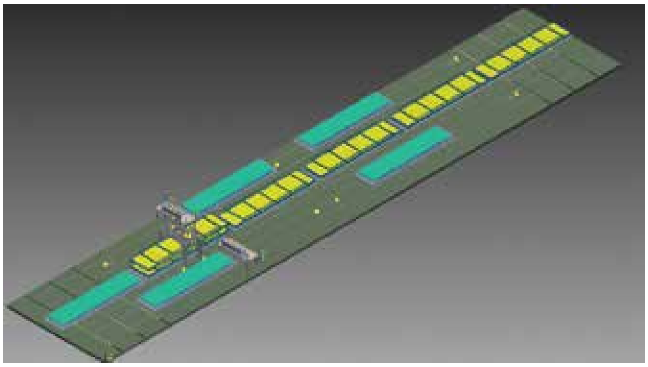

## Panel system schematic

This schematic shows the MVP automated panel production line concept. Panel layups (green) are produced in impregnator lines on either side of the gantry system, which then transfers them to the curing line (yellow). The gantry places a top mold half over each transferred panel, which then begins the 25-minute cure cycle as it shuttles forward (toward top right) to make room for the next panel.

Source | MVP

"The big challenge for this project, and for composites trying to compete in mainstream residential construction in general, is how to make composites competitive with wood by using automation," says Jansen. The system evolved from a process MVP first used to make equipment for the manufacture of boat hulls. The most significant modifications to the process entailed the development of a method and equipment to change it from a batch process into a continuous, assembly line-like method for high-volume production.

To make the panels, a stock roll of 0°/90° biaxial glass fabric is fed vertically into a set of impregnator metering rolls, positioned above a mold. For exterior walls, the mold is first fitted with a finished, textured facing sheet. The spacing between the metering rolls is precisely controlled, as is the feed rate of epoxy pumped onto the rolls. The epoxy is specially formulated with a catalyst and flame and smoke retardants. The wetted fabric is then fed into the bottom mold, which is moving at the same rate on a stationary friction-wheel conveyor. When the entire length of the mold has been layed up with glass, a polyurethane foam core is laid atop the wetted glass and the mold direction is reversed. It again passes under the impregnator metering rolls, which lay down a second, or, in the case of an exterior wall, the interior layer, of glass/epoxy laminate. As the length of the mold passes under the impregnator the second time, the glass fabric is cut and a top mold is affixed to the bottom. The top mold is vacuum bagged with an overlap at the seam between the two molds. Top and bottom molds are both heated to a range of 71°C to 82°C, and a vacuum is applied as the mold is transferred by a large gantry-based robot into the line's curing section for the approximately 25-minute curing cycle.

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The panel production facility is equipped with a 5-station curing line that is fed by two resin impregnator production units, one on each side of the curing line (see schematic at left). The two impregnator units lay up a new panel every 12 minutes, but layup is staggered so that one cured panel is produced every 6 minutes. After a panel is layed up, it's transferred by the gantry robot to an adjacent curing station on the curing line. There, the top mold half is placed atop the panel and 6 minutes later, when the next panel is layed up and ready, the curing line shuttles forward the length of one curing station; the gantry robot, meanwhile, travels to the end of the curing line, retrieves the top mold half from the first fully cured panel, and transfers that mold half back to be placed on the most recently layed-up panel. This configuration yields an assembly line-like multiplication of efficiency: While the overall cure time for a single panel is 25 minutes, when the line is fully loaded and multiple panels are cycling through, the effective panel cycle time is 6 minutes.

The cured panels are about 76 mm thick with a laminate layer that is ~60% glass fiber. After CNC machining, the exposed foam edges of window sills, doors and interior walls are encapsulated with moldings. The prefabricated elements are delivered to the construction site on pallets, stacked in the correct sequence for the construction process on conventional concrete foundations.

Pultruded U-channels are anchored around the perimeter of the foundation and the construction process starts with the installation of two corner walls. Walls are bonded into the U-channels and to each other with a proprietary adhesive over the entire length of the wall/joint. The composite panels also comprise the roof, to which a waterproof roofing mastic is applied, eliminating the time and cost of installing roofing tiles. The entire construction process requires about one-third less time than conventional construction, according to the kit manufacturer, and the finished house is waterproof, fire resistant and certified to withstand wind speeds up to 250 kmh. The composite housing manufacturer sells the kits to licensed contractors and is aiming to achieve an international presence, including in North America. Contractors have already completed the construction of several subdivisions made up entirely of the composite houses.

Jansen says the impregnator units provide significantly improved repeatability from part to part, compared to hand layup methods, a factor that is critical to ensuring the efficiency and cost savings associated with the construction process. "Earlier composite building systems were manufactured by highly manual means," he says. "Automation is the key factor helping this system gain commercial acceptance." CW

**ABOUT THE AUTHOR**

Michael R. LeGault is a freelance writer located in Ann Arbor, Mich., and the former editor of *Canadian Plastics* magazine (Toronto, Ontario, Canada).
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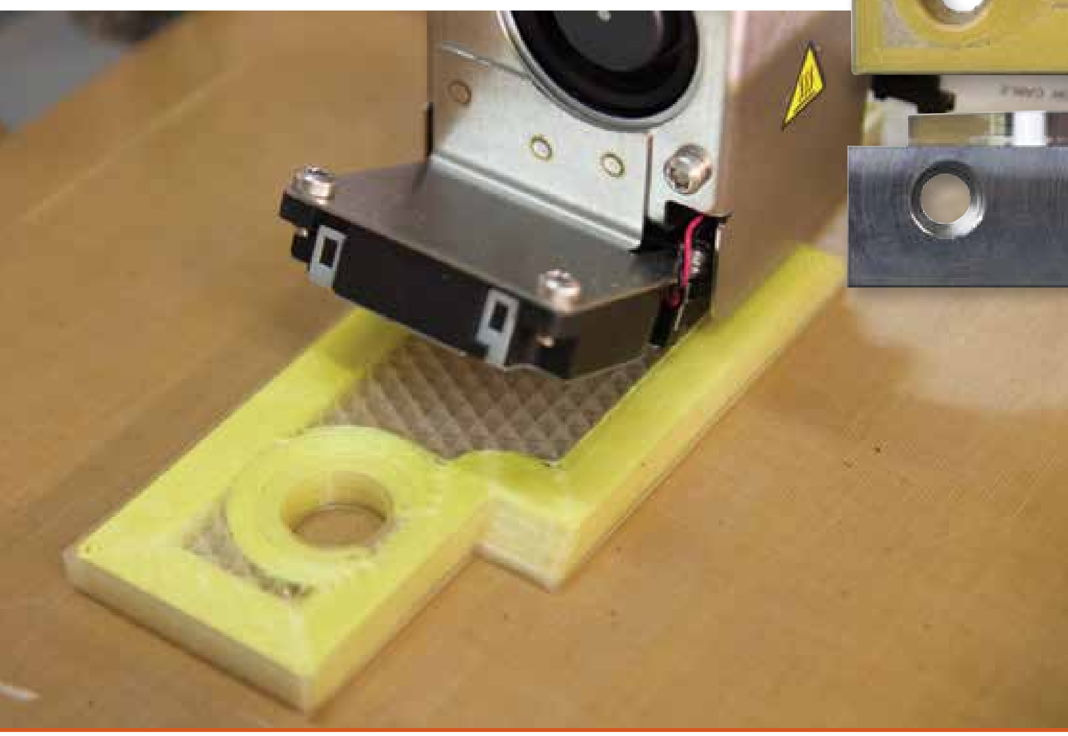
# 3D Printing: Niche or next step to manufacturing on demand?

## With and without fiber reinforcement, additive manufacturing is making an impact, but to what end?

By **Ginger Gardiner** / Senior Editor



**3D printing with *continuous* reinforcement**

Aerospace companies are replacing machined aluminum tools with composite tooling built by the MarkForged MarkOne 3D printer. The Somerville, MA, US-based machine supplier's system builds a continuous fiber-reinforced core to match metal strength and stiffness but prints a nylon outer layer to prevent scratches, which can lead to cracks and failures in the metal structures the tools help to create. Source | MarkForged

» Eighteen months ago, MarkForged (Somerville, MA, US) introduced the first commercial 3D printer that, its limited size format aside, was capable of building polymer structures with *continuous* carbon fiber reinforcement in the x/y plane (see "Learn More," p. 46). Last fall, Oak Ridge National Laboratory (Oak Ridge, TN, US) and Cincinnati Inc. (Harrison, OH, US) demonstrated large-format printing capability with the Big Area Additive Manufacturing (BAAM) system, working with Local Motors (Chandler, AZ, US) to produce the world's first 3D-printed, albeit short-fiber-reinforced, composite auto body in 44 hours and then increasing print size to 6m by 2.4m by 1.8m and speed to 45-68 kg/hr (see "Learn More"). Most recently, Arevo Labs (San Francisco, CA, US) announced its ability to combine high-performance polymers, e.g., polyetheretherketone (PEEK), with continuous fiber in the x-, y- *and* z-directions. Additive manufacturing (AM) of composites is obviously advancing, but to where? Is it bound for novel but niche applications? Or will it transform composites manufacturing?

### Low- to no-volume parts

In the short-term, the sweet spot for *all* additive manufacturing will be low production volume with high geometrical complexity. Prime examples are the medical fields of orthotics, prosthetics and hearing aids, applications that work best when customized for the user.

"Here is where 3D printing makes sense as a manufacturing process," MarkForged creative director Jeff Klein asserts, "allowing you to tailor each part to the individual, without a cost or time penalty. And it's a vast improvement over where the market is today." He adds that his company's MarkOne printer can be used to reinforce orthotic shoe inserts, for example, in dynamic ways: "We might lay fiber in the arch or part of the heel or at 45° in

## Continuous fiber, *contoured* orientation

This 40% chopped CF/PEEK aerospace bracket, 30% CF/PEEK crane part and compound-curved component (left to right) demonstrate Arevo Labs' (San Francisco, CA, US) ability to print continuous reinforcement along a contour with its machine's 5-axis degrees of freedom.

Source | Arevo Labs

certain areas to correct the heel strike or a gait issue." He contrasts this to how these devices have been made for the past 40 years, where measurements are taken, then a cast is made from the body part and sent out for hand-lamination and production. He concludes, "After thousands of dollars and 3-4 weeks, the device might be ready." In contrast, Klein claims 3D printed composites not only reduce cost, "but I can pick up my orthotic inserts in the same week that I ordered them."

Arevo Labs' system refines the concept behind BAAM — i.e., robotic arm- and CNC equipment-based 3D printing — to enable fiber application along complex contours, gaining z-directional strengthening. "What we're really talking about is going head-to-head with metals additive manufacturing," says Arevo's CEO Hemant Bheda. He sees unlimited applications for 3D-printed composites — medical, aerospace and oil and gas are already commercial markets — thanks to compression of the supply chain, where cost and delivery time reduction is enabled by tailored, unitized structures printed in hours vs. the weeks required for conventional manufacturing, assembly and logistics.

Part production extends to replacement parts. The oil and gas industry is already exploiting print on demand as a solution. Arevo's business development director Wiener Mondesir explains, "Out in the oilfield, if a part fails, the well stops producing. Every hour it doesn't produce is money lost. These parts must withstand ever higher pressures and temperatures. And the part replacement that can be offered in the shortest amount of time is the best solution."

Andrew Zwicker, the head of Science Education at the U.S. Department of Energy's Princeton Plasma Physics Laboratory (PPPL, Princeton, NJ, US), agrees. "Our first reaction to an equipment need is no longer whether we can purchase it, but can we print it?" he quips. The author of an *American Journal of Physics* article on the topic, Zwicker says printed electrode parts for a plasma physics experiment and replacement parts, such as a guard for a cooling fan, are good candidates for 3D printing, but he has concern when placing load on *plastic* parts. "I don't trust the structural integrity of a plastic part for things like motor mounts." Zwicker says the ability to orient fiber reinforcement in the direction where strength is needed "starts to open up possible applications that we would never have thought of printing."

Looking ahead, Mondesir sees some big possibilities. »

## Additive/subtractive process

Impossible Objects (Northbrook, IL, US) uses a very different AM process: polymer is printed onto a fiber sheet and repeated per layer. Layers are stacked and then heated to melt the polymer, then compressed and, finally, a chemical or mechanical process removes uncoated fibers to reveal the final 3D fiber-reinforced polymer part.

Source | Impossible Objects

| TABLE 1 | COMPOSITES AM TECHNOLOGY LANDSCAPE † | | | | |
|---|---|---|---|---|---|
| **Company** | **Process** | **Materials** | **Fiber** | **Build Size (x,y,z)** | **Example Parts** |
| **3D Alchemy** (Edgmond, UK) | SLS | Short fiber filled nylon powder | Chopped/milled | | |
| **Arevo Labs** (Silicon Valley, CA, US) | RFF** | PEEK, PPSU, PEI, self-reinforced polyphenylene (SRP); chopped glass and carbon fiber, continuous carbon fiber, CNTs | Chopped and continuous | Scalable to 600m x 1200 mm x 700m | Surgical instruments, satellite gears, aerospace brackets, electrical enclosures, high pressure sensor housing for oil & gas downhole tools |
| **CRP Group USA** (Mooresville, NC) | SLS | Windform‡ materials | Chopped/milled | | Stockcar electrical enclosure, satellite parts |
| **Graphite Additive Manufacturing** (Aylesbury, UK) | SLS | Short fiber filled nylon powder | Chopped/milled | | Product sponsor for SSC Bloodhound |
| **Impossible Objects** (Northbrook, IL, US) | Thermal inkjet + | HDPE, nylon, PEEK, PEKK (any thermoplastic); carbon, glass and aramid fiber in sheet form | Sheet form | 508 mm x 508 mm x 254 mm | Aerospace, automotive, medical, firearms, defense |
| **MarkForged** (Somerville, MA, US) | FFF, CFF* | Nylon; carbon, glass and aramid filaments | Continuous | 320 mm x 132 mm x 160 mm | Brackets, racecar and UAV components, impellers, shoe soles w/ RFID, space wrench |
| **ORNL** (Knoxville, TN, US) **Cincinnati Inc.** (Harrison, OH, US) | BAAM, modified FDM | PEEK, PEKK, ABS, PPS, PPSF/ PPSU, PEI; chopped carbon fiber, CNTs | Chopped | 2 m x 4 m x 0.9 m 6 m x 2.4 m x 1.8 m | *Strati* car, tooling for Cherry Point Marine Corps Air Station, furniture |
| **Windform** (materials only) **CRP Group** (Modena, Italy) | SLS | Polyamide (nylon) filled with short glass or carbon fiber | Chopped/milled | | Satellites, manifolds, brake arms, uprights, cold duct fan |

† This is not an exhaustive list.

* Fused filament fabrication (FFF) and MarkForged's proprietary composite filament fabrication (CFF) are modified forms of FDM.

** Reinforced Filament Fusion is Arevo Labs' patent pending technology enabling multi-material deposition of neat, chopped and continuous fiber reinforced high performance polymers.

‡ Though not detailed specifically, Windform materials are described in the 3D printing industry as nylon filled with milled, very short (100 µm) fibers.

"The aircraft industry is building 2,000 planes per year and then must maintain spare parts for 30-plus years. Being able to print on demand could solve a lot of problems here."

## Rapid moldmaking

Rapid tooling was a buzzword 10 to 15 years ago. "Multiple methods direct out of the machine, or indirect with intermediate steps, were heralded as the next great thing," says additive manufacturing research firm Wohlers Associates' (Fort Collins, CO, US) senior consultant Tim Caffrey. He notes that most were complicated or costly, and then CNC machines advanced significantly in both performance and affordability. "What has happened more recently," Caffrey observes, "is a re-visit of this whole area, but with more traction." AM mainstay Stratasys (Eden, Prairie, MN, US), for example, has been investing in polyjet materials for injection molding tooling inserts. He also points out the other end of the spectrum, where metals AM enables tooling with designed-in thermal paths to cool a mold much faster, producing more parts in less time. But, he concedes, "You still have to machine to get the parting lines perfectly flat and surfaces within tolerance."

"We are working with a number of industry partners to 3D print tooling for composite parts made with prepreg," says Tim Schniepp, a project manager/senior research engineer at Stratasys. Printed without fiber reinforcement, the tools nevertheless function as basic layup molds for autoclave cure (e.g., 180°C and 1.38-6.89 bar). The print material is Ultem 1010, a polyetherimide (PEI) with a $T_g$ of 217°C, supplied by SABIC (Pittsfield, MA, US). "This offers the ability to make extremely complex shapes that could not be produced economically otherwise," explains Schniepp. "We can provide tools within a day or two, so we are able to dramatically drop lead times, and at half the density of aluminum, tools can be lighter, and even incorporate printed-in handles." So far, Stratasys has printed tools for aircraft fairings, complex-geometry ailerons, UAV parts and sporting goods as well as repair tools for aircraft, a market that it believes has huge potential. Schniepp adds that his team is working with Abaris Training (Reno, NV, US) and other partners to evaluate tool life and coefficient of thermal expansion (CTE) data that will be included in a comprehensive design guide for 3D printed layup tooling. After this, the team will explore tools for other related processes, including infusion and resin transfer molding (RTM).

Although Stratasys currently has no fiber reinforcement capability, it is actively looking at materials that could enable it. In addition, although maximum print volume now is 0.9m by 0.6m by 0.6m, Stratasys Direct Manufacturing (via eight US locations) can print multiple mold segments and join them via adhesive bonding or thermal welding. "We then manually prepare the surface for sealing and layup," says Schniepp, noting that Airtech International's (Huntington Beach, CA, US) Tooltec and Toolwright adhesive-backed materials, "can be applied to our 3D printed tools and work really well, though they tend to be best-suited for less complex geometries." He adds that it is also possible to print in water-soluble materials for "lost-core" tooling, such as complex-shaped mandrels, which are then washed out after the part is cured. Stratasys also offers materials and machines for customers who prefer to 3D print in-house.

## The "velvet fist" approach

This 3D-printed nylon tube-bending fixture (white part within vise) is as strong as metal thanks to its internal glass-fiber reinforcement, yet will not scratch or damage the parts it helps to shape.

Source | MarkForged

## Composites with inserts an asset

3D printers can integrate inserts — e.g., pressure sensors and RFID tags — adding functionality to orthotics not easily achieved with conventional manufacturing. Source | MarkForged

### Fixturing for custom processing

MarkForged's Klein also sees AM composites increasing the efficiency of conventional manufacturing processes by producing fixtures on demand. "The MarkOne is a perfect companion for CNC machines because you can keep the machine running vs. having to wait for custom tools and fixtures to be made at a metal shop and delivered," he claims. "For example, to machine a fixture to hold a bottle would take all day. With 3D printing, it can take less than an hour." Composites come into play, Klein explains, because "fixtures must be strong enough to resist the forces imparted during these processes. We print soft jaws that don't even feel like a 3D-printed part because they are so rock solid." However, because they are made of nylon, they don't scratch the surfaces of metal parts like metal fixtures would. Similarly, fixtures that enable technicians to form custom musical instruments "need to be strong enough to help shape and assemble the brass tubes, but should not damage the surfaces," Klein explains. "This is using composite parts in a totally new way."

Further, 3D-printed fixtures are finding value in the hospital operating room. "We can print fixtures for surgical procedures," says Mondesir. "Right now, the only sizes available are small, medium and large, but with our technology — thanks to the very strong materials we use, which can match metals — these tools can be printed *to the patient's size*." Mondesir adds that entrepreneurs are requesting sockets for amputees that, today, via the traditional processes and supply chain take seven weeks and cost $30,000. AM offers a cropped supply chain that cuts overall delivery time despite the fact that AM is slower than conventional processes. "Additive is slow, and our materials cost more than typical plastic," he concedes, "but 48 hours is better than seven weeks. The benefits of composites here are already well-understood, and there is obviously a lot of margin in the current pricing."

### Smarter, stronger, better ... and, yes, cheaper

Mirroring a general composites trend in this decade, MarkForged's latest capability is to 3D print continuous-fiber-reinforced composites with integrated inserts to add *functionality* to orthotics. "A pressure sensor in the heel can monitor the strike force," Klein explains. "Also, orthotics now are labeled with a bar code, but that falls off within a month. With an embedded RFID tag, when you have an issue, you take the part in, they scan the tag and automatically pull up all of the info on it."

Klein sees an almost endless range of opportunities. For example, racecar companies use small-scale wind tunnel tests to reduce the time required in expensive full-size tunnels. They 3D print parts, dip them in ceramic coatings and then CNC mill to get precise dimensions. "We can just print these parts with load cells already inside, which provide the data used for aerodynamic modeling and analyses. We can also embed accelerometers and other types of sensors." Klein notes it is also possible to embed hard mounting points within the composite part, which is a great benefit, and RFID tags in tools and fixtures is an efficient way to check these in and out of storage/inventory.

An obvious need, and present push, in AM composites development is continuous reinforcement in three dimensions. Arevo Labs evolved from a background in parts for the aerospace/defense, oil and gas and medical industries using high-performance polymer — e.g., PEEK, polyvinylidene fluoride (PVDF), Ultem PEI and Radel and Udel polysulfone variants from Solvay Specialty Polymers (Alpharetta, GA, US).

"From day one, we started with high-performance industries that are used to designing parts with finite element analysis (FEA) and using fiber placement to achieve specific mechanical properties," says Bheda. "But this was missing in the additive manufacturing space. So we have had to create the software required »

## Flexible, adaptable, customizable

The MarkOne's continuous fiber-reinforced output includes soft-jaw fixtures for machining (top left), pulleys with press fit bearings and nylon outer shells for wear resistance (lower right) and orthotic inserts (far right). Source | MarkForged

## Molds for prepreg components

Stratasys (Eden, Prairie, MN, US) is 3D printing tools, using SABIC's (Pittsfield, MA, US) Ultem 1010 PEI for use in molding composite parts from prepreg, and plans to release a design guide for this type of tooling this year. Source | Stratasys

to orient the fibers." Bheda says that fused deposition modeling (FDM) and variants (see Table 1, p. 44) enable this because "you can control the direction in which you lay the reinforced extrusion." But he claims Arevo Labs can do more. "We can … achieve strength in the z-direction. For us, the whole object is constructed with continuous fiber, so that additive manufacturing has the same flexibility as fiber placement."

"The parts we are designing have contours in the geometry," explains Bheda, "so you could maximize the properties if you could print with more degrees of freedom." He claims that Arevo Labs' software can calculate the optimal path for machines now *and* in the future. "We've prototyped a 5-axis CNC machine retrofitted with an extruder and also a robotic arm with an extruder. We are running our tool-path generation software on both and producing 3D parts with contoured paths."

### LEARN MORE

Read this article online | short.compositesworld.com/WIP3DPrint

Read more online about MarkForged's introduction of the MarkOne printer in "3D Printing continuous carbon fiber composites?" | short.compositesworld.com/AM3Dcarbon

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Read more about using continuous process data to improve process control in bonded primary composite structures online in "Building TRUST in bonded primary structures" | short.compositesworld.com/DARPATRUST

See a video of the Impossible Objects AM system online | short.compositesworld.com/ImpObj

## Additive *and* subtractive

Relatively new to the AM scene is Impossible Objects (Northbrook, IL, US), which employs a form of thermal inkjet printing combined with a *subtractive* process. The system starts by layering and bit-mapping the CAD file of the part design. It then uses sheets about 0.08-mm thick and composed of long-fiber (25.4 mm) commingled reinforcement of almost any type, including carbon, glass and aramid. The sheets are passed through a printer to wet it in specific locations according to the layer being printed. This "wet" sheet is then layered with a thermoplastic powder, which sticks to the wet surfaces (a polymer bit map); powder not on a wet surface is blown off, collected and reused. After all layers of the part are thus "printed," they are stacked in sequence, heated and compressed. This stack is then sandblasted, which removes the portions of the stack (dry material) that are not infused and consolidated, leaving behind the finished part (see "Learn More").

CEO Larry Kaplan says Impossible Objects has successfully tried several thermoplastics and fiber types. Printing a sheet takes about 45 seconds, depending on sheet size and part complexity. Layers for multiple parts can be printed on one sheet. The current system build envelope is 508 by 508 mm, with part height dictated by press size. Testing, earlier this year, of a combination of 17-g/$m^2$ carbon fiber with polyethylene demonstrated 148.2 MPa peak stress, 1.45% strain-at-break and 11.2 GPa tensile modulus. Impossible Objects is currently printing parts for customers, but plans soon to introduce units for sale. Company founder Bob Swartz says, "Long term, this technology has potential to be substantially faster than current additive manufacturing processes."

## Engineer-savvy software

Bheda claims that current software used in 3D printing simply replicates the computer aided design (CAD) shape, but does not deal with the end-use properties. "Its only goal is to get as close to the dimensions as possible," he explains. "You actually start with a high-end file, but lose information in the transfer to STL [standard 3D printing language] and again when transposed through slicing software." Bheda proposes replacing this with the open-standard Additive Manufacturing File (AMF) CAD file format, specifically designed for 3D printing but which allows inclusion of other parameters, such as part orientation, layer thickness, fill ratio, fill pattern, materials, colors and tool-path orientation. "The printer now has more of the engineer's knowledge."

Another issue is dimensional inaccuracy introduced using extruders on the end of robotic arms. "Yes, the errors do accumulate as you move down the arm, but we are working with partners to correct the path errors with a controlled feedback loop and software that continuously give the tip its position and corrects it vs. the CAD file." Mondesir notes that using feedback to improve accuracy is expensive but not overwhelmingly difficult. "Servo and stepper motors are already well developed for this," Bheda claims. "For some industries, dimensional accuracy is critical. For others it is not. We believe we can operate within the tolerances being demanded so far."

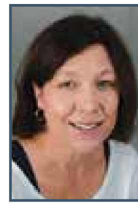
Bheda also sees a potential solution to print accuracy issues in continuous logging of process data, including extruder temperature gradient, melt flow pressure and print chamber temperature. These data, analyzed by quality-control software in real time, can ensure that process parameters are within the allowable range (see "Learn More"). Images taken of each printed layer also can be analyzed for printing errors, followed by corrective action. And data can be archived with a unique part identifier for QA tracking, similar to what is standard for aerocomposites.

Finally, AM saves steps and eliminates waste. "We are printing ultra-strong, complex parts with PEEK that are unitized to eliminate supply chain logistics," says Bheda. "So there is a lot of cost collapse that companies are capturing for savings." For example, a crane company wants to replace an arm made from four metal parts welded together, where each weld and the completed arm must be tested. "We can meet the specifications with a *single* part, printed in one shot in seven hours," says Bheda, "and it requires only one test for the final part."

### Integrated manufacturing?

On the near horizon, additive manufacturing cells also are a key element in more ambitious production schemes. "Companies are looking at software-configurable factories, essentially creating general-purpose manufacturing cells that can do additive, subtractive and perhaps even injection molding," Bheda explains. "These hybrid cells can be continuously repurposed."

"AM ... is becoming part of a manufacturing ecosystem that can combine multiple materials, subtractive machines, and factory automation," Caffrey agrees. "In the future, you may see antennas printed with conductive traces on a carbon-fiber-reinforced thermoplastic structure. The question is, how and where will composites AM fit? And will it be cost-effective enough to reach beyond niche markets to mass production?" CW



**ABOUT THE AUTHOR**

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# Laser projection: Envisioning *more* than templates


## Advanced systems offer ply-placement verification, aids to faster assembly and manufacturing process and quality control.

**By Sara Black** / Technical Editor

» Of the thousands of beneficial composites processing innovations developed over the past decades, laser projection systems rank near the top. Introduced in the 1990s, they replaced physical cumbersome templates as customer demand for shorter production cycles became more aggressive, significantly reducing labor, time and part scrap during layup. More recently, however, laser projection systems originally purchased to speed ply placement, in some settings, are finding application *beyond* manual ply placement/verification. Suppliers and their customers are adapting them to perform process and quality control and expanding the scope of their effectiveness, taking advantage of their already established links to the part's CAD design software.

"Laser projection is changing," says Scott Blake, president of Assembly Guidance Systems Inc. (Chelmsford, MA, US). "It is starting to be used to determine if parts are being built as designed, using the fewest resources, not only for hand layup but in automated work environments."

"Automated layup is the way of the future," agrees Sean Francoz, senior product manager at Virtek Vision International Inc. (Waterloo, ON, Canada, a subsidiary of Gerber Technology, Tolland, CT, US). But he's careful to point out that

**From templates to new territory**

Laser systems are moving beyond layup aids into in-process design verification and process control. Here, a worker uses Assembly Guidance's handheld instrument, called a HAMPI (High Accuracy Manually Positioned Inspector), part of the company's Automatic Ply Verification (APV) system. The FAA and US Army consider APV the equivalent of a required second inspector who measures fiber orientation with a calibrated instrument.

Source | Assembly Guidance

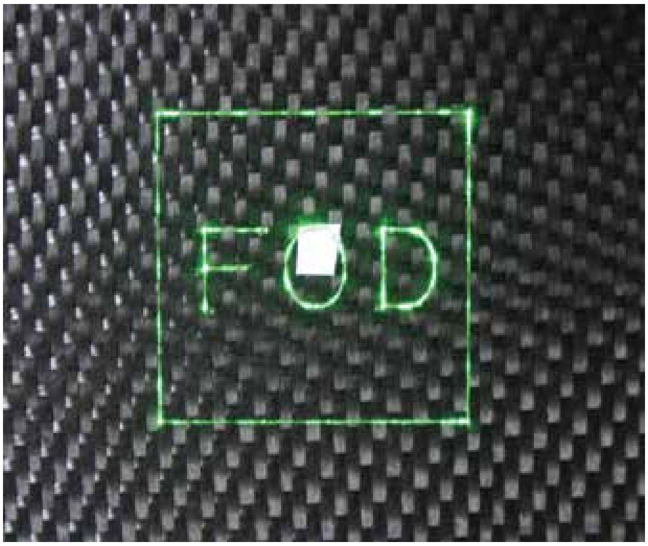
laser projection's root application will remain the same: "Manual layup isn't going to go away," he asserts. "There will always be manual assembly steps on aircraft, for instance."

## Laser projection: Systems & software

The key to understanding where laser projection is going is found in how it works. In a nutshell (for more, see "Learn More," p. 57), a projector mounted above the work area produces a light beam from a low-level laser source. Using a system of mirrors and galvanometers controlled by a computer, it converts the laser's stationary dot of light into a "traveling" sequence of points that refreshes so quickly that it can create what appears to the human eye to be persistent, accurate ply outlines — a glowing virtual template. Historically, retroreflective alignment pins or targets positioned at the edges of the tool (*retroreflectors* direct light back to the source with minimal scatter) have acted as reference points, enabling the system to accurately establish the tool within three-dimensional space. Some newer systems, as we'll see, no longer require reflector targets. Using the part's CAD file information, the projector's computerized system projects onto the tool the exact boundaries of successive prepreg plies. As the technician places each ply, he or she confirms each step on the computer screen as layup advances. Although first-generation systems used heavy hot-gas lasers, advancements have resulted in smaller, more compact units with diodes that project cool green light with less flickering, at safe laser levels.

Those who use projectors must have a way to access the part's CAD ply design information. They have several options. Some CAD software packages include laser projection modules — Dassault Systèmes' CATIA (Waltham, MA, US) has a generic module within its Composites Product Design (CPD) package. The Fibersim composite engineering suite from Siemens Product Lifecycle Management Software Inc. (Waltham, MA, US) offers a laser projection interface that generates and verifies data consumed by laser controller software solutions. Fibersim, given its open architecture, can generate data from the ply boundaries in its CAD composite engineering solution for *all* laser systems, says Leigh Hudson, Fibersim product manager at Siemens. In addition, the Fibersim laser projection interface generates data consumed by laser verification systems, such as the Automated Ply Verification (APV) solution from Assembly Guidance (noted below), that validate that a ply has been properly placed on the tool. "It is very important to ensure the 'as-manufactured' and 'as-designed' product is the same," says Hudson.

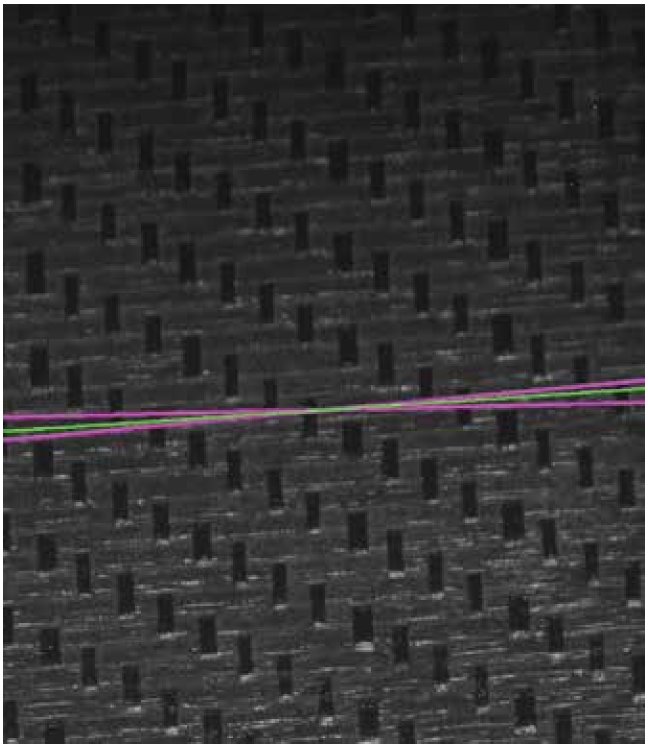
Several third-party interface options also facilitate laser projection with software solutions. One is metrology specialist Verisurf (Anaheim, CA, US). Built on the company's CAD/CAM system, Verisurf Laser Projection enables users to create laser projection programs from any supplier's native CAD file format, including SolidWorks, SolidEdge, AutoCAD, CATIA and more. It enables live "pick-and-shoot" programming, for selection and instant projection of ply geometry. Verisurf Laser Projection software is reportedly compatible with laser projectors from all suppliers. Magestic Systems Inc. (Westwood, NJ, US, now owned by AutoDesk, San Rafael, CA, US) began development in the mid-1990s of add-on »




### Foreign object detection

Laser projection systems can be equipped with vision systems to help in foreign object detection (FOD). This FOD indication shows the operator of an Assembly Guidance laser system where its Process Control System has detected a problem. The operator cannot proceed unless the problem is resolved or the operator overrides the system.

Source | Assembly Guidance



### Fiber orientation: Verification & documentation

This closeup shows a 2° tolerance (the purple lines) and the green line indicating the measured fiber orientation in this composite layup, an example of how the laser system can verify and document fiber orientation, even on a ply-by-ply basis.

Source | Assembly Guidance

software that integrates the laser projection system's software control system with the exact ply-by-ply CAD data, regardless of the CAD system used. The company's TruLASER software enables a more accurate layup, says the company, because it adjusts the projected laser line to avoid parallax error as the layup increases in thickness on the tool.

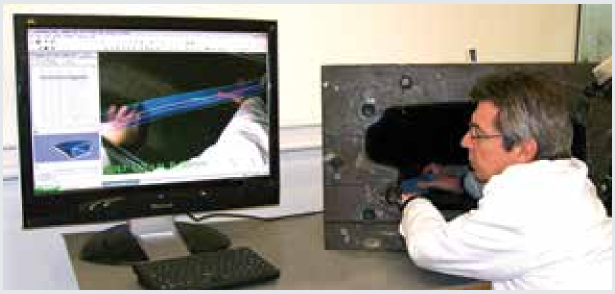
### From ply placement to design verification

With its many benefits, laser projection has some limitations. Cost is one. For very simple parts, tens of thousands of dollars for a laser projector doesn't make sense when a low-cost physical template fits the bill. Says Blake, "Our applications can significantly improve cycle time for very complex layups that take dozens to hundreds of plies." Another issue is deep draw or very complex, curved molds, such as flap track fairings. A laser also can have difficulty holding tolerances on steep vertical surfaces and cannot project a ply boundary on a surface obstructed by an overhang. In some cases, multiple projectors can do the job. But such realities pose a challenge. "Design is too often isolated from manufacturing," Blake points out. "The design process has to make it to the shop floor." For that reason, Assembly Guidance took a role in pushing laser placement into in-process design verification, or process control, as early as the mid-1990s, and it was the impetus for the development of his company's APV System.

"We won an SBIR [Small Business Innovation Research] grant and developed a system while working with Sikorsky on layup of helicopter blades," Blake notes. The OEM wanted to be able to verify with great accuracy exactly how each blade had been

SIDE STORY

## Camera-based ply placement



### Capturing the action on camera

PlyMatch from Anaglyph is not a laser projection system, but works by filming the work area and mold with a video camera, and blending that live image with the ply software image, generated by CAD or design file, on a monitor. The operator watches the monitor as the ply is placed, matching the software-imposed outline, and the camera documents each step. It is reportedly ideal for deep or cavity molds. Source | Anaglyph

Although it is not based on laser projection, Anaglyph's (London, UK) camera-based PlyMatch system serves the same purposes as today's other ply-placement systems: to aid ply layup and part assembly and provide the additional benefits of tracking and validating process steps. The PlyMatch system is the result of a two-year research initiative with the UK's National Physical Laboratory (NPL).

"PlyMatch works by filming the work area and mold with a video camera and blending that live image with the ply software image, generated by CAD or design file, on a monitor," says Emmanuelle de Posson, marketing manager at Anaglyph. "The operator looks at the monitor to see where to place the plies, and the camera documents each step."

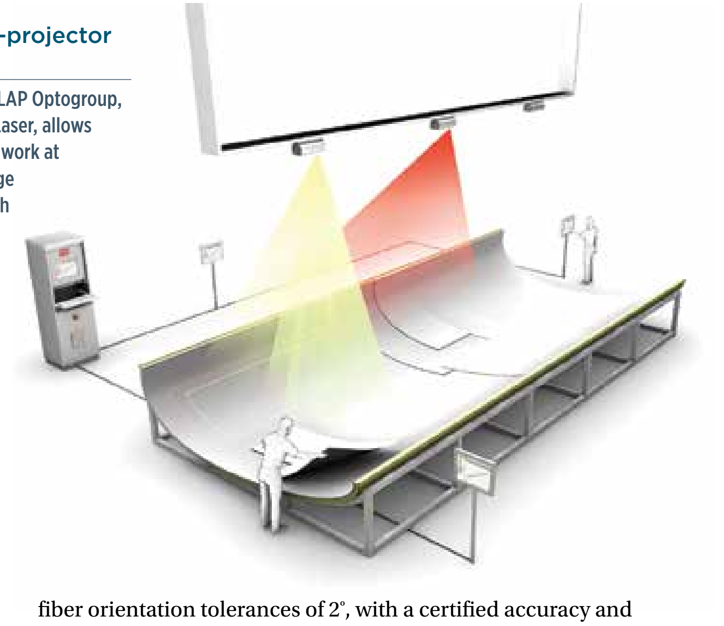
The system is very flexible, because the camera or the mold can be moved at any time by the operator during the layup process without the need for recalibration. An optical sensor tracks the position of the mold and the camera in 3D space, in relation to each other, and feeds that information to the control system. The system constantly updates that positional relationship in real time so that the ply image matches the filmed image of the tool.

"Each ply is always shown correctly in relation to the mold, even as the mold or camera is moved," she explains. This flexibility makes PlyMatch a good tool for complex, curved and deep-draw molds, like that shown above, where laser projection has difficulty. Asserts de Posson, "This system gives visual access even when the structure has deep cavities."

Although PlyMatch is typically used for layup of complex, small- to medium-sized parts, it can be modified for larger parts through the use of additional hardware. PlyMatch can use IGES and 3D DXF files and is, thus, compatible with virtually any CAD application, or it can be used with Anaglyph's proprietary composites design and analysis software, Laminate Tools.

For quality-control purposes, the system enables the user to record the assembly procedure and save it in .avi file format, to prove that the part has been manufactured according to specifications. The system can measure boundary deviation or fiber orientation misalignment, if required. And, De Posson points out, PlyMatch can be adapted to automated manufacturing, by positioning the camera and sensors to track machine movements and material placement.

produced, down to precise fiber angles for each ply. Blake's group developed a projector combined with a camera, with the camera images referenced to the CAD design model. Blake says the system was so successful that the US Federal Aviation Admin. (FAA) and the US Army ultimately accepted it as a substitute for one of two required human inspectors who manually verify fiber orientation of composite plies for flight-critical parts using a calibrated instrument. (One supplier has adapted a camera-based system for ply-placement duty. See "Camera-based ply placement," on p. 50.)



## Multi-team/multi-projector control capability

This rendering shows how LAP Optogroup, a concept offered by LAP-Laser, allows several teams or groups to work at different locations on a large object, simultaneously, with shared projection capacity controlled by remote devices.

Source | LAP-Laser

The current version of APV involves Assembly Guidance's Laserguide laser projection system combined with a handheld instrument called a HAMPI (High Accuracy Manually Positioned Inspector) — the latter for key parts on which critical fiber orientations must be verified, documented and traced. The Laserguide software tells the operator where to place the HAMPI device; HAMPI then illuminates, captures, calibrates and analyzes a digital image of the region. The APV system, using the image, can verify material type, ply presence and sequence, correct location and orientation. The system won't allow the operator to proceed to the next layup until the inspection results fall within manufacturing tolerances, and all data is archived in a report format to ensure comprehensive traceability. "Even after the part is cured, there is a quantitative, physical record of what is inside," says Blake. "Quality departments love this because they don't have to be present at the tool to buy off on each ply, and layup operators love it because they don't have to stand around waiting for inspectors," he quips.

He adds that APV has been through a rigorous failure analysis with the US Army. The system reportedly can verify and document fiber orientation tolerances of 2°, with a certified accuracy and resolution of 1°, based on required customer certification procedures. Blake recalls that he has seen distracted or fatigued shop technicians refuse to believe that a mistake has been made: "They'll say that the APV system is broken!"

To prevent debris from turning a part into scrap, APV includes foreign object detection (FOD) capability that halts the manufacturing process until the object is removed, and projects an outline around FOD on the mold surface (see top photo, p. 49).

"We're finding that manufacturers are being required to maximize the information content delivered with each part. They want to know that ply orientation for the part was correctly manufactured, and that information documented and traceable, even to material batch for each ply or the vacuum gauge used in each debulk," says Blake. In response, an enhanced version of »


## Targetless work area alignment

The new IRIS Spatial Positioning System (SPS), a targetless vision technology from Virtek, pairs a Virtek projector with a vision system, called a "spatial locator." The locator takes visual measurements of the tool or work area, aligns to predetermined physical datum features on the tool, like surfaces, edges, or holes, and transmits that data to the projector to align the CAD model correctly in 3D space, onto the work area. The system expands laser projection's capabilities by allowing its use on very large or awkwardly shaped tools, because it can "see" all parts of the work area.

Source | Virtek Vision

**Next-gen green/blue lasers maximize optical output**

Z-LASER recently launched the third generation of its ZM18 machine vision lasers. The ZM18S3 (left) increases modulation frequency (TTL) from 1 kHz to 500 kHz, while the ZM18H3 (right) is a power-stabilized laser with green or blue wavelength. The third-generation lasers also increase maximum optical output to 200 mW.

Source | Z-LASER

Laserguide, called Laserguide ProjectorVision, records signals directly from each layup operator's remote control as it is used for data collection, including scanning barcodes, entering data (i.e., mold release application) and system control functions, and securely saves the information even in the event of a power failure. More importantly, says Blake, the system reduces uncertainty in the composites design/build process, because the designer has confirmation that the part has been built as designed. Assembly Guidance is working with several composite design software providers, including Siemens, to develop more optimized design tools for aerospace composites.

### A more complete composites toolbox

"Manual ply layup is important in manufacturing processes," says Karsten Hofmann, co-owner and innovation manager at LAP Laser LLC (Erlanger, KY, US, and Lüneburg, Germany), "but today's composites manufacturing technology is becoming as automated as possible, for example, in automated tape laying or compression molding." Hofmann adds that even when the majority of composite plies are placed by machine, many shops can still benefit from a laser assembly-guide system, for quality assurance and to support efficient production processes.

LAP Laser's Composite PRO laser projection system is already recognized as compact and lightweight. It also offers outlines in different colors, for easier display of ply groups, and its Viewport feature selects and highlights certain complex areas for better visibility. "Load balancing," adds Hofmann, "distributes projection data by mold area and part complexity, rather than by projector position, so that the greatest illumination power is focused on the area requiring the most attention." Further, LAP Optogroup, a client-server concept, enables several teams or groups to work at different locations on a large object, simultaneously, with shared projection capacity controlled by remote devices (see top photo, p. 51).



He points out that the LAP Laser projection system organizes the workflow on the shop floor: "It creates a structural work order, a systemic list of tasks, which really helps a company technician to go beyond the physical ply layup." In Hofmann's view, this kind of organized system can help speed the part manufacturing process. While LAP Laser receives customer requests for the automated quality control and verification functions described above, he believes there's still a long way to go in that area, and says LAP Laser continues to research new QC technology. Hofmann offers a "pragmatic" solution, where the Composite PRO system directs the technician, who then verifies that the plies are located within tolerances, noting that this still improves productivity at a lower cost.

"We've still got a long way to go in the aerospace industry in terms of improving production speed," says Hofmann, pointing out that "laser systems can play a big role in hastening aircraft assembly, hole drilling, bracket placement and so much more."

Jason Galek, president of SL-Laser Systems (Charlotte, NC, US, the North American arm of SL-Laser Systems LP (Traunreut, Germany) describes his company's products as ranging from the small and compact ProDirector XS2 for confined spaces (e.g., an aircraft interior) to the larger format ProDirector 6 for workcell and "harsh" industrial environments. But he adds, "SL-Laser is as much a software company as we are a hardware company. Our SL3D software suite is open and adaptable for customer integration, additional hardware, such as coordinate measuring devices, or third party software."

SL-Laser's software reportedly includes a unique, integrated "CAD engine" that takes data from any CAD package, even the most basic, to enable smaller composites shops to use laser projection. Explains Galek, "A small shop may not have the budget or engineering training to deploy an integrated design software program, and this enables them to employ the laser device in their operations." That said, SL-Laser has partnerships with several large industry software providers as well. The company introduced software and hardware at JEC Europe 2015 to assist fabricators in 3D structural assembly applications, particularly for the ground transportation sector, including trains, trucks, buses, cars and heavy equipment.

The company's calibration method reportedly provides better *linearization resolution* (that is, sharpness of the projected ply boundaries) than other laser projectors, claims Galek. "This allows us to hold tighter tolerances on steep, vertical tool surfaces in deep-cavity tools and shows fine detail on tight-radius curves."

If a company requests it, SL-Laser also can incorporate inspection "brakes," that stop the layup process until a supervisor has verified that layup can proceed. Other available tools include barcoding and ply placement recording, with cameras and production data logging. "As shorter cycle times increasingly dominate the conversation in composites production, we want to incorporate quality improvements that can be seamlessly integrated in parallel with the process rather than contributing to added production time," he asserts.

Freiburg, Germany-based Z-Laser Optoelektronik GmbH offers its LP-HFD laser projectors, with flicker-free beam and »

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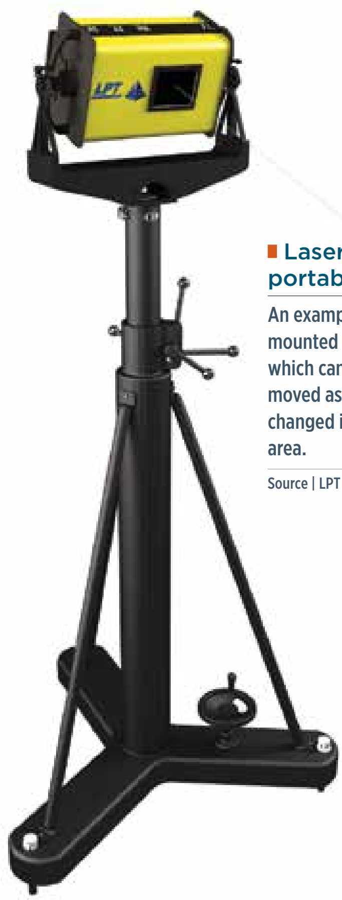

**Laser projector portability**

An example of a projector mounted on a stand, which can be easily moved as tools are changed in the layup area.

Source | LPT Corp.

durable performance, in a wide choice of output power, from 7 mW to 40 mW, in red or green output, says sales manager Dr. Roland Fritz. *CW* previously documented the Advanced Manufacturing Innovation Initiative (see "Learn More"), during which multiple Z-Laser projectors were ganged together above wind turbine blade molds in a production scenario. Precise projections of plies, core, shear web and adhesives placements helped reduce blade cycle time by 37%.

Z-Laser has contributed to automotive projects as well, and has provided projectors to guide workers through each step of automotive interior equipment assembly (e.g., car doors). Because Z-Laser can display instruction text and point out FOD or other problem areas, worker training time can be reduced while simultaneously improving quality control.

At the recent JEC Europe 2015 event, Z-Laser introduced its Z3D-Control system, which combines laser projection and a stereo camera system, says Fritz. Intended for large parts or objects with a great depth of focus, the system has FOD capability, and projects the defective area's location directly onto the workpiece. "Vastly increased efficiency and cost reduction can be achieved in assembly of large parts by combining 3D object data acquisition, variance analysis and laser-based assembly guidance," says Fritz.

### Beyond laser to radar

Steve Kaufman, president, Laser Projection Technologies (LPT, Londonderry, NH, US), confirms the trend: "We're definitely seeing a shift. Customers now want in-process verification — to know that manufacturing is proceeding according to plan." LPT offers several levels of systems capable of process control and verification, including FOD and 3D measurement in real time.

Kaufman cites a phenomenon he calls "tribal knowledge:" Workers on the shop floor receive CAD designs and lay up parts; if something isn't quite right, they "fix" it — adjusting or trimming a ply, for example — typically *without* providing feedback to engineering. He points out that if


that skilled technician isn't around to make that fix, and tribal knowledge breaks down, the part isn't going to be right.

"Our LPT15 system uses two projector units, working together, to provide high-speed, noncontact measurement technology that allows the company to validate what's being built." And, it does this without photogrammetric targets, he adds. Guided by LPT's RayTracer software code, the LPT15 system scans features of a part, tool or assembly such as drilled holes, corners, edges or tooling balls, using LPT-patented technology devices called PMTs (Photo Multiplier Tubes) for laser signal feedback. A PMT, explains Kaufman, is an extremely sensitive light-detecting system — much more sensitive than typical photo detectors used with standard laser projectors: "These PMT light detectors allow the scanning projector to detect enough laser energy reflected from tool or work surfaces to create an image from the scan." The scanning laser projectors emit and steer a visible green laser beam (<5 mW) across features in a raster scan array. The PMTs reportedly can sense 100 million times less light energy than the scanning projector sends out, enabling it to detect the key features.

Working with the CAD data file, the projectors scan the projected laser "spots" to determine their location in 3D space with respect to the tool. The LPT15 can detect and measure the angles of composite plies during the layup process, and verify that parts and assemblies are being manufactured within the process tolerances. In addition, the system can scan parts, tools and work areas for foreign objects during the process and stop the process until the object is removed.

> Laser projection technology is becoming an antidote to the shortcomings of mold layup "tribal knowledge."

Kaufman dislikes camera technology for in-process verification: "The problems with cameras are numerous, least of which is the inherent poor granularity, instabilities and the inaccuracy of the chips. They should only be used in a bundling setup, where multiple pictures are taken from multiple angles, using coded photogrammetric targets stuck to the surface of the object." That's why the LPT15 uses the paired lasers, a process Kaufman calls "lasergrammetry."

LPT's latest product offering is the LPT100. It uses a similar detection system as the LPT12 and LPT15, but adds a high-resolution, extremely high-speed, "time of flight" LIDAR (light detection and ranging) noncontact measurement system. In high-accuracy measurement mode (0.125 mm, full field) this system can deliver 4,000-5,000 measured points on a 3D object (e.g., a part in a tool) per second, asserts Kaufman. Those points form a "point cloud" that is compared to the CAD model to identify the sections of the object that are out of tolerance. The LPT100 then projects a high-speed, glowing image directly onto the surface where discrepancies are located, to facilitate in-process fixes. »


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## Moving targets

"The current state of the art is human inspectors," says Virtek Vision's Francoz. "Highlighting ply boundaries on the part speeds that inspection. Yet, there's a balance between maintaining adequate inspection for quality control and maintaining fast cycle times."

Virtek's trademarked LaserEdge laser templating system is used to guide operators in many industries, including composites, and has features that maximize productivity, asserts Francoz. Multi-Task enables one LPS 7H projector to serve multiple workstations, so that ply layup can occur on multiple parts, in parallel, or multiple projectors can be networked. The system's application programming interface (API) uses a standard web service that integrates external devices or automated equipment that might include CNC-based flatbed cutting systems, automated layup, barcode readers and/or other manufacturing execution solutions. "Our system projects recognizable icons directly onto the work surface and minimizes the need to go back and forth between the tool and the computer workstation, and it eliminates the need for remote control units," he explains.

The newest addition to Virtek's product offerings is its trademarked IRIS Spatial Positioning System (SPS), a targetless vision technology. The system pairs a Virtek projector with a vision system, called a "spatial locator." The locator takes visual measurements of the tool or work area, aligns to pre-selected physical datum features on the tool, such as surfaces, edges or holes, and transmits that data to the projector to align the CAD model correctly in 3D space, onto the work area.

The system expands laser projection's capabilities by allowing its use on very large or awkwardly shaped tools, because it can "see" all parts of the work area, something not possible with older-style reflective targets. IRIS periodically checks for the position of the part relative to the spatial locator, and any changes in the position of the projector or tool are updated and realigned in the projection system to ensure projected line accuracy for placement of plies or elements on the work surface. An intuitive, user-friendly operator interface speeds workflow, and a remote controller reduces trips back to the computer screen.

A Virtek LaserEdge system was recently installed by Fives Cincinnati (Hebron, KY, US) for use with its Viper automated fiber placement (AFP) machine, one of several used to lay up very large carbon composite parts at an aerospace manufacturing facility, says Fives Cincinnati technical sales director Robert Harper. Virtek laser projectors are mounted above the Viper machine, making them independent of the AFP's movements, a key point for accurate projection.

"The Virtek projector's control system and the Viper's machine control system work hand in hand," explains Harper. "The Viper sends a signal to the laser unit, telling it it's done with that ply, and a human inspector verifies that the ply is correctly placed in relation to the

projected image." The operator must "accept" the ply on the Virtek control system for the projector to advance to the next ply boundary image, and the Viper begins the next sequence. "It is being employed as a manufacturing aid, for faster part production, but is not a 'vision' system for process control."

Because of the part's large size and round shape, numerous projection targets are needed. Fives Cincinnati worked with Virtek to create magnetic reflective targets that fit down into holes in the tool. Held in place with bushings, the sealed targets are placed as needed to define the fiber placement work area, and to track the long Viper machine movements during layup. The targets are removed before part cure.

Harper stresses that Fives Cincinnati works with all of the laser projection system suppliers and is brand-agnostic. The aerospace project was "an end-user preference," he asserts. He also notes that any of Fives Cincinnati machines could be adapted to work with a laser projection system. *CW* has spoken with other automated composites processing machine suppliers who are adopting laser projection, as well. One willing to speak about applications this early was MTorres (Torres de Elorz, Navarra, Spain), which is incorporating laser projection on its automated tape-laying machines used in Airbus A350 XWB production, to enable "on-the-fly" inspection of tape position as tapes are applied to the tool. The company says the laser inspection saves significant time in on-machine inspection.

## Bringing part cost down

In the end, laser projection is one of many tools for the composites industry for making better parts, faster. "It's all about optimization of design," concludes Blake.

Virtek's Francoz sums up, "The trend we see is the use of laser projection to lower the total cost of composite part ownership, that is, making production, whether manual or automated, more efficient with less down time." Adds SL-Laser's Galek, "We're living the future now. There have been huge leaps in laser component technologies, and even after a quarter century, we still talk to companies with new applications ... we're adapting this technology to new industry needs." CW

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# The Rise of HP-RTM

## Decades of development have propelled it to prominence, but its future demands industrial solutions for handling cost, complexity and process control.

**By Ginger Gardner** / Senior Editor

» Already used in series production of structural carbon fiber-reinforced plastic (CFRP) parts for BMW's (Munich, Germany) *i3* and *i8* models, high-pressure resin transfer molding (HP-RTM) is viewed by some as new technology. To others, it is merely modernization of early RTM processes, like that used to build Dodge *Viper* parts 25 years ago! What differentiates HP-RTM from RTM? "The cycle time is much faster than standard RTM," points out Matthias Mayr, head of project management at Engel Austria's (Schwertberg) Center for Lightweight Composite Technologies. And that difference is wrapped up in the "HP." Conventional RTM, by comparison, is "LP."

"Low pressure RTM — injecting at 10 to 20 bars — has a standard cycle time of 30 to 60 minutes," says Slavko Karas, project manager at Mubea Carbo Tech's (Salzburg, Austria) newest facility in Zebrak, Czech Republic. "It can be as low as 5 minutes, but only for very small parts."

"High pressure," says Mayr, "means up to 150 bar in the mixing head and from 30 to 120 bar inside the mold, depending on part size and geometry." Automation is also key to HP-RTM, but that demands an increased investment in both capital and process control. According to equipment suppliers, that investment is indeed being made. The goal: integrated, lightweight structures with cycle times of less than 10 minutes.

### Molding complex parts at high volume

HP-RTM is already being used in series production of large, integrated CFRP auto components, such as this BMW *i8* sideframe.

Source | BMW

### Preforms: A production bottleneck

A BMW *i8* sideframe preform undergoes a visual quality check before moving on to a BMW HP-RTM workcell. BMW says a key need in terms of productivity is greater preform permeability during resin injection. Source | BMW

## The what and when of HP-RTM

HP-RTM still comprises a fiber preform, a closed mold, a press and a resin injection system, but the latter is now an *impingement mixing head*, like that first developed for polyurethane (PU) foam applications in the 1960s. In fact, metering/mixing/injection suppliers for the PU and reaction injection molding (RIM) industries were among the early developers of HP-RTM, including KraussMaffei (Munich, Germany), Hennecke (Sankt Augustin, Germany), FRIMO (Lotte, Germany) and Cannon SpA (Borromeo, Italy).

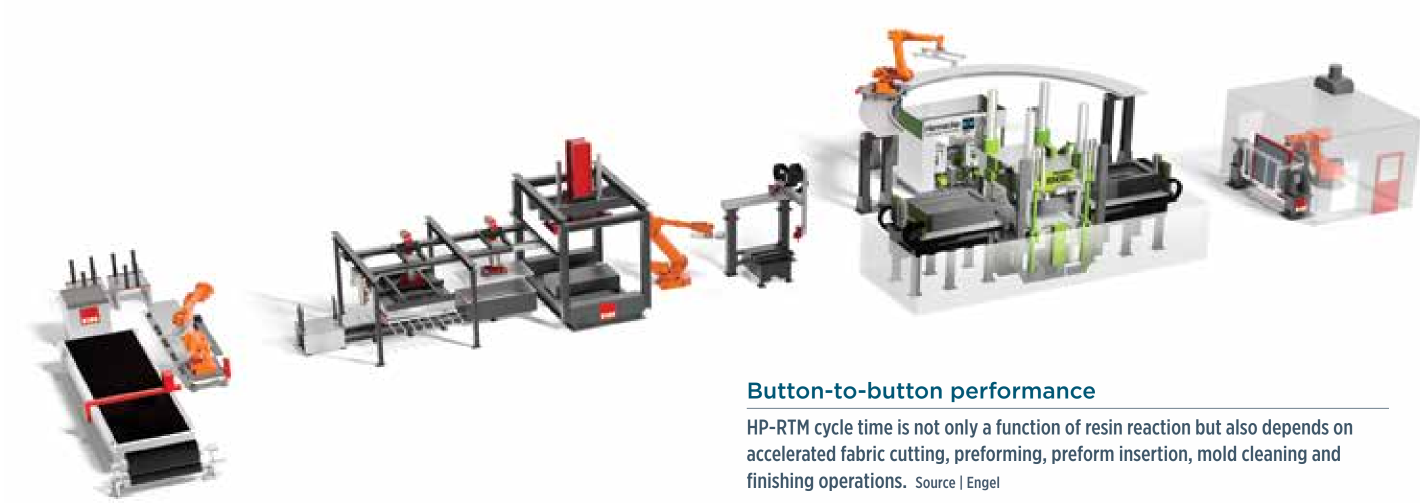
Structural RIM (SRIM) uses the RIM technique, but like RTM, the mixed resin is injected into a fiber preform in the mold. Fiber content is lower, typically up to 30% by weight. (Fiber weight up to 75% has been claimed for HP-RTM parts.) During its heyday, SRIM development included automated preforming and blurring of the lines between the two processes.

"RTM has been around for decades," says Erich Fries, head of KraussMaffei's composites business unit. "For us, it was *always* HP-RTM because we were always using impingement mixing in a chamber, even though most companies using low-pressure RTM were using static and dynamic mixers."

By 2005, RTM had been used heavily in the Dodge *Viper* and also by Sotira Composites (Meslay du Maine, France) for a wide range of OEMs, including a joint development effort (see "Learn More") with Ford Motor Co. (Dearborn, MI, US) and Aston Martin (Gaydon, Warwick, U.K.). The process also was gaining traction in heavy trucks, where Class A requirements are less rigorous. And then came a turning point. Although not necessarily an HP-RTM process, RocTool (Le Bourget du Lac, France and Charlotte, NC, US) introduced its induction-heated molds as "high-speed RTM" at JEC 2007, touting a cut in cycle time by as much as 50%. Then, in 2008, carbon fiber producer Toray (Tokyo, Japan) listed "faster-cycling RTM" in its presentation, "CFRP: What Is Needed Next For Mass Production In The Automobile?"

Preceding all of these efforts, however, was the ongoing work by the BMW Group. "For more than 10 years, BMW Group has used CFRP in the roof of its *M3* and *M6* models, opting for HP-RTM for reasons of cycle time, surface quality and industrialization," explains Dr. Thomas Wolff, head of CFRP technology development at BMW. "During this time we have gained valuable experience for volume production of CFRP components. Thus, it was useful to keep with this process as we faced the challenge to step from small quantities to fully industrialized production."

Wolff relates that cost and cycle-time reduction were key issues that BMW Group faced with the intricate geometry of the *i3* and *i8* body components. HP-RTM also offered the potential to produce large, complex structural components, such as sideframes (see photo, p. 60). "Now we are able to volume-produce these to a high »



### Button-to-button performance

HP-RTM cycle time is not only a function of resin reaction but also depends on accelerated fabric cutting, preforming, preform insertion, mold cleaning and finishing operations. Source | Engel


quality and with high process stability, cutting manufacturing costs for CFRP body components by around 50%." That's compared to roof production, he notes, assuming the same boundary conditions and process chain.

This increased structural and geometrical complexity has posed additional challenges. "Now, we are seeing different parts, with very high fiber content," says Fries. "This causes high pressure to build up in the mold, but you must still fill the cavity, so pressure up to 110 bar is required." He claims that while low-pressure machines using gear pumps can run against pressures up to 40 bar, "we use HP axial piston pumps, which can go against 200 bar. So everyone, now, is using HP mixing and injection heads."

And although PU is still being offered, especially in more cosmetic applications, epoxy is gaining ground. "At Engel, we actually started with PU, but today our customers show equal interest in epoxy and PU," says Mayr. "Both material systems seem to have further application potential."

### Abbreviating mold cycle time

HP-RTM has been a catalyst in the development of more reactive, faster-curing resins. Although work in this area has been ongoing since the 1990s, BMW Group gave it a boost by adopting a fast-cure EPIKOTE epoxy from Hexion (previously Momentive Specialty Chemicals, still based in Columbus, OH, US) in its initial CFRP roofs, and choosing Huntsman Advanced Materials' (The Woodlands, Texas and Basel, Switzerland) Araldite LY 3585/Hardener XB 3458 epoxy system — which boasts a 5-minute cure at 100°C — for the *i3* Life Module (BMW reports that its

**Preforming and molding**

Preforming and HP-RTM molding operations are shown here for the BMW *i8* sideframe. Source | BMW

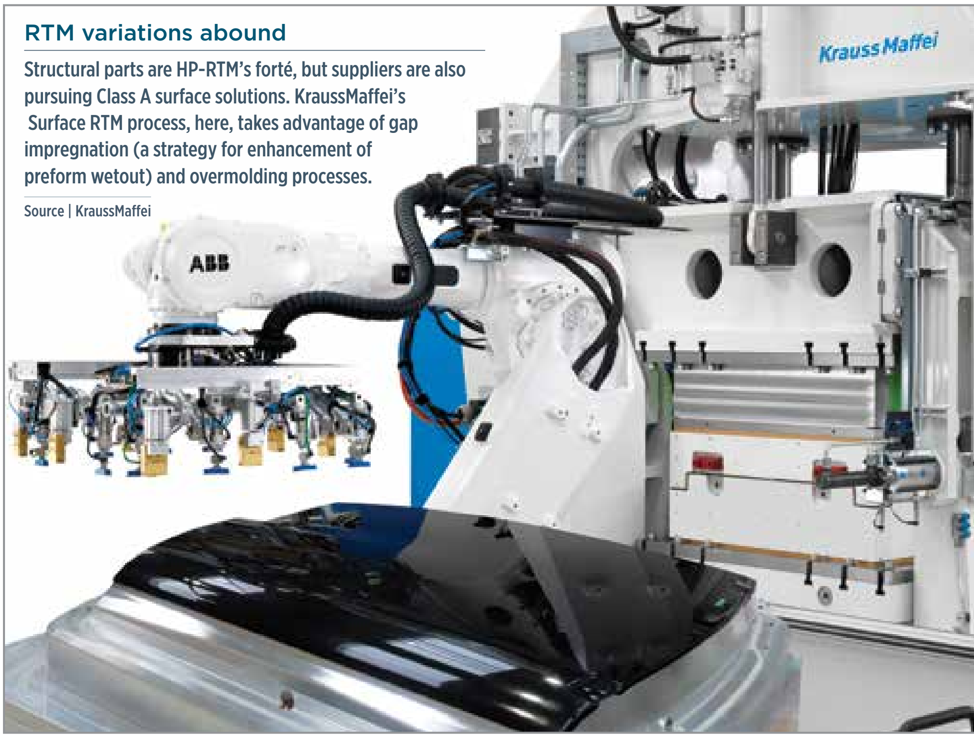
cure cycle for *i3* and *i8* parts is less than 10 minutes). By 2012, the 5-minute cure EPIKOTE Resin 05475/EPIKURE Curing Agent 05443 was superseded by the same resin with EPIKURE Curing Agent 05500 for a 1-minute injection window and 2-minute cure at 120°C.

Meanwhile, Dow Automotive Systems (Schwalbach, Germany and Auburn Hills, MI, US) improved its VORAFORCE 5300 epoxy from a sub-90-seconds mold cycle in 2014 to under 60 seconds in 2015.

"Of course there are epoxies available with a 1-minute cure time," says Fries, "but it's only for a simple, flat part, not a complex structural part." He warns against "best case" thinking, noting that parts are realistically produced in 3 to 7 minutes, a function of part size and complexity.

Mayr adds this caution: "The cycle time of HP-RTM is not just a function of the curing time, but of the whole process, starting with dry fabric. From this you generate a preform, transfer it to the mold and then start the HP-RTM process." He contends that larger production cells and more investment are required to speed the overall cycle time.

According to Mayr, then, *overall* cycle time remains the top priority: "Right now, molding is *not* the time-critical part of the process." Preforming is a bottleneck. The cutting, positioning and forming of fabric layers takes longer than the mold cycle. Similarly, he says, mold cleaning is an issue. Although mixing mold release into the resin helps, Mayr notes that the number of mold cycles between mold-prep sessions touted by mold-care product suppliers are only achievable under *ideal* processing conditions and depend heavily on the mold surface and design. In future efforts to improve process cycle time, says Wolff, "the automation of sub-processes like mold cleaning carries great potential." »




### RTM variations abound

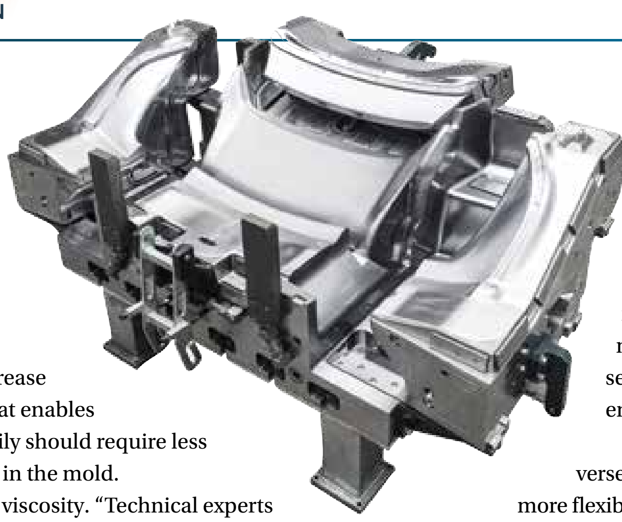
Structural parts are HP-RTM's forté, but suppliers are also pursuing Class A surface solutions. KraussMaffei's Surface RTM process, here, takes advantage of gap impregnation (a strategy for enhancement of preform wetout) and overmolding processes.

Source | KraussMaffei


### Advanced process control

As composites manufacturers have integrated HP-RTM into automated production lines, robotic preforming and handling equipment (at left) has played a key role.

Source | Engel



**Expert toolmaking required**

Alpex Technologies developed this Porsche GT3 trunk lid HP-RTM tool, featuring sliding sides and rear.

Source | ALPEX Technologies GmbH

## Pressure vs. preform

BMW Group also sees a need to increase preform permeability. A preform that enables resin to permeate it quickly and easily should require less wetout time and build less pressure in the mold.

Another option is to reduce resin viscosity. "Technical experts recommend resin viscosity between 50 and 200 cps to get good injection speed and impregnation," advises Sebastien Taillemite, business manager for Arkema and its Elium liquid thermoplastic polymer (LTP). He points out that epoxies are higher in viscosity, so they must be heated for HP-RTM. "But Elium is 100 cps at room temperature, so you can inject it without heating. Also, if injection pressure is too high it can move the fabric preform and you get fiber washout," Taillemite adds.

Indeed, preform permeability must be high (resin flows through easily) if resin viscosity is high, and both must be balanced with injection and mold pressure to achieve a successful part. Numerous studies over the past several years have explored mold filling simulation and optimized temperature, pressure and preform binder configurations to avoid fiber washout while decreasing cycle time. Typical of composites, the abundance of material and process choices makes optimizing parameters more difficult. Although not insurmountable, the analysis required can seem daunting to manufacturers just entering the HP-RTM arena.

BMW Group, however, is already well-versed in this optimization, and thus seeks more flexibility via advanced process control.

"We are looking for all possibilities to shorten cycle times," says Wolff. "This could be tools and machines offering more flexible and faster temperature variations, or the ability to influence the resin system due to better flow or faster curing by variably adjusting the hardener during injection." He says this applies to both epoxies and PUs, although the latter presents some challenges with the fabric systems BMW Group has already developed.

Fries points out that the need gets greater as production volumes grow: "You must have close process control. This was not needed 20 years ago because then the cycle was so slow — only 1,000 to 4,000 parts per year. But now, with 12,000 to 50,000 parts per year, you must have an interface between the tool, metering and injection systems." He describes KraussMaffei's integration of pressure


sensors: "If we see pressure over 100-110 bar, we know there is high risk of washout, so the sensors allow us to manage this with vacuum or by reducing throughput."

Mayr adds that customized pressure sensors like those from Kistler (Winterthur, Switzerland) and dielectric sensing systems to monitor the curing process — e.g., those from Netzsch (Selb, Germany) — are increasingly becoming standard.

A third, and somewhat ironic, solution to the challenge of preform permeability is a recent trend toward reducing injection pressure in favor of mechanical means to deliver resin throughout the mold cavity. High-pressure compression RTM (HP-CRTM), also known as gap injection or wet compression, involves injecting resin into a *partially* closed mold. The resin flows *over* the dry preform (rather than through its length), and then, as the mold closes, the resin is mechanically forced the short distance through the preform's thickness. This method requires less clamping force and press tonnage and, therefore, reduced capital expense.

> Are auto manufacturers buying HP-RTM? Yes. Yet all agree that HP-RTM still has a long way to go.

Fries says the gap does not result in fiber slippage because various fiber clamping methods are used, such as vacuum. "We demonstrated gap injection molding in 1990 for the US Air Force," notes Dimitrije Milovich, president of Radius Engineering (Salt Lake City, UT, US), a supplier of RTM tooling, injection equipment and presses. "We called it Variable Cavity Geometry and used an adjustable seal to maintain vacuum as we opened and closed the tool." He adds that the method was faster for the radomes under trial and had the ability to produce a high-quality surface finish.

Surface RTM is KraussMaffei's name for gap impregnation, using a PU matrix as a first step, followed by overmolding in the same tool with PU as a second step — i.e., the gap is flooded with a thin layer of PU to make a Class A carbon fiber-reinforced exterior panel paintable directly from the mold without additional surface preparation (see "Learn More").

Two additional innovations, both resin-based, show promise to alleviate concerns about both fiber misalignment and preform permeability. The first is thermoplastic RTM (TP-RTM or T-RTM), or what Engel calls *in-situ polymerization*: A preform is placed in a mold, the mold is closed and a caprolactam monomer is injected with a catalyst and activators. These then permeate the preform in about 30 seconds — thanks to a watery viscosity of 3-5 cps — and polymerize in the mold cavity at 150°C, becoming a solid polyamide 6 (PA6) composite within 2-5 minutes. The extremely low viscosity enables excellent resin-to-fiber distribution and permits high directional fiber content — up to 65% by volume. However, it also causes issues with mold leakage, and thus demands more attention during mold design. »

KraussMaffei demonstrated the process with BASF AG (Ludwigshafen, Germany) and Volkswagen AG (Wolfsburg, Germany) in a fiber-reinforced B-pillar with a 5-minute cycle time. Engel, which has worked on this technology with Fraunhofer ICT since 2009, is refining its prototype e-victory 120 machine into a second-generation system, while Hennecke and Mahr Metering Systems (Goettingen, Germany) have developed meter/mix systems that can deliver caprolactam into an HP-RTM process.

The second innovation is Arkema's (Colombes, France) Elium liquid acrylic/peroxide-initiated thermoplastic polymer. "We fine-tuned the viscosity of Elium for HP-RTM," explains Taillemite, to make structural parts, at volumes of 30,000 up to 200,000 parts/yr. Injection of the acrylic resin and initiator does not require heating, he says, although molds are heated to about 100°C. He adds that Elium is not sensitive to moisture during injection. (Moisture, reportedly, can stop polymerization of caprolactam). The resin has been designed for aesthetic composite parts (modulus ≈10-15 GPa) and structural parts, achieving a modulus of 20-45 GPa with glass fiber and up to 125 GPa with carbon fiber. Yet, Elium reportedly has roughly 50% higher toughness vs. epoxy and absorbs twice the impact energy that a polyester can. Further, structural parts with Elium matrices are said to age better than those made with PA6. "Arkema also produces PA6 polymer products," says Taillemite, "so we know well its moisture pickup of 5-10%. With aging, this tends to plasticize the composites and decrease the $T_g$, lowering mechanical properties over time." He explains that designers take this into account, for example, by doubling the thickness of a part.


### Industry buying in

Are auto manufacturers buying HP-RTM machines? "Yes," says Fries at KraussMaffei. "All of the equipment for the BMW *i3* and *i8* uses our metering machines, and other OEMs have followed." He says the company is talking to manufacturers globally, which now include Tier 1 suppliers.

"It's starting," says Mayr at Engel. "We sold a large clamping unit to BMW Group Plant Landshut, a 1,700-MT v-duo unit to the University of Warwick in the UK, and a third machine to a Mexican auto industry supplier." He says other machines have been sold and more projects are in the pipeline, including one that begins this summer and another in first-quarter 2016.

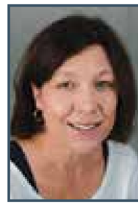
Arkema is building an HP-RTM line with several partners to use Elium for auto parts. "We are planning to run this line at the beginning of 2016," says Taillemite, "and currently have trials ongoing with five OEMs globally." This includes OEMs testing Elium parts for Class A surface, mechanical properties, chemical and fatigue resistance and crash testing. "In automotive, you need several years of testing before a new technology is validated," he explains. "We have started this testing in order to be ready for a project in five years." Feedback is that thermoplastic RTM will be in use after 2020.

And yet, all agree that HP-RTM still has a long way to go. "It is easy to find toolmakers in injection molding, but not so yet for HP-RTM and *in situ* processes," says Mayr. "The molds are more complex and need different sealing concepts around the cavity. You also have to accommodate how to insert the preform and make sure it is fully impregnated."

Part engineering is also a need, says Fries. "In automotive, not many people are familiar with how to avoid designing 'black metal' or how to design a part that offers high performance but is also producible with respect to preforming and impregnation."

Wolff notes that "many requirements are new, and there are not yet any state-of-the-art-solutions available, thus strong partnerships with suppliers are important to obtain the best and most economical options." He believes that as more expert knowledge is available in the market, the range of partnerships with different suppliers will expand to develop new solutions.

"There are many different views in this industry right now," says Mayr. "We come from injection molding, so our view is mass production and to help our customers reach the level of automation and the lot sizes of injection molding processes." Injection molding/RIM is, indeed, a vital part of both HP-RTM's ancestry and its promise, but can it make good? Perhaps a telling indicator is the installation of HP-RTM systems at both SGL-Benteler (Ried im Innkreis, Austria) and Mubea Carbo Tech, both backed by large steel auto parts manufacturers. "We have managed the transition from small series to industrial production of CFRP auto components," says Joachim Siegmann, head of Mubea Carbo Tech automotive sales. He views HP-RTM as simply one in a *range* of processes that achieve complex structures offering the highest grade of functional integration. Siegmann's associate Karas sums up: "Mubea sees a future in carbon fiber, and it is actually happening." CW



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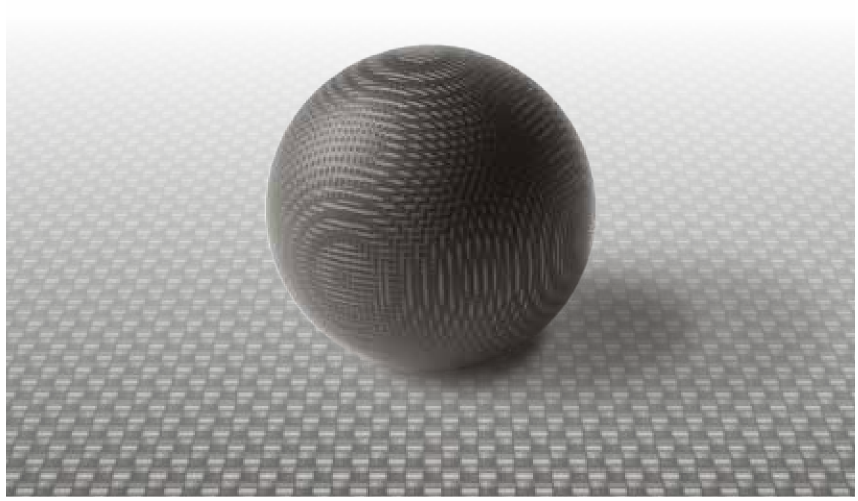

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# Thermoplastic composites "clip" time, labor on small but crucial parts

## Preconsolidated carbon fiber/PPS and PEEK and automated thermoforming enable six-figure production of connectors for the Airbus A350 XWB.

**By Sara Black** / Technical Editor

### Small parts that make a large difference

Premium Aerotec (Bremen, Germany) is a subsidiary and risk-sharing Tier 1 partner of aircraft OEM Airbus (Toulouse, France), responsible for production of, among other key parts, thousands of "clips" necessary for the assembly of the Airbus A350 XWB fuselage. The company has developed a high-speed thermoforming cell concept for rapid clip production from thermoplastic composites.

Source | Premium Aerotec

» The reality for aircraft OEMs today is that each new generation of commercial aircraft delivered to airline and cargo customers must be lighter and more efficient than the planes that preceded them. The demand for greater efficiency led to the adoption of a composite airframes for the 787 *Dreamliner*, in The Boeing Co.'s (Chicago, IL, US) case, and the A350 XWB at Airbus (Hamburg, Germany and Toulouse, France). Given the successful launches of both aircraft, each manufacturer now faces a huge backlog of orders — and the heat is on all the suppliers in each OEM's value chain to develop efficient, automated composites production to keep up with accelerating build rates.

Boeing opted for one-piece fuselage barrels for the 787, but Airbus enclosed each of the A350's five major fuselage sections with four large shells or panels: two side panels, and an upper and a lower panel. Each panel is supported by a system of internal frames and stringers. The stringers are bonded directly to the skin panels, but an array of parts, called "clips," attach the frames to the skin.

"We are responsible for the design and manufacture of more than *3,000* clips for different parts of the aircraft," declares Dr. Angelos Miaris, responsible for operational part testing at Premium Aerotec (Bremen, Germany). As an Airbus subsidiary and part supplier, Premium Aerotec realized early on that its share of the huge clip part count on the aircraft would require a very short manufacturing cycle time, low labor demand and a great deal of flexibility. For these reasons, he says, thermoplastic matrix composites were the obvious material choice, paired with an automated thermoforming process.

"We started thermoplastic composites part manufacturing in 2005 in Bremen [Germany]," says Dr. Klaus Edelmann, responsible for thermoplastic technology at the company. "In 2007, we made 50 parts. Last year we produced more than 150,000 parts." Indeed, Premium Aerotec Bremen is a major risk-sharing Tier 1 supplier partner in the A350 program, and is a "center of competence" for thermoplastics manufacturing. On the A350 program, the company is responsible for work packages that include fuselage section 13/14 (side, upper and lower shells, floor grid and assembly), and fuselage sections 16-18 (side shells, floor grid and pressure bulkhead), including all necessary clips involved in assembly. The clips have undergone an extensive testing campaign to ensure they meet Airbus requirements, and are already flying on the first A350 XWBs delivered to customers.

## Clips and more clips

According to Miaris, the clips can be divided into four general categories: L-shaped, cleat, auto-stabilized and special (for examples, see Step 1, this page). Dimensions for clip types range

> Premium Aerotec realized that its share of the huge clip part count would require … a great deal of flexibility.

from approximately 100 mm up to 800 mm in length (special clips are among the longest), and from 30 mm up to approximately 400 mm in width. As the smallest parts, cleats are considered stabilizing elements — they are mounted on other clips to provide locally higher stiffness at certain attachment locations, he explains.

To meet performance requirements, Premium Aerotec's design engineers specified intermediate-modulus carbon fiber in either a polyphenylene sulfide (PPS) or polyetheretherketone (PEEK) resin matrix. The selected materials were PPS-CETEX semi-finished, pre-consolidated thermoplastic panels manufactured by TenCate Advanced Composites BV (Nijverdal, The Netherlands), reinforced with woven carbon fiber fabrics made with T300 carbon from Toray Industries (Tokyo, Japan). The carbon fiber/PEEK material used is a pre-consolidated Tenax TPCL laminate, also based on woven fabrics and manufactured by Toho Tenax Europe GmbH (Wuppertal, Germany). The panels have a quasi-isotropic layup and are supplied in different thicknesses, ranging from 1 mm to 5 mm, or 5 to 14 fabric plies, depending on attachment location and fuselage load conditions »

1 The A350's clips vary in size and design, from simple L-shapes to more complex shapes, called "auto-stabilized" (upper middle image). The smallest clip shown, termed a "cleat," is typical of stabilizing elements that are mounted on other clips to provide local higher stiffness and structure.

2 The clips are made from carbon/PPS CETEX pre-consolidated panels manufactured by TenCate Advanced Composites, and from carbon/PEEK Tenax TPCL pre-consolidated panels from Toho Tenax Europe. Both are supplied in a range of thicknesses, depending on the clip location and function.

3 The fully automated clip workcell comprises six steps, including cutting, transfer to ovens, transfer to thermoforming press, forming, transfer to trimming, and inspection. Three such cells are now making parts in Bremen.

**4** Blanks are cut on a high-speed, flatbed table cutter of proprietary design. Nesting software minimizes waste, and all waste can be recycled.

**5** A closeup of a laminate blank as it is heated in one of two infrared ovens within the cell. Two ovens keeps the total cycle time lower; the heating step is the longest step, so two blanks can be heated while one is being shaped.

**6** A clip is shown being robotically transferred from a tool in the 125-MT thermoforming press to the trimming station. The second, "slave" robot (visible in the foreground) transfers the correct tools to the press ahead of each heated blank that is transferred by the primary robot from the oven.

**7** The trimming station cuts off booked edges and ensures that the clip's final contour and shape are correct.

**8** In the final step, all parts are inspected using phased-array, pulse-echo ultrasonic equipment. The parts are immersed in a water tank, and following inspection, are marked with an RFID tag for paperless tracking.

Source (all step photos) | Premium Aerotec


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**Small improvements that multiply**

Future technology-development plans include investigation of localized heating and forming strategies, to support production efficiencies. Premium Aerotec also is investigating optimized designs that will incorporate unidirectional carbon fiber/thermoplastic tapes (lower right) for higher performance.

Source | Premium Aerotec

in that area. "The clips' designs were optimized for the lightest possible weight," Miaris explains. "We are using different material thicknesses for different load cases within the fuselage, to try to minimize weight."

Edelmann adds that the higher-strength Tenax carbon fiber/PEEK was specified for clips in fuselage regions where higher loads will be experienced, generally around openings, such as cargo doors and passenger doors.

Premium Aerotec designed and developed an automated thermoforming production cell to meet the production demands. The cell incorporates two robots — one a "master" and the second a "slave" — driven by a sophisticated, proprietary computer process control system that, Miaris explains, is able to calculate workflow and rate based on forecasted OEM assembly demands, for just-in-time part delivery.

> Premium Aerotec now has three fully automated clip production workcells in operation at Bremen.

"The cell has a high degree of automation," he says. "We've kept in mind the principles of high-rate manufacturing to make the work flow smooth, fast and paperless."

To meet Airbus' increasing production, which will be 13 shipsets per month by 2017, two more cells of the same design have been added at Bremen within the past six months, he adds.

Each work cell comprises six steps or functions:

1) Cutting of thermoplastic panels into blanks on a high-speed automated cutting table
2) Robotic transfer of the blanks to one of two infrared ovens for polymer melting (because PEEK and PPS require different melting temperatures)
3) Robotic transfer of the heated blanks from infrared ovens to the thermoforming tool in the press
4) Forming in the thermoforming press
5) Robotic transfer of formed clips to the trimming station for edge trimming (and drilling of holes in some cases)
6) Ultrasonic inspection and part number marking

The master, six-axis robot works four positions approximately every 20 seconds: moving a blank from the cutting table to the oven, taking a heated blank from the oven, moving the heated blank to the press and removing formed clips from the press to the trimming station. The slave robot's role is to quickly change and position the correct forming tools in the press, depending on the type of clip needed. Miaris says that the cell produces clip parts on a "work order" or lot basis, with different clips produced for each order: "We may need 150 of one clip style, and only two of another, for a particular lot."

Edelmann points out that two ovens are used for a shorter cycle time, since the melting process is the most time-consuming task in the system. Thus, two parts are always in the oven as a third is moved to the press.

Blank-cutting occurs on a high-speed, automated flatbed cutting table. A robust milling tool cuts the pre-consolidated panels, and the automated cutting system's software nests the blank shapes for maximum efficiency and minimal waste. The scrapped nesting "skeletons," or leftover cutting waste, are collected for recycling (described below).

As the robot moves a blank from the cutting table to an oven, it immediately transfers an already heated blank from the second oven to the press tool: "The two-oven design allows for different temperatures and helps maintain cycle speed, if material type changes," explains Edelmann.

Meanwhile, the slave robot ensures that the correct forming tools are placed in the 125-MT thermoforming press ahead of the heated blanks. Forming tools are made of tooling steel or aluminum, depending on the part, and are designed in-house for each clip style by Premium Aerotec, but fabricated out-of-house by a tooling supplier. Edelmann adds that the tool-change operation is critical, given the large number of clip designs and sizes.

The master robot removes formed clips from the press and transfers them to the trimming station. Miaris explains that heating and forming of multi-ply thermoplastic material causes the plies to slide relative to each other, in-plane, similar to what happens if you bend a bound book. This "book effect" and the resulting sharp, stepped part edge is unacceptable, he explains, because it causes dimensional inaccuracy and can interfere with proper assembly. The edges are trimmed, therefore, with a milling tool at the trim station to achieve a clean edge that is perpendicular to the reinforcing plies, for final contour.

> The company has built a prototype demonstrator workcell to investigate local heating/forming of clips.

The final step is inspection of all parts, using phased-array, pulse-echo ultrasonic equipment from a European supplier. The semi-automated testing involves immersing parts in a tank for C-scan testing, but Miaris says that a few, more complex clips with joggles are manually inspected, using hand-held A-scan transducers. Tested parts are marked with an identifying radio frequency identification (RFID) tag to enable paperless tracking throughout the fuselage assembly process. Edelman reports that parts cycle through the stations in a mere 85 seconds.

### Continuous improvement

Although the three existing cells continue serial clip production, Premium Aerotec has already determined where improvements can be made. The company is in the process of validating and qualifying new technologies: "We have a good process in place but, nevertheless, that doesn't mean that all of the properties of the thermoplastic matrix are currently being used to the maximum," asserts Miaris. Clips could be lighter, thinner and made still faster.

The company has built a prototype demonstrator workcell to investigate local heating and forming of clips — that is, instead of heating the entire blank prior to thermoforming, a portion of the blank is heated only where the shape change is needed. "Heating the entire blank and forming it works well for small, complicated parts, but it is very inefficient for production of larger, plain parts »

with just locally formed features, such as the L-shaped clips," explains Miaris.

Local forming requires a infrared oven specially designed to heat only the specified region of the blank; robotic handling of the partially softened blanks; and a forming tool and press with positioning features that can locate the heated region correctly for forming. The concept has been extensively trialed, and parts have been tested using carbon fiber/PEEK and carbon fiber/PPS blanks. Adds Miaris: "Mechanical tests of locally formed parts have shown that mechanical properties fulfill the design requirements. And, differential scanning calorimetry [DSC] tests prove that resin crystallinity in the heated and formed region does not deviate from the crystallinity observed in the rest of the part." Additional qualification with Airbus is underway.

In some cases, clips need to have a titanium shim attached, for additional fastener strength. Edelmann explains that at present, the titanium pieces are manually bonded to the clips using an adhesive, which slows the overall production process.

"We want to reduce the labor demand and develop a more cost-effective welding technology," says Miaris. Two methods are under investigation: ultrasonic welding and induction welding. Tests have shown that the faster ultrasonic welding process holds the two materials together with strength adequate to endure handling, drilling and assembly on the shop floor, without damage to either material. Here, too, qualification of the process is pending.

Lastly, Premium Aerotec is investigating alternative reinforcement forms, specifically, unidirectional tapes, to replace woven carbon/thermoplastic panels. The company is working with research partner Fraunhofer ICT (Pfinztal, Germany) to design an automated method to produce custom layups for specific clips. "This would allow us to optimize, in an unrestricted way, the stacking sequence and ply orientation, for maximum design flexibility," explains Miaris. Fraunhofer is developing a thermoplastic uni tape preforming sequence that employs Dieffenbacher's (Eppingen, Germany) Relay automated moving-table layup technology, originally developed by now-defunct Fiberforge (see "Learn More"), to create a flat preform. The preform blank then could be stamp-formed in a thermoforming cell. According to Miaris and Edelmann, tests on stamped uni tape demonstrator

> Investigations into custom uni tape layups have produced clips that outperform semi-finished panel stock.


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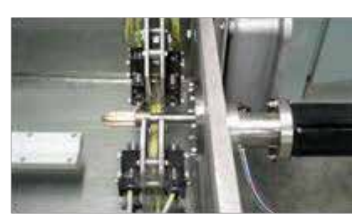

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parts of high complexity have shown that they far surpass the performance possible using the woven carbon fiber-reinforced, semi-finished panel stock, with larger fiber volume fraction (60%, up from 55%) and less than 0.1% void content.

### Sustainable production

Thermoplastic composites also bring to aircraft construction the additional promise of recyclability. Premium Aerotec is testing ways to reuse the scrap generated by the blank-cutting process in a long-fiber thermoplastic molding process. In one test, scrap is chopped and then hammer-milled, with the resulting chips processed with neat PPS in an extruder. The resulting compound was pressed into a clip shape and tested. Flexural strength of the molded clip showed that it retained 85% of the strength of the original carbon/PPS sheet material. Although no details on reuse have been revealed, Premum Aerotec indicates that the promising mechanical test results likely will lead to development of a secondary process.

"The challenge is to further expand the use of thermoplastics in the aerospace industry," concludes Miaris. "In order to achieve that goal, new technologies are needed." Thermoplastic composite parts certainly present attractive options in aircraft production, and Airbus has proven for several years — starting with thermoplastic wing structures on the A380 (see "Learn More") — that it is willing to apply this material in many new and interesting ways. Ongoing innovation of the type envisioned by Premium Aerotec appears to promise an increased profile for thermoplastic composites for many years to come. CW

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For background on the RELAY automated tape-laying system, see the following, online:

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

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

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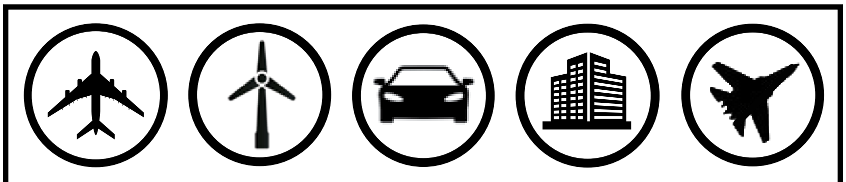

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SPE Automotive Composites Conference and Exhibition (ACCE)
www.speautomotive.com/comp.htm

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SpeedNews 16th Annual Aviation Industry Suppliers Conference
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**Sept. 15-17, 2015 — Louisville, KY, US**
IBEX 2015
www.ibexshow.com

**Sept. 15-17, 2015 — Amiens, France**
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www.sampe-europe.org

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HUSUM Wind 2015
www.husumwind.com/content/en/start/welcome-2015.php

**Sept. 21-22, 2015 — Stuttgart, Germany**
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www.avk-tv.de/events.php?page=&year=2015&month=09

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Composites Europe
www.composites-europe.com/startseite_1.html?sprache=englisch

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CAMX – The Composites and Advanced Materials Expo
www.thecamx.org

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# ARMORED-VEHICLE AND RAPID-TRANSIT PODS

## Composite crew/passenger compartments drop vehicle weight but boost functionality

Source (all photos) | Morgan Advanced Materials

› Drawing on 40 years of materials and engineering expertise, Morgan Advanced Materials (Morgan, Windsor, UK) has designed and produced a custom crew compartment for Mumbai-based Tata Motors' Light Armored Multipurpose Vehicle (LAMV) for the Indian Ministry of Defense. The composite-and-ceramic pod cuts vehicle weight by 1000 kg. The pod is 50% lighter than equivalent steel armor, yet defeats a wide range of modern battlefield threats.

"This is a new variant on our proven CAMAC technology, which has been developed over the past 20 years and is used widely in the UK," says lead engineer Mike Sandercott. Ballistic-grade, fiber-reinforced thermoset composite panels in combination with a ceramic armor strike face enables a modular monocoque construction that permits users to easily upgrade or downgrade the vehicle's armor as its threat environment changes. The prepreg panels are precision-molded in shapes to match individual vehicle configurations. "They are cured on composite tools and bonded with an aerospace-grade adhesive," says Sandercott, "and though the technology is similar to that used on our aerospace and motorsports parts, the assemblies are very large." For example, the LAMV crew compartment measures 2.5m long by 1.4m tall by 2.1m wide, roughly the same as that on the US military's *Humvee*.

The bonding minimizes joint lines for a stronger structure and more repellent surface. He adds, "We encapsulate the ceramic strike face in a Morgan proprietary way to enable multi-hit capability, an improvement we've implemented in the LAMV."

The blast and ballistic-resistant CAMAC monocoque pods provide customized armored composite crew compartments for reconnaissance, tactical and special forces vehicles. They are detachable and, thus, easily integrated into customer-produced chassis, and they also are easily modified. Meanwhile, the weight savings CAMAC offers enables transport of more gear and/or better fuel economy as well as less vehicle wear.

Morgan designs and manufactures composite structures for the aerospace, defense, medical, motorsports and transportation industries, including the recent composite pod for the Personal Rapid Transit (PRT) vehicle used in South Korea's Suncheon Bay, a coastal wetland that requires a tourist transportation system with minimal environmental impact. Morgan was tasked by the pod's designer to develop a one-piece, structural frame with an integrated, 9m-circumference door surround, which would be rigid, lightweight and flexible. Morgan developed advanced "blown tube" techniques to create hollow composites with integrated stiffening ribs, all molded in a single curing process. Drawing on this experience, Morgan recommended a carbon fiber core comprising woven materials structured in two directions, for flexibility and ease of surface finishing, and unidirectional materials, optimizing the structure for a range of load cases. The component was autoclave-cured using phenolic resin for fire resistance and is now part of the pod used to transport an estimated 3 million tourists annually. CW

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DATE AND TIME:
**May 13, 2015 • 2:00 PM EST**

PRESENTER

JOHN O'CONNOR
Director, Product and Market Strategy, Aerospace and Defense, Specialized Engineering

## Collaborative Design of Advanced Aerostructures: Optimizing Composite Designs for Manufacturability and Performance

### EVENT DESCRIPTION:

To speed the overall development process while enabling lower costs and higher rate production, aerospace companies are turning to new technologies to optimize designs for performance and manufacturability. In this webinar, John O'Connor will discuss best practices in the Aerospace industry for composite design, and provide an overview of technology that is making it faster to design composite parts and enable rapid optimization cycles. Join us as we discuss the latest engineering software to efficiently engineer composite products and manage the complexities of mixed material assemblies, and how you can use Siemens PLM Fibersim and Syncrofit solution to support the composite engineering process.

### PARTICIPANTS WILL LEARN:

- Understanding best practices of composite design and engineering in the aerospace industry
- Industry trends related to engineering and design of composites and mixed material assemblies
- How technology can support the optimization of designs for performance and manufacturability
- Introduction to Siemens PLM Fibersim and Syncrofit software

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# POLYAMIDE IMPROVES IMPELLER PERFORMANCE

## Direct-to-milled-tool process simplifies large deck mold development


Source | BASF

Although there will always be a place for metals in industrial fans and fan blades, there are compelling advantages to using a reinforced engineering plastic when the manufacturing goals include reducing the cost of balanced, complex airfoil shapes; weight reduction; better corrosion resistance; and noise/vibration damping. Axial fan/impeller manufacturer Multi-Wing International A/S (Vedbaek, Denmark), founded in 1938, was on board with composite designs as early as 1958, when a cousin of the firm's founder developed an thermoplastic axial fan concept — essentially a propeller inside a pipe that pushes air or water parallel to the impeller's shaft.

According to Multi-Wing's development manager Victor Silbermann, axial fans are subjected to high speeds, undesirable natural oscillations and vibrations. Further, the fans need to absorb impact and shock energy at temperatures as low as -30°C without breaking, and perform at high temperatures as well, without excessive creep.

The firm was on the lookout for an improved thermoplastic that could deliver the performance it needed for the circular hubs of its new mixed-flow cooling fan design for the engines of heavy construction equipment. The circular hubs fit onto the impeller axes to transfer rotational motion to the fan blades. Working in partnership with **BASF AG** (Ludwigshafen, Germany), Multi-Wing began trials on a new BASF long-glass fiber-reinforced polyamide formulation, trademarked Ultramid Structure LFX (B3WG10 LFX) with high weld strength and good creep resistance, for the hubs. The new, injection molded polyamide system reportedly improves resin/fiber interfacial bond strength, which results, says BASF, in a more stable fiber "skeleton."

Ultramid Structure LFX reportedly withstands extreme stresses and, thus, can provide protection against damage and excessive deformation of the plastic, says Silbermann, as demonstrated by high notched-impact strength test results. "In numerous tests we have found that the material can withstand extreme centrifugal forces. The stable fiber network makes it ideal for heavy loads and, therefore, a good alternative to metals in the production of our hubs."

Working closely with BASF throughout the development phase has enabled the company to continuously optimize its molding processes and molds, as well. Ultramid Structure LFX is easy to process, claims BASF's Andre Schäfer, involved in applications development for engineering plastics: "We have optimized the material's properties to such an extent that the plastic has proved a good investment in a number of client projects." CW

# MASSIVE, BONDLINE-FREE TOOLING BLOCK

## A candidate for the biggest "bun" from high-density urethane foam?


Source | Coastal Enterprises

Tooling board manufacturer **Coastal Enterprises** (Orange, CA, US) is certainly used to producing foam for use as composite layup tooling (see short.compositesworld.com/HDPUblock). Typically, the company manufactures blocks of Precision Board high-density urethane tooling foam and bonds them together to form a rough tool shape as directed by the customer, which then machines the bonded assembly to its specs. However, a recent aerospace customer, Ascent Tooling Group's Coast Composites (Irvine, CA, US), needed a large foam tool for a project, and because the tool would be autoclaved at elevated temperature, Ascent wanted *no bond lines* in the foam that might impact uniform heating.

Coastal's president Chuck Miller says, "We had to produce a 1.5m by 3m by 300 mm thick monolithic foam block, at a specified density of 1.2 kg/liter, which was a pretty big deal." Why such a big deal? According to Miller, this block may be the largest ever made, at that size and density.

Although Coastal won't reveal its exact recipe for producing its foam "buns," or blocks, Miller does say that the large PBHT-75 high-temperature-capable foam block, which included a number of proprietary additives, took a great deal of planning and preparation before the final mixture could be injected into the rectangular metal mold. The injection and reaction process was followed by a controlled cure and postcure. Key to the process, says Miller, is knowing how to successfully control the foam's reactivity profile and the exotherm generated during the pour and cure process.

Coast Composites recently took delivery of the 1,180-kg tooling block, and is currently machining it to final profile. "We are seeing the composites industry going more towards bigger tooling," concludes Miller, "and we're going along with it." CW

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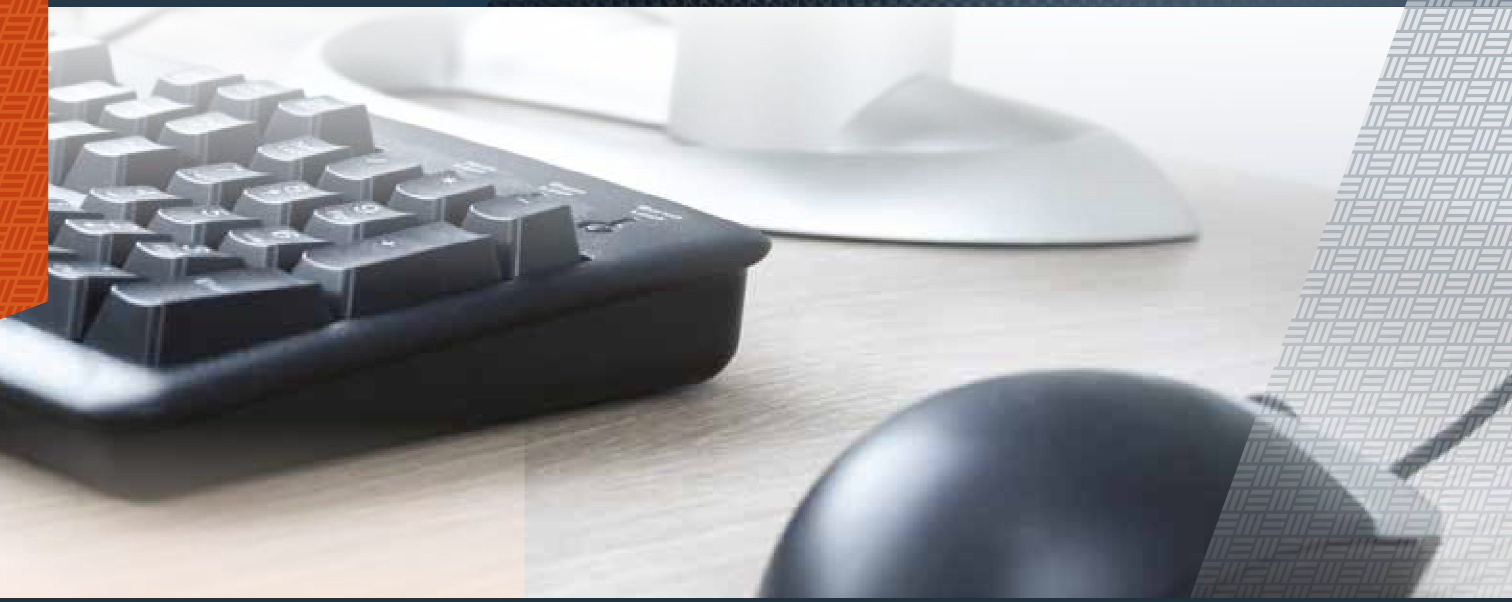

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DATE AND TIME:
**May 28, 2015 • 2:00 PM EST**

PRESENTER

DOUG KENIK
Product Line Manager
for Simulation

## Automotive Lightweighting using Advanced Materials

### EVENT DESCRIPTION:

Automotive lightweighting is a hot topic throughout the automotive industry, as OEMs accelerate efforts to comply with the Corporate Average Fuel Economy (CAFE) standards by the 2025 deadline. Composite materials offer an opportunity to significantly reduce the weight of a vehicle while still meeting strength requirements. In order to explore lightweighting opportunities with advanced materials, simulation is essential. However, because of the construction of these materials, you must use the manufacturing process to drive material properties to get accurate structural simulation results. Using Autodesk® Moldflow® and Autodesk® Helius PFA you can bridge the gap between manufacturing simulations and structural simulations.

### PARTICIPANTS WILL LEARN:

- How to determine fiber orientations with Autodesk Moldflow
- The nonlinear material behavior of as-manufactured materials
- Mapping as-manufactured properties for structural simulations
- Completing structural simulations of fiber reinforced plastic parts

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# In Depth: Dark Matter Composites

By Peggy Malnati / Contributing Writer

» REPAIR AND MAINTENANCE EQUIPMENT

## Field repair: Step-sanding tool kit and more

### Onsite repair kit

Field repair of damaged composite parts can be time-consuming, and success often depends not only on the repair technician's skill and experience but also on the effectiveness of the tools at hand. This off-the-shelf step-sander kit, assembled by Dark Matter Composites Ltd. (Redbourn, Hertfordshire, UK), promises to speed composite repairs and improve their quality and consistency. Source | Dark Matter Composites Ltd.

Onsite repairs to damaged composite parts, historically, have involved a time-consuming process, the success of which depends on the skill and experience of the repair technician and the availability of suitable tools. The need to make repairs to critical structures, such as composite aircraft wing/fuselage skins and auto body panels, has stimulated much research into and development of repair techniques and the tools they require. One result of these efforts is a new off-the-shelf step-sander tool kit available from composites training and consultancy company Dark Matter Composites Ltd. (Redbourn, Hertfordshire, UK).

Reportedly useful not only for the aerospace sector but also other sectors served by composites manufacturers (e.g., civil infrastructure, marine and automotive), the kit is designed to reduce the time required for, and improve the quality of, composite repairs and is intended to aid both experienced and novice technicians. Its use is said to simplify material discovery (identification of the layup sequence via removal of a small amount of material) and subsequent repair work on a variety of gel-coated, chopped strand, unidirectional, stitched or woven composite mats (with or without veils) and thermoset or thermoplastic matrices.

The company claims that when the kit's tools are combined with an appropriate dust-extraction system, removal of dust generated at the point of source is so complete that it eliminates the need for technicians to wear dust masks during surface preparation and saves the time required to set up containment curtains. Further, it reduces the risk that carbon dust abraded from carbon fiber-reinforced composites will become airborne and short out nearby electrical equipment and circuitry. "Imagine destroying a car's electrical system while trying to repair a damaged body panel," says Rodney Hansen, managing director, Dark Matter Composites. "Such a possibility was the main reason we developed this kit. We wanted the best extraction tool available for use in our own repair courses to mitigate just this type of risk." »

### What's Inside?

The standard step-sanding kit includes the following:

- Dynabrade 51333 air router
- 6.35-mm Dynaswivel and Hi-Flow air-line connection
- 31.8-mm swivel high-vacuum extraction connection
- Set of four diamond-tipped planing/cutting heads (grit sizes: 36/44, 44/60, 60/85 and 85/100)
- Small-diameter circular routing jig for 40- to 160-mm diameter repair surfaces
- Flexible, small-radius arm jig for 150- to 610-mm diameter repair surfaces
- Flexible, large-radius arm jig for 150- to 1,220-mm diameter repair surfaces
- Set of 10 reusable jig datum points (four of Type A and six of Type B)
- 3M (St. Paul, Minn.) VHB self-adhesive pads (pack of 100)
- Pen insert and compass center for marking parts and materials
- A full set of Allen wrenches/keys, spanners, and a screwdriver for assembly and kit adjustment
- A full-color, printed user's manual

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The **SPE ACCE** draws over 900 attendees from 15 countries on 5 continents who are interested in learning about the latest composites technologies. Fully a third of attendees work for a transportation OEM, and roughly a fifth work for a tier integrator. Few conferences of any size offer such an engaged, global audience vitally interested in hearing the latest composites advances. Interested in presenting your latest research? Abstracts are due **March 31, 2015** and Papers on **May 29, 2015** to allow time for peer review. E-mail abstracts or papers to ACCEpapers@speautomotive.com. Approved papers will be accessible to attendees on a cloud-based server and later will be available to the general public.

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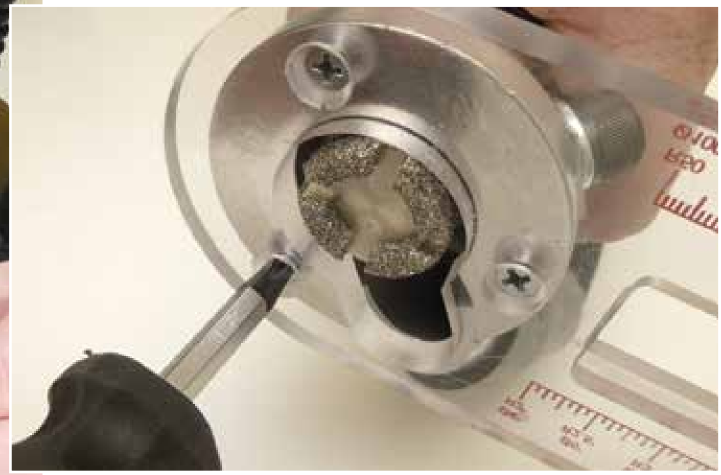


### Optimizing sanding and dust extraction

The kit's Dynabrade air router, modified to Dark Matter specifications, comes with four diamond-tipped planer heads (above), each featuring different a grit level, from coarse to fine. When paired with an appropriate dust-extraction system (left), it reportedly removes dust generated at the point of source so effectively that containment curtains and dust masks are unnecessary.

Source | Dark Matter Composites Ltd.

Dark Matter worked with a number of equipment suppliers to modify existing tools to make them better suited for composite repairs. One result was a modified Dynabrade air router (Dynabrade Europe Sàrl, Wormeldange-Haut, Luxembourg) with special diamond-tipped planing heads. The router can accommodate a portable dust-extraction unit.

The air router is used in combination with a versatile system of moveable jigs to make *step-sanded* repairs to composite surfaces — even those with internal and external double curvature — faster and more accurately than standard scarf repairs can be made. Scarfing, or tapered sanding, is a common method of removing damaged material from a composite surface via a high-speed grinder, prior to bonding in a repair patch. Step sanding is an alternative method of material removal that is generally considered the superior technique for structural repairs, but also is more difficult and requires greater skill.

The equipment in the tool kit has been selected to facilitate abrasion of vertical and horizontal surfaces while capturing dust at the source. The system reportedly enables repair surface preparation on damaged areas up to 1,220 mm in diameter, in step increments as small as 1 mm and depth increments as accurate as ±0.05 mm. The kit comes standard with four diamond planing heads in four grit levels for removal of a range of thermoset composite materials from coarse to fine. For thermoplastic composites, the kit's standard diamond-tipped planers can be replaced with planers that use conventional abrasives, which are better suited to those polymers.

All kit components fit into a foam-lined insert in a Dynabrade case complete with Dark Matter Composites nameplate and serial number (see "What's Inside," on p. 82). The router itself enables depth adjustments in increments of 0.05 mm via pointers and laser-engraved scales in metric and

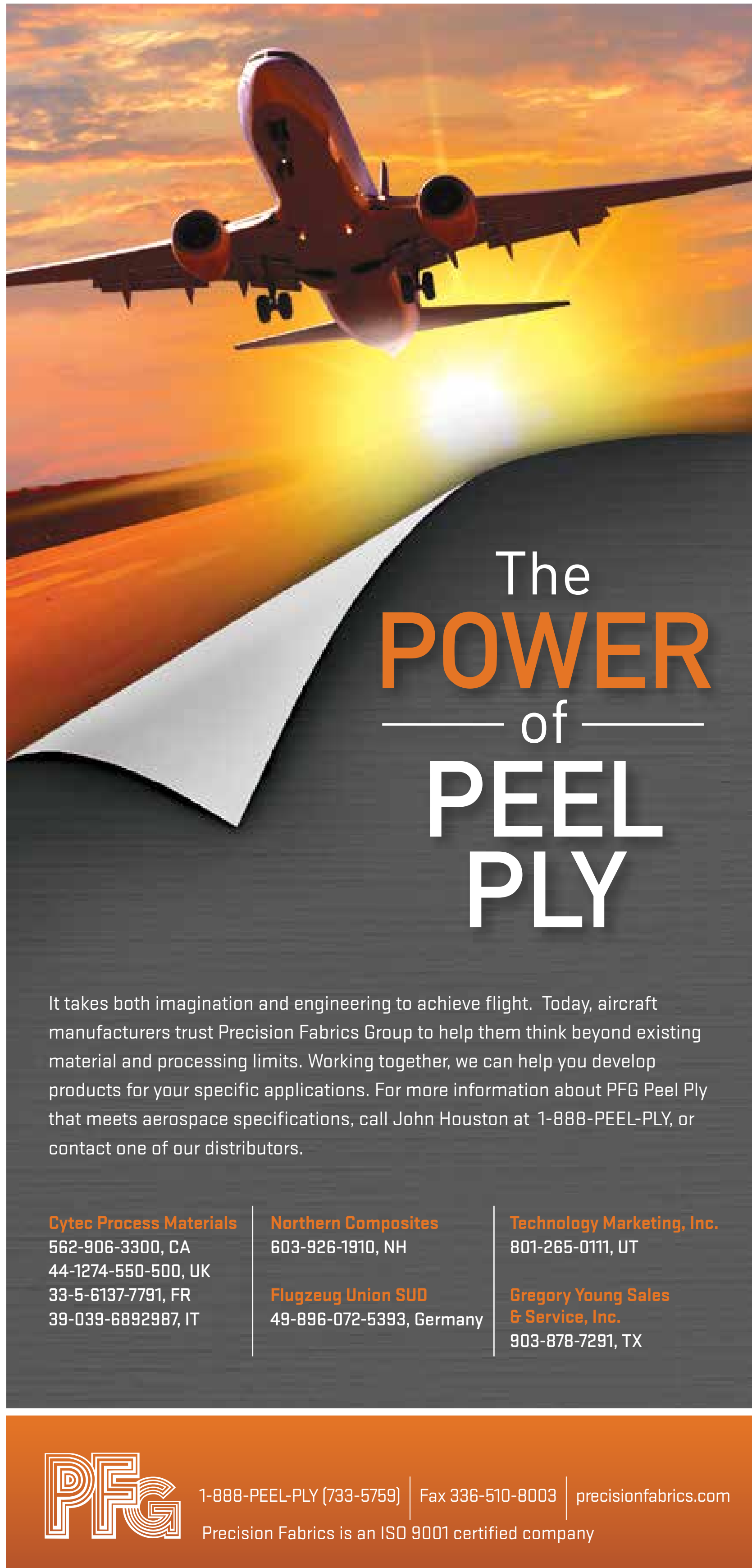
imperial units. All jigs are adjustable in 1-mm increments (also with scale pointers and laser-engraved scales in metric and imperial units for radii and diameters).

Two types of portable dust-extraction systems (one electric-powered and compatible with carbon fiber dust, the other air-powered for use in hazardous areas, such as when fuel is present, both equipped with boom arms) are available for use with the kit. And Hansen says that when the kit is combined with nondestructive testing (NDT) technologies like the DolphiCam ultrasonic camera system (produced by DolphiTech AS, Raufoss, Norway), the use of "standard" repair patches is viable and can even eliminate discovery activities. "We've also demonstrated that the use of temporary repair tooling and pressure-debulked standard repair patches can improve the quality of a repair. The composites industry is currently on the cusp of having much simpler repair processes that will benefit all."

The company claims that skilled users can make structurally superior step-sanded repairs to composite parts in one-half to as little as *one-quarter* the time required with current practices, and further claims that even novice technicians can save time and, more importantly, achieve consistent, repeatable results. Time savings can lead to significant reductions in the cost of *in-situ* repairs, a topic that will become more important as more composites are used in structural applications in other markets — for example, the automotive industry.

To enable user success with the kit, Dark Matter also offers, beyond its printed user's manual, nine videos (supplied on a USB drive with the kit and available free on its Web site). They demonstrate important steps in setting up the system, adjusting it and using it for material removal and identification. In addition, the organization offers two-day training courses on tool-kit use at its UK facility. The small classes (class size is limited to a maximum of eight students) are described as 30% instruction and 70% hands-on experience and are open even to those with no prior experience in composites repair. Dark Matter Composites also is working on a smaller version of the kit that can be used on more intricate surfaces with greater curvature.

**www.darkmattercomposites.com | www.dynabrade.com | www.dolphitech.com**

# JEC Europe 2015 Product Showcase

***CW* staff members saw much that was new in Paris. Here's a sampling of what they found.**

» COMPOSITE MATERIALS

## Reinforced thermoplastics/ thermosets

**TenCate Advanced Composites** (Almelo, The Netherlands) launched new products across its composite materials portfolios:

- TenCate CETEX TC1320 PEKK — a new thermoplastic composite aimed at commercial aircraft applications, ranging from structural components to interiors. TenCate says high-grade TenCate CETEX features flame retardancy, low moisture uptake, excellent resistance to solvents and outstanding toughness for impact resistance.
- TenCate CETEX TC912 — a PA6 thermoplastic for a range of structural and semi-structural, high-volume automotive applications, offering improved mechanical properties and tailored fabric architecture, available in both woven and UD reinforcements.
- TenCate E760 — a highly toughened epoxy resin system with exceptional high-temperature performance, designed for use in mechanically demanding structural applications exposed to elevated temperatures, such as Formula 1 and other high-performance automotive applications.

www.tencate.com

» PREIMPREGNATED MATERIALS

## Carbon/glass towpregs & prepregs

**SGL Carbon Group – The Carbon Co.** (Wiesbaden, Germany) showed for the first time its pre-impregnated SIGRAPREG TowPregs: fiber bundles made from carbon or glass, with reportedly excellent winding behavior and constant width. Said to be especially suitable for challenging winding and layup processes, the towpregs not only give components very good mechanical properties but also permit much more uniform layup. Towpregs offer advantages over standard wet winding, SGL contends, by saving customers time and money, while at the same time providing benefits in terms of health, safety and environmental protection.

Also highlighted was a SIGRAPREG prepreg with a newly developed transparent resin system, suitable for visible components in the automotive and other sectors. Its use in combination with SGL's SIGRATEX design fabric reportedly produces components with extremely high surface quality and a stylish appearance.

www.sglgroup.com

» FLOW-ANALYSIS EQUIPMENT

## Measuring fabric impregnation in three dimensions

**PPE** (Saint-Avold, France) offered live demonstrations to JEC Europe 2015 attendees of its EASYPERM technology, introduced at JEC Asia late in 2014. The system measures and then evaluates the ability of a fibrous reinforcement to allow resin flow, and characterizes that ability in three dimensions. PPE says EASYPERM is the only system currently on the market that offers an industrial-grade solution for measuring the permeability of a dry reinforcement by a liquid resin in both the through-thickness (z) and in-plane (x, y) dimensions. EASYPERM is said to be a reliable quality-control system because it relies on pressure measurement recorded automatically via a network of sensors (it is not affected by variables that might be introduced via human input). The sensor data is then post-processed using Darcy's law. EASYPERM's configuration also allows a visual check of the flow front. The system received the 2015 JEC Innovation Award in the "Laboratory Equipment" category.

www.ppe-composites.fr

» RESIN SYSTEMS TECHNOLOGY

## Epoxy for AFP of aerospace primary structure

**Park Electrochemical Corp.** (Melville, NY, US) introduced a new, toughened 177°C-cure epoxy resin aimed at automated fiber placement (AFP) processing. E-752-LT is designed for aerospace primary and secondary structural applications and is available in standard- and intermediate-modulus, precision-slit tapes and fabrics. It has been formulated to optimize efficient, high-volume AFP processing, says the company, with a controlled rheology specifically formulated for a wide range of cure methods (e.g., autoclave and press cure), while delivering as low as <1% void content. It provides a combination of toughness, low moisture absorption and good mechanical properties, with a dry $T_g$ of 220°C and wet $T_g$ of 157°C.

www.parklectro.com

» RESIN SYSTEMS TECHNOLOGY

## UV-curable, styrene-free, low-shrinkage and/or cobalt-free

**DSM Composite Resins AG** (Schaffhausen, Switzerland) premiered Beyone 120-Q-01, a styrene-free vinyl ester resin for filament winding applications, which contains photoinitiators to facilitate UV-light curing. It reportedly easily wets out glass fibers and cures quickly by application of low-energy UV-light (365-420 nm) or with appropriate conventional curing agents. The resulting composite laminates are said to be strong and can be used in demanding applications, such as gas pipes for trenchless horizontal drilling installation. The styrene-free formulation can contribute to a better environment for workers and reduce the need for costly ventilation and emission-control equipment.

For electrical and transportation market components that are often unpainted, DSM's Beyone 820-H-01 low-shrinkage additive for sheet molding compound (SMC) formulations reportedly combines a low-shrinkage feature with excellent pigmentability. The additive is said to be unique in that it enables "zero" shrinkage during cure in combination with homogeneous pigmentation and is, therefore, ideal for components that must have color without a painting step. Further, the parts are strong and resistant to mechanical impact. "Zero" shrinkage minimizes warpage, ensures dimensional consistency and, thus, better fit during final assembly. For OEMs and designers, part design is eased, because the impact of shrinkage during cure on part dimensions is minimal. Formulations with the additive feature lower viscosity and, thus, easier fiber impregnation, improving mechanical properties and flow control during SMC processing.

A third product addresses the risk of future reclassification of cobalt carboxylates as hazardous. DSM's novel Beyone cobalt-free product line of pre-accelerated resins for hand lay-up and spray-up applications is formulated to provide customers a sustainable cobalt-free resin system that provides desirable end-use performance and processing characteristics. The product series is based on trademarked BluCure Technology. The new Beyone 170, 177 and 185 resin series are based on Ortho, DCPD and vinyl ester chemistries, respectively. Resins are available for a broad range of applications with different levels of reactivity.

**www.dsmcompositeresins.com**

» COLORMATCHING SERVICES

## Fully automated gel coat tinting/matching

**Scott Bader** (Wollaston, UK) featured the Spanish *Ariane 3 Moto3* World Championship racing motorcycle in its booth, with its Crystic gel-coated and vacuum-infused carbon fiber Crestapol 1250LV resin composite body panel parts, bonded with Crestabond structural adhesive. New for 2015 was GelTint, a new, fully automated, high-speed gel coat volumetric tinting and color matching service, developed by Scott Bader's R&D group. This new gel coat service is able to rapidly fulfill orders in 20-kg batches for a pigmented gel coat from the full RAL color range, with the new tinting system also able to color match to order from a suitable sample provided. The new volumetric tinting system reportedly can pigment any gel coat base resin to a high level of batch-to-batch consistency; brush and spray grades are offered across the Crystic gel coat range. Currently, the GelTint service is only available to UK customers, but plans are in place to extend the service more locally across Europe and beyond, later in the year.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» PRESS MOLDING SYSTEMS

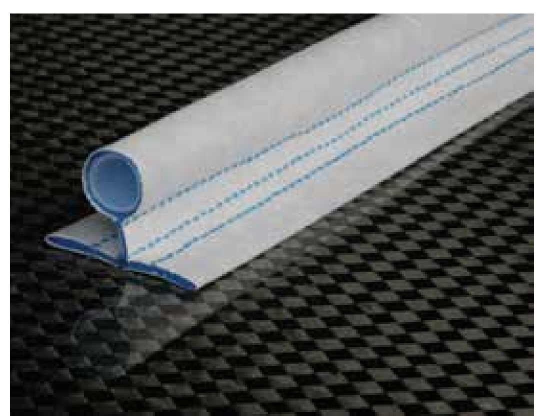
## Compression molding for thermoplastic or thermoset composites

**Dieffenbacher** (Eppingen, Germany) introduced a new series of presses, called Compress Lite, for cost-effective production. Available in both upstroke and short-stroke design, in addition to down-stroke, the Lite press has an energy-saving drive, high-precision parallel-run behavior, and ease of access on all four sides of the press, for faster die changes using moving bolsters. Compress Lite is designed for pressing fiber-reinforced thermoplastics as well as thermosets. It is available in press forces from 4,000 to 12,500 kN, and complements Dieffenbacher's existing Compress Plus and Compress Eco series.
www.dieffenbacher.com


» RESIN INFUSION TECHNOLOGY

## New resin feed line integrates spiral tube and flow media

**DD-Compound** (Ibbenbüren, Germany) has developed its Blade Runner resin feed line for vacuum infusion processing (resin infusion) to help achieve better part quality with a "perfect" surface: No print-through, fewer voids and easy handling. Blade Runner replaces spiral tube or omega-profile channel feed lines on the part during infusion setup. DD-Compound claims Blade Runner is easier to place and fix than other feed lines due to its more stable construction, which integrates a spiral tube, a type of fleece and two different flow media. The new product's design reportedly maintains enough distance from the part surface that it does not leave any print and minimizes air impacts especially in the area where the resin feed line is placed. Claimed results include higher molded part quality and improved part structural properties, a reduction in the hours and corresponding costs devoted to molding process setup, and less cost in the labor and materials necessary to perfect the surface finish after infusion and cure.



Blade Runner is said to be suitable for all parts produced using vacuum infusion, including prototypes, small series, batch production and molds/tooling. Developed for large and long parts (e.g., boat hulls and wind turbine rotor blades), it also is expected to find application in the automotive, aerospace and recreational/sporting goods sectors.
www.dd-compound.com

» RESIN SYSTEMS TECHNOLOGY

### Laminating resins, binders and bonding pastes

**Hexion Inc.** (formerly Momentive Specialty Chemicals, Columbus, OH, US), introduced several new composite resin systems and showcased composite automotive, aerospace and railcar parts made with Hexion systems. For the automotive industry, Hexion introduced an epoxy system specially designed for structural components, with a 60-second injection-and-cure cycle and enhanced demolding properties, compared to predecessor systems. EPIKOTE TRAC 06170 epoxy and EPIKURE TRAC 06170 curing agent were formulated for larger automotive structural components, which present different challenges than smaller composite parts. Hexion, therefore, has optimized the system's chemistry to maintain the resin injection window necessary for larger parts while reducing the cure cycle duration. The resin infusion system is compatible with a new, fully crosslinkable preform binder from Hexion, EPIKOTE TRAC 06270, which is applied during fiber layup to fix the fibers in the shape of the composite and avoid displacement during infusion.

Also new is EPIKOTE MGS PR685, a epoxy-based, spray-applied binder for securing reinforcements in molds, particularly for the manufacture of large wind turbine blades. Hexion says the binder is compatible with RTM and RIM processes and dissolves into the final resin matrix and, thus, participates in matrix crosslinkage. It does not, says the company, adversely affect the mechanical properties of the final composite product.

Also for the wind energy industry is a new bonding paste, EPIKOTE MGS resin BP 535/EPIKURE MGS curing agent BPH 538, designed specifically for the manufacture of long turbine blades, which require longer processing time. Hexion says this bonding paste will not form a film until after four hours or more of open time, even at 70% relative humidity. Other features include good fatigue performance, good sag resistance, minimal bleeding from vertical gaps, long pot life and low exotherm. It also can be used in marine, sporting goods and mold manufacturing applications.

**www.hexion.com**

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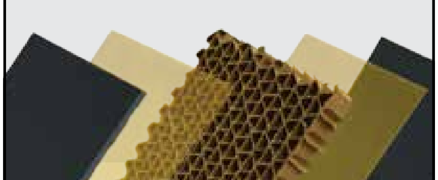
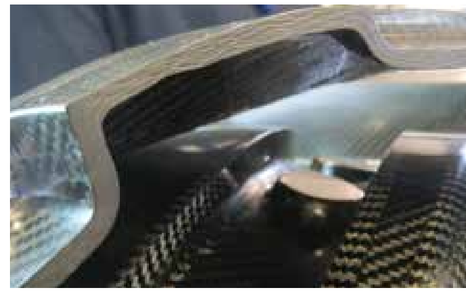


» TOOLING MATERIALS

## Epoxy, BMI fabric prepreg "tiles"

**Cytec Industries Inc.** (Woodland Park, NJ, US) launched new epoxy and bismaleimide (BMI) versions of its DForm (Deformable Composite System) fabric tooling prepreg. DForm is a prepreg format that combines short-fiber conformability with the handling and laminate characteristics of a conventional long-fiber composite. For the new epoxy and BMI versions of DForm, Cytec is manufacturing the fabric in multi-ply "tiles." The epoxy version is available in two tile types, one with two layers of 3K carbon fiber twill and four layers of 12K carbon fiber twill; the other epoxy tile type is composed of just four layers of 12K carbon fiber twill. The BMI version is available in one tile type, composed of eight layers of 6K carbon fiber twill. Cytec says a typical tool will use two layers of tiles, with an autoclave debulk between tile layers. The tiles, Cytec points out, allow a tool to be layed up faster with fewer debulk cycles, thereby saving costs associated with labor and time. Further, Cytec officials said the material, because of its easy conformability, does not need to be laboriously pushed into female tool details. As a result, Cytec says labor savings using the new DForm tiles, compared to a traditional 10-ply epoxy layup, are about 80%. Compared to a traditional 16-ply BMI layup, labor savings are about 87%, says Cytec.



DForm deformation characteristics are achieved through selective fiber slitting of a fabric prepreg. Cytec selectively slits the material in a discrete pattern, with the slits at a 45° angle to the axis of the tape. Each slit or cut is approximately 50 mm long, effectively creating a web of discontinuous fibers. The prepreg tape retains its overall integrity and fiber alignment, but the slits allow intraply movement. When the tape is layed up, the slits open slightly, allowing stretch and conformability while good strength is maintained. Cytec notes that abutting tiles can be chamfered and reports that the material's conformability greatly reduces the risk of bridging. DForm currently ships from Cytec's plant in Tulsa, OK, US, and eventually will be available from its Heanor, UK, facility as well.

www.cytec.com/dform

» HIGH-TEMPERATURE MATERIALS

## RTM resin, honeycomb for jet engines

**Hexcel** (Stamford, CT, US) showcased a new RTM resin, HexFlow RTM230 ST, that it says performs at high temperatures with superior toughness and has excellent high-rate impact resistance. The resin is said to be particularly suitable for jet-engine components, such as fan blades and fan cases, spacers and outlet guide vanes. Matching the current market leader in terms of high in-plane and impact performance with good long-term thermal stability, HexFlow RTM230 ST is reportedly easier to process, having a 45-minute injection window. In addition, the system, Hexcel says, demonstrates outstanding resistance to aggressive fluids, including commonly used solvents and aviation fuel.

Hexcel says it was the first company to manufacture honeycomb on a commercial scale more than 60 years ago. At JEC Europe 2015, Hexcel launched HexSHIELD, a honeycomb designed to provide high-temperature resistance in aircraft engine nacelles. By inserting a thermally resistant material into its honeycomb cells, Hexcel provides a core product with unique heat-shielding capabilities, which allow for the potential re-use of material after a fire at 1093°C. The product builds on Hexcel's long history of heat-resistant honeycombs, including HexWeb HRH-327, with temperature resistance up to 260°C. HexSHIELD combines the structural and formable benefits of honeycomb with thermal-resistance performance and can be combined with various facing materials, making it tailorable to customer needs.

www.hexcel.com

» FIBER REINFORCEMENTS

## Noncrimp fabric-and-core combinations

**Saertex GmbH & Co. KG** (Saerbeck, Germany) offered several new products, among them SAERTEX LEO, a composite system of noncrimp fabric layers and customized core that meets the highest fire safety standards (IMO FTP, Part 2, Part 5) for the offshore energy, marine and mass transit sectors. The company also is developing its 3D fabrics, made with "endless" fibers in the z-direction that help resist delamination; fabrics are available in thicknesses of 1.5 and 3 mm. In addition, 3D "billets" or fabric blanks up to 50 mm in thickness can be produced for high-production-rate applications that demand very high mechanical performance.
www.saertex.com

» THERMALLY CONDUCTIVE MATERIALS

## Carbon/glass fiber-based flexible heating fabrics

**LaminaHeat LLC** (Greenville, SC, US) introduced PowerFabric, a new addition to its line of thin, flexible heating materials. Made from the same lightweight and homogeneous carbon fiber/glass veil with copper contact strips that is used in its original PowerFilm product, PowerFabric sandwiches this heating technology between woven fabrics, giving the resulting product improved flexibility and broader application potential. Using a standard fiberglass mat on either side enables the new PowerFabric heating technology to not only add heat where it is needed but also to add structural reinforcement. As is done with the company's PowerFilm, current is applied to the copper strips of the PowerFabric to generate evenly distributed and localized heat across the fiber sheet at required temperatures that can range as high as 300°C. PowerFabric is produced in a proprietary, continuous process and can employ various woven fabrics and finishing options that offer manufacturers the ability to incorporate PowerFabric into their products during fabrication. PowerFabric can be provided in options based on the types of fabrics and fibers needed and/or the electrical properties required, comes in continuous rolls or individual sheets, and can be tailored to fit specific customer applications.
www.laminaheat.com


» FIBER REINFORCEMENTS

## Biaxial carbon fiber fabrics for structural parts

**FORMAX** (Leicester, UK) put the emphasis on its new range of biaxial fabrics made from intermediate-modulus carbon fiber for motorsports (see photo) and sporting goods manufacturers. The -45°/+45° biaxials have been developed for the manufacture of structural composite parts in the motorsports industry. Compared with the woven fabrics currently used in these applications, which are mainly made from 3K/6K tow intermediate-modulus carbon fibers, the FORMAX multiaxial fabrics use 24K intermediate modulus fiber and, therefore, offer material cost savings. Typically available in weights of 200 $g/m^2$ and 300 $g/m^2$, the new biaxial fabrics can be used for prepreg, resin transfer molding (RTM), infusion and wet layup composite processes. FORMAX also says that its fiber-spreading technology enables the company to work with a range of fiber types from 3K through 50K, from all the main carbon fiber suppliers, including PAN- and pitch-based carbon fibers.

www.formax.co.uk

» FIBER REINFORCEMENTS

## Application-optimized roving and chopped strand

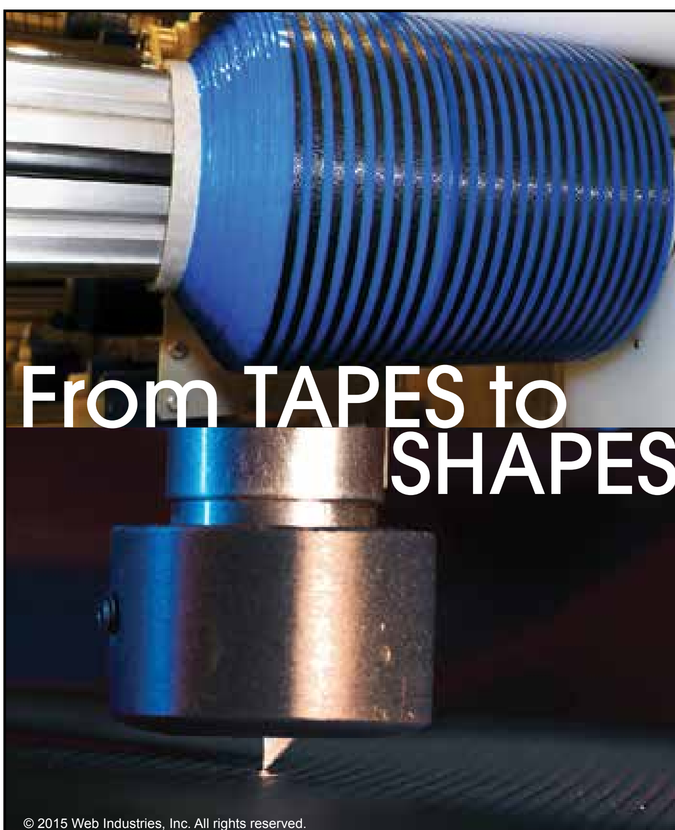
**Owens Corning** (Toledo, OH, US) launched five new products at the JEC Europe show. These included PulStrand 4100 single-end roving for pultrusion, compatible with polyester, vinyl ester, epoxy and polyurethane resin systems. Compared to competitive glass fibers, the new roving reportedly offers superior processing qualities, with higher flexural and ultimate shear strength, and enables faster pultrusion line speed, while providing better modulus and durability in pultruded parts.

Another new offering, HydroStrand 258 chopped strands, provides good properties in polyamide resins, particularly in glycol-resistant PA formulations. Up to a 22% increase in impact strength and 13% increase in impact after hydrolysis is reported, in applications such as oil and fluid pump housings and oil pans.

Also on offer for the automotive market was Performax SE4850 roving for polypropylene (PP) direct long fiber thermoplastic (D-LFT) molding, where the glass roving's good adhesion to PP reportedly improves the resulting composite's mechanical properties by as much as 80%.

Another product, TeleStrand 2000 UV-series glass roving, brings benefits to customers who produce optical fiber cables, where the impregnated glass fiber acts as a central strength member in the cable assembly. Owens Corning sees significant demand for this product in areas of the world where communication and digital networks are being expanded.

www.owenscorning.com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» FIBER REINFORCEMENTS

## Ultralight NCFs for infusion, RTM and prepregs

**Chomarat** (Le Cheylard, France) announced two brand-new reinforcements: G-FLOW glass fiber fabric for infusion, which combines structural and flow functions, and the latest product in the C-PLY line, C-PLY ULTRA THIN, which it claims is the first noncrimp fabric (NCF) made with ultra-thin, intermediate-modulus carbon fiber plies at a very low areal weight (50 g/m² per ply).

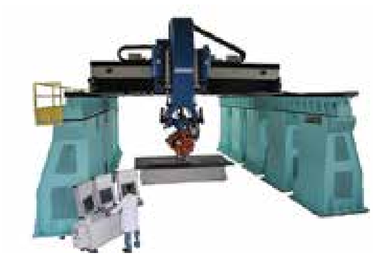
G-FLOW reportedly offers good permeability and resin flow rate over long distances without the addition of an external flow medium. Its flow function is made possible by an unusual textile structure that reduces the number of resin supply lines required, the use of consumables and total processing time. Testing shows material costs drop by 20-30% and cycle times are 10% shorter compared to a system using external flow media. It also demonstrated that use of G-FLOW preserves the same tensile and flexural properties gauged in a laminate infused using an external flow medium. Chomarat believes the material will adapt equally well to marine, wind energy and transportation applications.

With C-PLY ULTRA THIN, Chomarat claims it is pushing the technological envelope by enabling the production of a biaxial NCF with 50 g/m² plies (for a total of 100 g/m²) made of intermediate-modulus carbon fiber. Reportedly offering excellent mechanical performance and weight reduction, this reinforcement can be molded via RTM, infusion or prepreg processes. Developed for the sports-and-leisure sector, C-PLY ULTRA THIN also is suitable for the automotive industry. Chomarat now supplies NCF products in bi-, tri-, quadriaxial or unidirectional (UD) form, with 70 g/m² plies made of IM carbon fiber (24K), and plans to industrialize this new biaxial prototype with ultra-thin plies (50 g/m²), starting in 2016.
**www.chomarat.com**

» PRODUCTION MACHINERY

## Concave-surface-capable automated tape layer

Machinery manufacturer **Mikrosam** (Prilep, Macedonia) featured its new automated tape laying (ATL) system, developed for a civil airplane parts manufacturer. This contour automated tape laying (CATL) equipment consists of a layup head and an assembly of three rotational axes and three linear axes in portal style, suitable for automated laying of carbon fiber tapes for production of composite parts for the aerospace, shipbuilding and wind energy industries.



The ATL head consists of independently controlled, multi-segmented shoe members used to apply the tape, and an additional compaction method used to complete tape application. Both are linked through a dynamic servo control system, which is said to improve tape-laying precision and reduce errors. This reportedly provides for highly controlled shoe and roller movement, fine adjustment of compaction force against the work surface, and different laying paths, yet avoids bubbles, gaps, overlaps and wrinkles.

The head's innovation is in achieving a very large, free envelope angle of ±40°, which Mikrosam says represents a 60% wider laying range, compared to previously known solutions. Therefore, it gives the manufacturer the opportunity to lay on concave surfaces. As such, this ATL solution increases laying performance, productivity and precision and avoids tape deviations and vibrations during layup.

www.mikrosam.com

» CORE MATERIALS

## 3D foam core for complex shapes

**Evonik Industries AG** (Essen, Germany) showcased at JEC Europe 2015 a new cost-effective manufacturing method for three-dimensional shaped foam cores, intended for carbon fiber automotive parts. In a joint venture with **SECAR Technology GmbH** (Mürzzuschlag-Hönigsberg, Austria), dubbed **LiteCon Advanced Composite Product GmbH**, Evonik's ROHACELL Triple F polymethacrylimide (PMI) foam is being converted into crumb, then molded using a new in-mold foaming process to create any desired complex shape and foam density; inserts and fasteners can be molded in, and the Triple F foam is compatible with conventional resins. LiteCon exhibited a variety of complex foam core shapes, aimed at the automotive industry. This new technology aims to replace traditional and slower methods of shaping cores, where foam produced as large blocks is CNC-machined to the desired shape.

www.rohacell.com

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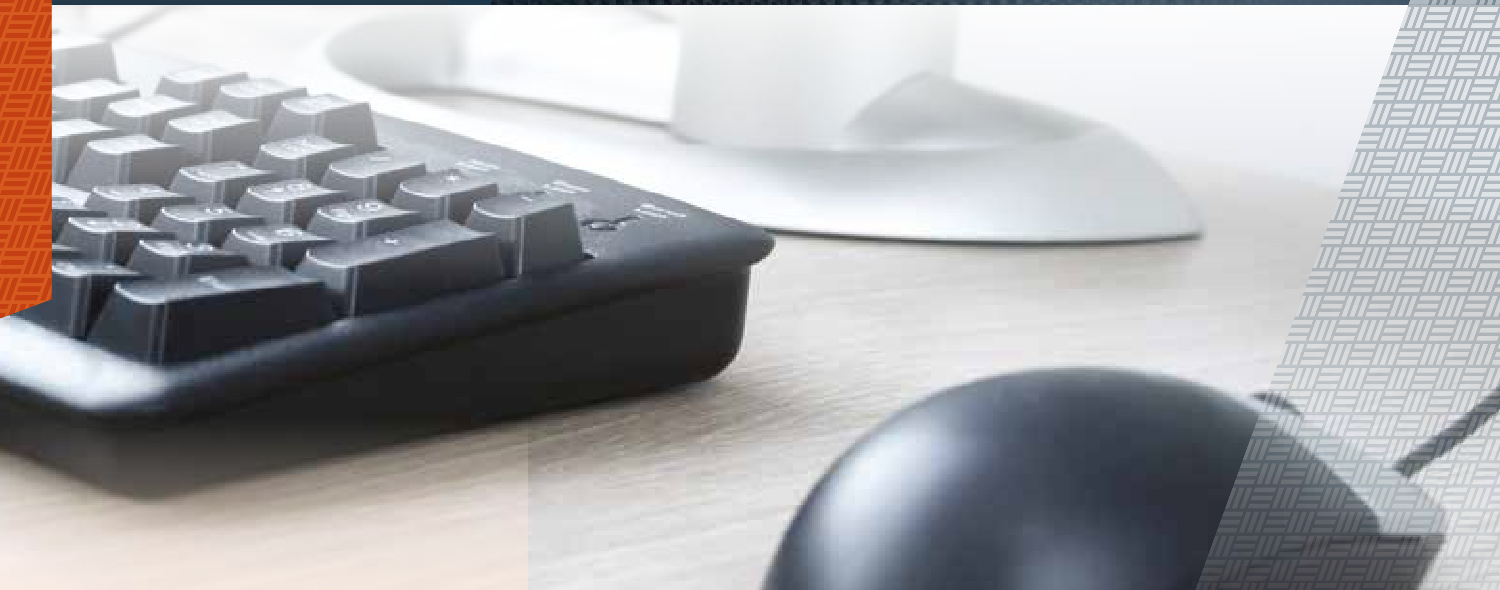
# WEBINARS



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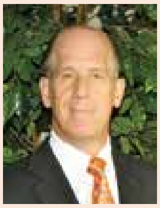

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Vice President, Aerospace and Composites - Altair

JEFFREY WOLLSCHLAGER
Sr. Technical Director, Aerospace - Altair

# Optimizing Structures for Damage Tolerance

### EVENT DESCRIPTION:

Composite materials offer many advantages in terms of weight and stiffness. They can also offer advantages in damage tolerance but the mechanisms of damage initiation and propagation are less well understood in composites. Micromechanical analysis provides a method to analyze and understand the mechanical behavior at the fiber- or particulate-matrix level. A review of micromechanical analysis techniques will be provided and how they can be implemented with structural optimization methods to achieve minimum weight damage tolerant structures.

### PARTICIPANTS WILL LEARN:

- Concept design synthesis for composites
- Modeling and analysis of laminated structures
- Methods to analyze mechanical behavior of composites at the fiber- or particulate-matrix level.
- Structural optimization methods to design lightweight damage-tolerant structures

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» STRUCTURAL ADHESIVE SYSTEMS

## MMA bonding systems for ground transport

**SciGrip Smarter Adhesive Solutions** (Durham, NC, US) introduced at JEC Europe 2015 its new SG800 range of methyl methacrylate (MMA) bonding systems that are specially formulated and developed for automotive, agricultural vehicles, rail and heavy truck applications. SG800 adhesives, with customizable room-temperature cure, reportedly have 85-90% of the strength of epoxy, but with much higher elongation and toughness, and they can withstand working temperatures up to 120°C. Plus, they produce very low bond-line read-through, for better part aesthetics. SG800 products work with unprimed metals, sheet molding compound (SMC) and dicyclopentadiene (DCPD) materials.

www.scigrip.com


» DESIGN & SIMULATION SOFTWARE

## Multi-scale modeling platform

**MSC Software** (Newport Beach, CA, US) subsidiary **e-Xstream engineering**, developer of Digimat, a nonlinear multi-scale material and structural modeling platform, announced at JEC its latest software solution, Digimat-VA.

It's designed to replace and complement physical testing of composite materials with advanced simulation to enable on-the-fly allowables predictions. It combines a solution-oriented graphical user interface, efficient micromechanical modeling, accurate progressive failure analysis, nonlinear finite element analysis (FEA) and uncertainty quantification.

Digimat-VA allows design engineers to virtually compare materials before going into a lengthy physical allowables test process. The software is designed to generate virtual coupons, apply loads and generate test results data, including statistical treatment for allowables

computation. The user can choose from a database or define any material systems, a variety of layups, multiple test types and a variety of environmental conditions. e-Xstream engineering is working with Wichita State University's (Wichita, KS, US) National Institute for Aviation Research (NIAR) to validate Digimat-VA predictions. Validations indicate that a prediction error within 10% is achievable. Initial focus has been on carbon fiber/epoxy combinations, but company officials say that the methodology is also applicable to continuous fiber-reinforced thermoplastics. It is powered by a nonlinear FEA solver coupled with Digimat multi-scale material modeling, including Digimat progressive failure technology.

Digimat-VA's developers emphasize that the software is not designed to fully replace the physical testing typically used to develop design allowables data. Instead, by generating virtual allowables, engineers can start the component design in parallel with physical allowables testing. Furthermore, it enables the user to explore material sensitivity to parameters variability and, thus, better understand the performance of composites.

Digimat-VA, says e-Xstream, is a decision tool that allows exploration and experimentation at low cost; it allows the user to fine-tune material selection and more carefully decide what will be tested in the physical world.

www.e-xstream.com

» ACOUSTIC DAMPING TECHNOLOGY

## Thin-film damping material for laminates

**Kraiburg GmbH & Co.** (Waldkraiburg, Germany) had an interactive stand displaying laminate panels both with and without the company's Kraibon lightweight rubber damping material. When whacked with a drumstick, the panels exhibited dramatic acoustic differences. Kraibon is a thin film of uncured rubber added to the laminate stack, which cures with the laminate. Aimed at automotive parts, the very thin rubber material ply is significantly lighter than the aluminum butyl vibration insulation material typically added by the auto industry for acoustical damping and NVH (noise/vibration/harshness) control. And, Kraibon improves composites' damage tolerance, says the company.

www.kraibon.de

» INJECTION MOLDING TECHNOLOGY

## Injection overmolding for aircraft applications

**Victrex Plc** (West Conshohocken, PA, US) introduced at JEC Europe 2015 its new Victrex hybrid molding technology, which combines the strength of VICTREX PAEK-based continuously reinforced composites with the design flexibility of VICTREX PEEK injection molding solutions. This overmolding process enables the production of a part in minutes compared to the hours it could take for a metal or thermoset equivalent. In addition, achieving high specific strength with up to 60% weight savings as well as consolidating parts to create an elegant, highly functional component, helps to reduce aircraft manufacturing time and weight.

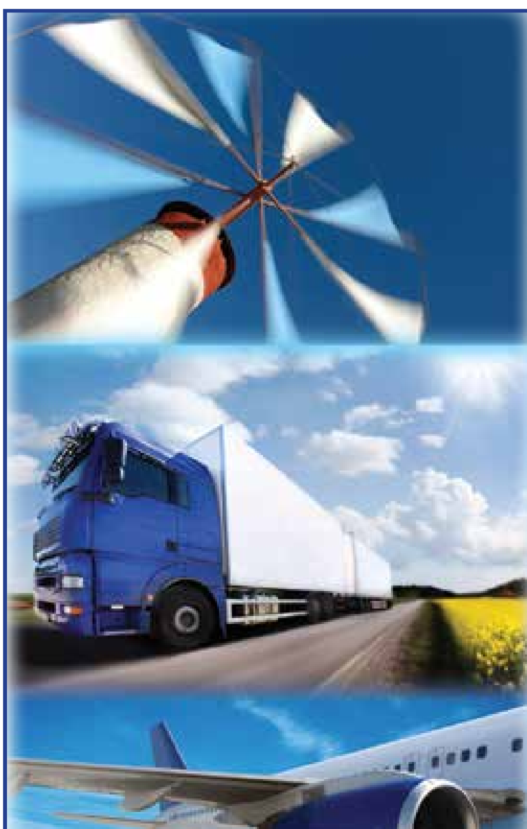
www.victrex.com

» FIBER SIZINGS & COUPLING AGENTS

## Water-based sizings for the fiber/thermoplastic resin interface

**Michelman Inc.** (Cincinnati, OH, US) introduced a number of new fiber sizings to support engineered thermoplastic resins being employed in automotive design and manufacturing applications, as lightweight composites replace metals. The new products include trademarked Hydrosize U2-04, a water-based polyurethane dispersion compatible with polyamide resins; Hydrosize PA846, a water-based polyamide dispersion that is highly stable with good thermal resistance; and Hydrosize U9-01, a water-based, blocked isocyanate that enhances the reactivity of the fiber/resin interface. These products help support requirements for good thermal performance, hydrolysis resistance and mechanical performance.

www.michelman.com

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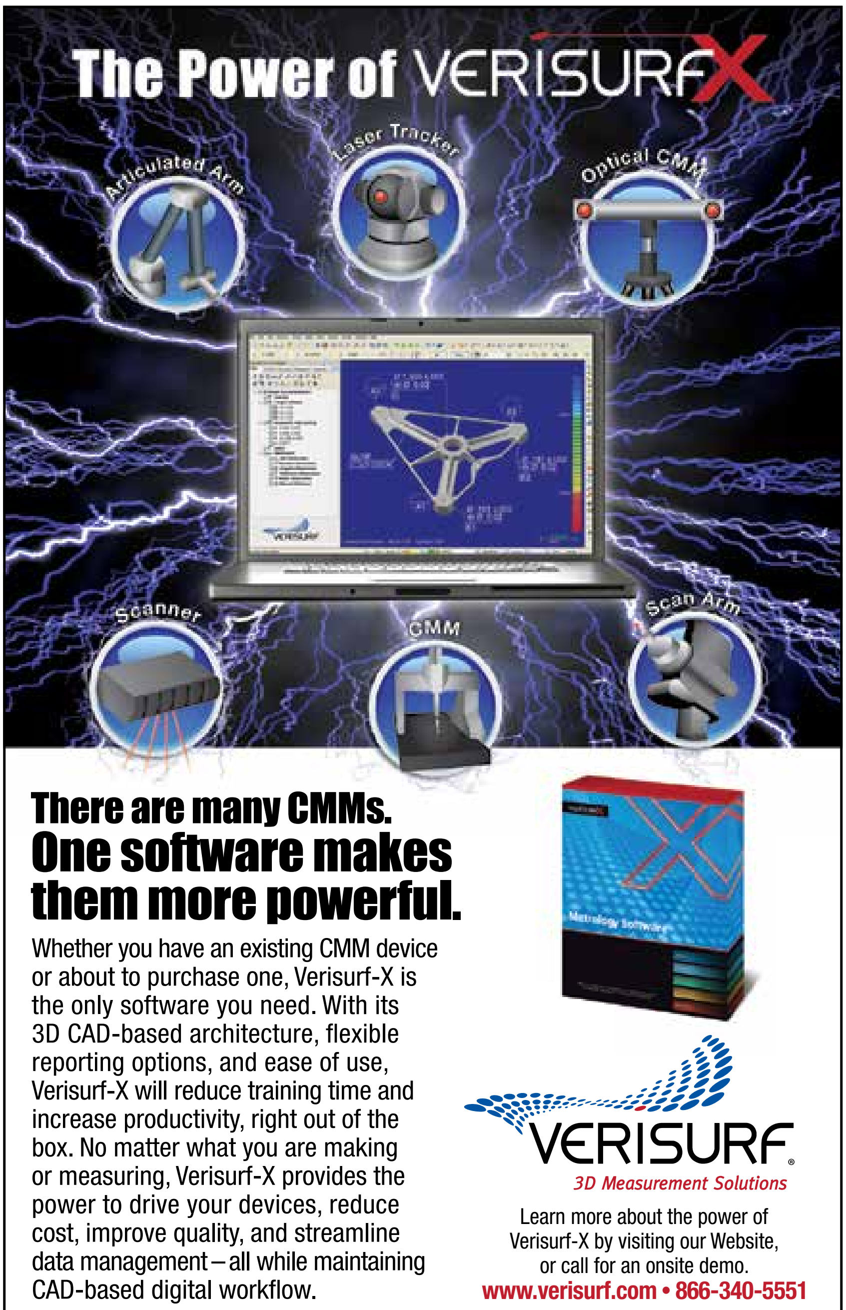
» FIXTURING EQUIPMENT

## "Universal" 5-axis holding device

**CMS Industries** (Zogno, Italy and Caledonia, MI, US) introduced its recently patented 5-axis "universal holding fixture" employing vacuum-assisted "pogos" for securely holding parts and tools during machining. The fixture automatically positions the object thanks to the unique "pan and tilt" function of the pogos, which can eliminate the need for customized metal fixtures and jigs, says the company. The universal fixture can handle very large parts or tools, and can position them correctly within 15 seconds. CMS says the system is very reliable, with a small number of moving parts that are sealed from the cutting environment, particularly carbon fiber dust, and the pogos can be quickly changed out, if necessary, in a plug-and-play manner. www.cmsindustries.it




» RESIN SYSTEMS TECHNOLOGY

## VOC-free resins for pultrusion, winding, infusion, and wet layup

A new line of Advalite vinyl hybrid liquid resins from **Reichhold Inc.** (Durham, NC, US) are low-viscosity products designed for high-performance structural applications, including those in the automotive and wind energy sectors. Formulated for use in pultrusion, filament winding, wet molding and infusion processing, the resins have no monomer and, therefore, emit zero VOCs, and feature a $T_g$ up to 190°C. They also exhibit excellent wet out, particularly with fiberglass reinforcment, are stable at room temperature and don't require refrigerated storage, yet cure rapidly at elevated temperature. Reichhold says the resin is flexible and tough, with high strength and stiffness. Advalite also can be produced as a hot-melt prepreg resin. www.reichhold.com

» FIBER REINFORCEMENTS

## Glass fiber for high-pressure cylinders

**3B-the fibreglass company** (Battice, Belgium) launched HiPer-tex H2020 high-performance roving to meet the needs of composites manufacturers for lighter but less expensive high-pressure-capable cylinders. The new roving is said to offer more than 25% greater strength than standard glass products, providing 1,420 MPa strength modulus in a typical unidirectional laminate (average glass fiber volume fraction of 60%). 3B claims the fiber's good fatigue performance and acid resistance makes it, at the moment, the only glass fiber that can be used as the sole material in the manufacturing of fully wrapped composite cylinders that are approved per the United Nations' ECE R110 regulation. Further, compared to all-steel pressure vessels, those vessels wrapped with HiPer-tex H2020 offer a 50% weight savings. Lastly, HiPer-tex H2020 is specifically engineered for epoxy polymer systems that are used in filament winding processes.
www.3b-fibreglass.com

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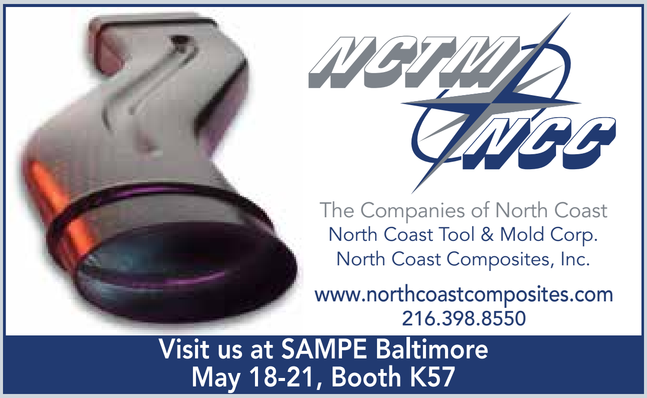
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## ADVERTISING INDEX

# Uncompromising composite hyperbaric oxygen chamber closes the gap

## Flexible, filament-wound composite reduces weight and cost, increases performance of first transportable high-pressure oxygen-delivery system.

**By Peggy Malnati /** Contributing Writer

» An established medical procedure, hyperbaric oxygen therapy (HBOT), temporarily delivers pure oxygen to a patient under higher-than-atmospheric pressure, enabling blood to carry more oxygen, which, in turn, helps fight infection, stimulates release of growth factors and stem cells and speeds healing. Most notably used to treat divers afflicted with decompression sickness (the "bends"), it's employed routinely to treat altitude sickness, severe anemia, carbon monoxide poisoning and many other medical conditions — and to enhance the performance of elite athletes.

HBOT requires a hyperbaric chamber. Large multi-person units resemble hospital rooms, where patients receive oxygen via facemask or clear hood while sitting or lying down. Much smaller, single-person systems come in rigid and flexible formats, and treat patients as they recline inside a narrow tubular chamber. Rigid (hard-shelled) systems can reach pressures up to 3 atmosphere absolute (ATA; that is, three times normal atmospheric pressure) and weigh up to 1,500 kg. Permanent installations, they typically are constructed of metal, with entry hatches/airlock doors, glass or acrylic observation windows or closed-circuit TV, plus two-way communications for patient monitoring. Considerably heavier, bulkier and costlier to build and operate than flexible units, most are owned/operated by naval or diving organizations, hospitals and dedicated recompression facilities. Flexible systems operate at much lower pressures (to 1.4 ATA) and don't provide the same efficacy or meet the same performance requirements as rigid chambers, but they are usually transportable because they are constructed of lightweight urethane- or vinyl-coated nylon-bonded fabric and can be collapsed. Patients enter through a full-length, double-zipper seal from the top of the chamber, which is pressurized with oxygen-enriched compressed air.

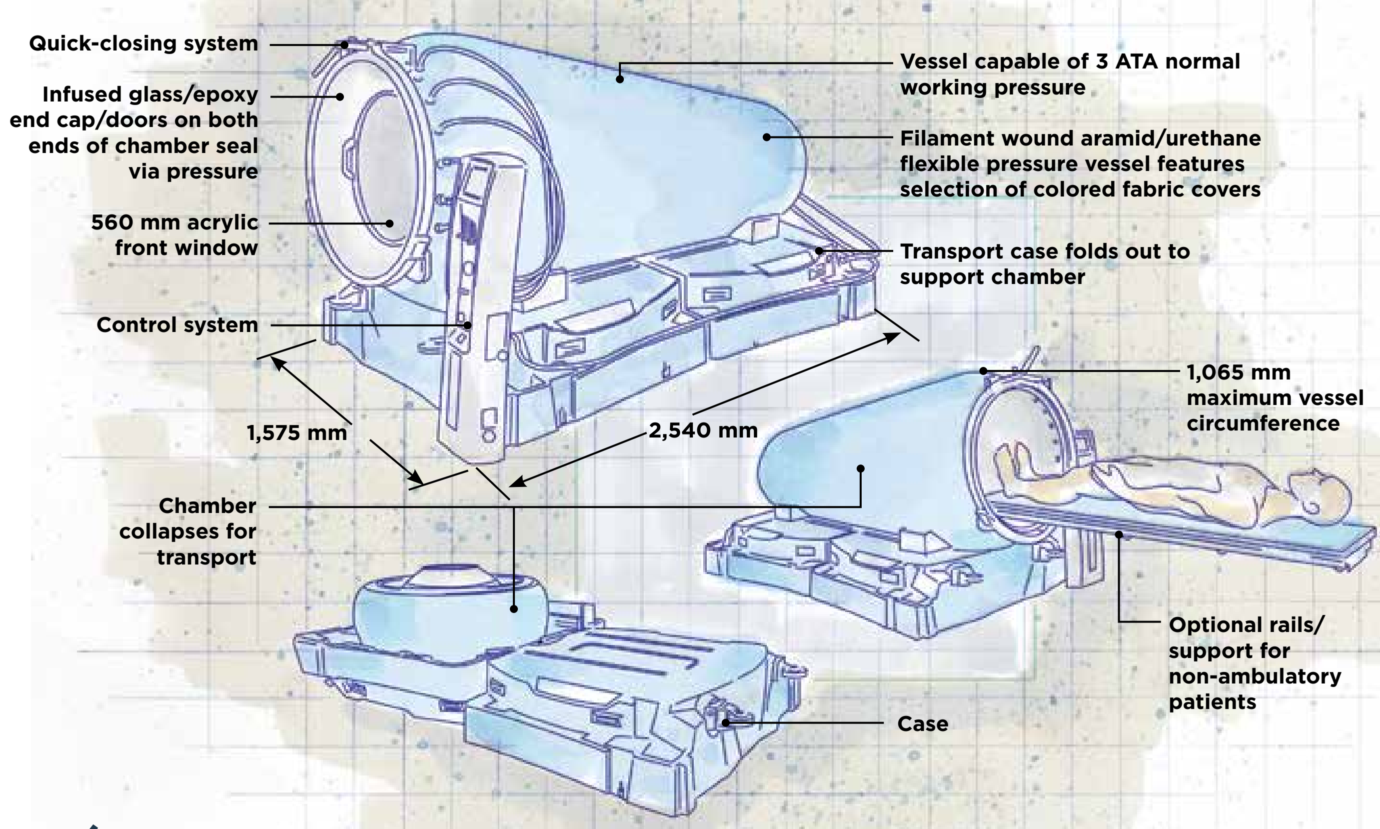
Now, the HematoCare, a new hyperbaric chamber from Groupe Médical Gaumond (GMG, Montréal, QC, Canada), is set to close the gap between rigid and flexible single-person systems. Unique composite construction enables the chamber to deliver oxygen at the high pressures of rigid systems, but keep system cost, weight and collapsed size down for maximum medical utility, convenient stowage and portability, and rapid deployment.

### A decade in development

Claude Gaumond, GMG's CEO, made a decidedly untraditional transition into the medical-device field. An elite cross-country skier and triathlete, his initial interest in HBOT was to enhance his own competitive performance. However, while exploring available units in 2001, he recognized that each had shortcomings, and he started wondering how to design a better system. During his university business studies, he took the opportunity to use his idea as a business case in his classes. As a graduate, he had a good idea and a solid business plan, but limited funds and little technical knowledge about how to engineer such a complex product. Here, an early and ongoing resource was the National Research Council Canada's (NRCC/CNRC) Industrial Research Assistance Program


#### Flexible, portable HBOT chamber

The HematoCare, a new, transportable hyperbaric oxygen therapy chamber developed by Groupe Médical Gaumond (GMG, Montréal, QC, Canada) features a collapsible filament wound aramid fiber/polyurethane chamber (see inset) capable of handling pressures previously reached only by rigid systems. GMG's CEO Claude Gaumond initially launched the unit with a decorative, protective fabric covering in blue (shown here), silver, pink and red with matching HDPE cases, but will supply it in nearly any color. Because HBOT sessions can last 60-90 minutes, the chamber also has piped-in sound (via earphones) and home-theater capabilities. Source | Groupe Médical Gaumond




**DESIGN RESULTS** | **Groupe Médical Gaumond's HematoCare HBOT Chamber**

- Composite construction enables a more durable, transportable unit, able to withstand the pressures previously achieved only in 1,500-kg rigid systems.
- Flexible aramid fiber-reinforced chamber is collapsible, enabling easy system assembly/ disassembly and transport via truck or SUV.
- Portability, functionality, ease of access and low cost make the system practical and affordable for small clinics and individuals.

Illustration / **Karl Reque**

(IRAP, Ottawa, ON, Canada), which in 2005 provided funding and connected him with specialists in the regulatory, electronics, engineering and composites arenas.

From the start, Gaumond's team wanted to build a low-cost, flexible unit that could match the 3.0 ATA pressures of rigid hyperbaric chambers. This was a tall order: no other soft-sided system had yet been rated higher than 1.4 ATA, because to be certified by the US Food & Drug Admin. (FDA) at a maximum allowable working pressure (MAWP), devices are tested at *six times* that pressure.

Another challenge was that the chamber needed to be sufficiently pliable to fold and store compactly, and light enough to move around but also strong enough to withstand pressure differentials without tearing during normal use. While benchmarking fabrics from existing systems, Gaumond's researchers realized these membranes would never survive such high pressures without leaking, so something new would be needed.

Also, many HBOT patients have impaired ambulation so existing flexible designs that required them to enter from the top were judged clumsy and undesirable. That led to brainstorming about ingress/ egress options that would permit efficient chamber sealing, yet keep the system lightweight and inexpensive. The team took its cues from rigid units, which have doors in the horizontal chamber ends. That necessitated finding new ways to meet cost, mass and pressure targets. GMG also wanted to make the chamber as large in diameter as possible to accommodate larger patients (up to 220 kg). The largest flexible systems measured 102 cm in diameter, but the team's target was 107 cm. (As diameter increases, thermodynamic requirements in pressure vessels increase much faster.) Durability was another important criterion (the goal was 10 years/4,000 cycles), and Gaumond was adamant: he wanted something as good-looking as it was functional. Citing former Apple Inc. CEO Steve Jobs' influence on his design sensibility, Gaumond recalls, "I told my team in the beginning, 'You make the system good, and I will make it beautiful.'"

Another goal was global sales, so the design had to accommodate multiple electrical systems and receptacles and meet challenging hyperbaric standards worldwide, preferably with one design to keep costs down. That committed team members to expensive and time-consuming rounds of testing in each target region.

## Developing the system

A major obstacle was developing a flexible membrane capable of meeting the application's mechanical performance, softness (Shore »

### As tough as rigid hyperbaric units

At a mere 125 kg, HematoCare is nonetheless the largest-diameter “soft” hyperbaric chamber (107 cm vs. 102 cm), easily accommodates patients that weigh 220 kg, and is the world’s lightest and least costly hyperbaric unit certified at 3 ATA pressures. Source | Groupe Médical Gaumond

### Versatile case for easy set up/take down

HematoCare’s standard system components fit in this tough but lightweight and easily transportable two-piece case, rotomolded from unreinforced, high-density polyethylene. The system can be set up by two people in 15 minutes and re-stowed in half that time. Source | Groupe Médical Gaumond

D 25) and stringent self-extinguishing flame-retardancy requirements. Given his elite athletic background, Gaumond was accustomed to paying a premium price for premium performance and associated that equation with composites, so the team began with conventional glass-reinforced vinyl, but it quickly failed. Likewise, no zipper systems withstood high pressures without leaks. In 2007, a French professor of textiles joined the team. Representatives from Cytec Industries Inc. (Woodland Park, NJ, US) and aerospace/defense composites molder, Stelia Aerospace North America (Lunenburg, NS, Canada), also came aboard. After much research and testing, the material that finally worked was a high-performance aramid fiber from Teijin Ltd. (Osaka, Japan), impregnated with a custom polyurethane formulation. Carbon fiber had proved too stiff and glass fiber too heavy. Aramid was light, tenacious, flexible *and* flame retardant. Many forming processes were considered, but filament winding was deemed best for the conical chamber. The commercial chambers are produced by Stelia.

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To meet the ingress/egress challenge, the team developed round doors and windows at both chamber ends. The gel-coated, fiberglass-reinforced epoxy end caps are infused by GMG, which is now an ISO 13485-certified medical-device manufacturer. Post-mold finishing involves machining and insertion of an aluminum 6061-T6 support ring, which is bonded to the composite prior to acrylic-window insertion. A rubber O-ring and final clamping ring lock the curved window into the chamber side of the door. Cleverly designed, the caps fit snugly into the flexible membrane, yet are not permanently attached — when air is flowing into the chamber, pressure *alone* holds caps and windows tightly in place, preventing leaks. An optional stretcher-support add-on features two rails that run along each side of the chamber to assist attendants with patients too ill to enter on their own (lower right image in drawing, p. 103).

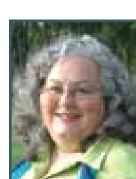
A tough but lightweight, two-piece transport case with casters (packed dimensions are 1,510 mm long by 725 mm wide by 1,200 mm tall) opens to form the support base for the 2,540 mm long by 1,575 mm wide by 1,420 mm tall deployed chamber. GMG rotomolds the cases, which are certified to hold 200 kg, from unreinforced high-density polyethylene.

At only 125 kg packed weight, it is the world’s lightest and least costly 3 ATA-certified hyperbaric chamber. Last year, the system won a JEC Innovation Award in the Medical category and an Alliance Monde Polymères prize.

## Chasing global certification

Because HBOT is a medical procedure involving pure oxygen (a fire hazard) delivered inside a pressure vessel, it’s a heavily regulated device. Before a manufacturer can sell one, it must be certified. GMG has spent years in long and costly testing toward that end, and in fortifying its global patent portfolio. To date, HematoCare has been approved in many markets, including the prestigious CE Mark from the European Medical Device Directives. At press time, *CW* received word that it had received PVHO Committee Approval from the American Society of Mechanical Engineers, making GMG’s HematoCare the first transportable HBOT system rated to 3 ATA with *global* approvals. Distribution deals are in the works, and commercial sales are expected soon.

“Claude Gaumond has endured a lot of challenges developing this product, but has solved them one by one,” recalls team-member Claude Baril, Stelia managing director. “He has worked so hard and never stopped believing in his vision, like a true entrepreneur. What has been done here is quite an accomplishment.” CW



**ABOUT THE AUTHOR**

Contributing writer Peggy Malnati covers the automotive and infrastructure beats for *CW* and provides communications services for plastics- and composites-industry clients.
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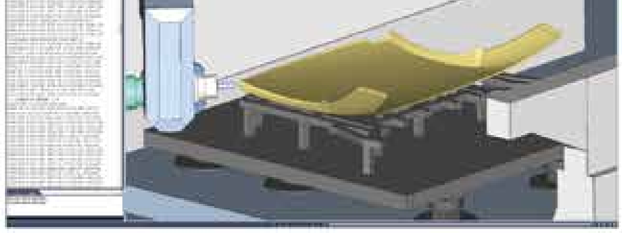

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