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From rebar to kayak paddles: THE POTENTIAL OF BASALT FIBER

Fusing waterjet, laser for CFRP/CMC machining / 22

Smarter, integrated data for ATL/AFP / 44

Impact shield protects 12-volt battery in severe crash / 60

MAY 2019

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VOL 5 №5

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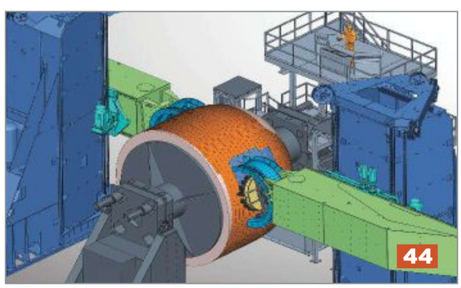
COLUMNS



FEATURES

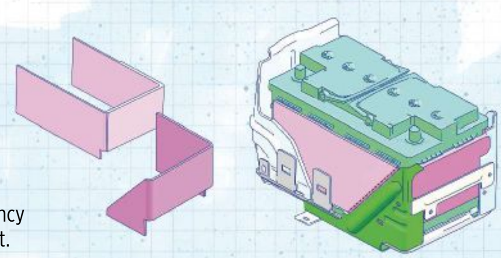
» DEPARTMENTS

» ON THE COVER

Kayak paddles are one among many sporting goods applications that benefit from basalt fiber's combination of "give" and strength. Along with sporting goods, basalt fiber composites are being used for a range of infrastructure and automotive applications as well. See p. 36.

Source / Nimbus Paddles

FOCUS ON DESIGN



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It's April 9 as I write this and this week *CW* senior editor Scott Francis and I are in Colorado Springs, Colo., attending the 35th Space Symposium, a four-day conference and exhibition that, as the name implies, is focused on the exploration, use and development of near-Earth space, as well as technologies to transport cargo and people to the moon, Mars and beyond.

This event, however, is not focused strictly on the benign use of space for scientific and exploration purposes. Indeed, within just a few minutes of arriving at the Space Symposium, it is obvious that there is a serious and substantial military component as well. The event is replete with uniformed U.S. Air Force personnel of all types, ranging from very young U.S. Air Force Academy cadets to seasoned, decorated generals. In addition, there are uniforms from a range of other countries.

Space: The next frontier and battleground

On the exhibition floor you can find many of the companies you would expect, such as NASA, Northrop Grumman, Lockheed Martin, United Launch Alliance, Boeing, Airbus, BAE Systems, Firefly, RUAG and Ball Aerospace.

It was from the speakers, however, that I got the truest sense of this event. In an auditorium filled to overflowing with about 3,500 people, we heard presentations from acting U.S. Secretary of Defense Pat Shanahan, U.S. Secretary of Commerce Wilbur Ross, U.S. Secretary of the Air Force Heather Wilson, NASA administrator James Bridenstine, U.S. Air Force Chief of Staff Gen. David Goldfein, Air Force Space Command Commander Gen. John Raymond and Northrop Grumman CEO and president Kathy Warden.

The keynoting started with Shanahan (ex-Boeing), who set a somber and militant tone as he described a near-Earth space environment that has become the target of aggressive and threatening actions by China and Russia, designed to compromise and disrupt American satellite technologies, including communications, surveillance, location and targeting systems. He described an American policy that advocates a free, unfettered, unmolested near-Earth space environment, and allows all countries equal, fair access to the advantages space provides. Shanahan also admitted that the Department of Defense was "behind" in its development of space-based technologies and that U.S. military presence in space requires additional resources to catch up.

As part of catching up, Shanahan echoed the message coming from the Trump administration, announcing the creation of the U.S. Space Force, a sixth branch of the U.S. armed services that, if Congressional funding is approved, will be formed and trained up and will have a seat on the U.S. Joint Chiefs of Staff. Shanahan also stated repeatedly that the U.S. could not act alone to protect its interests in space, and he pointed to international partners that he would work with, as well as commercial partners who already have technology and tools to enable a more assertive American presence in space.

Secretary Ross, whose presence in the speaker lineup was somewhat of a head-scratcher at first, made sense as he spoke: The U.S. Department of Commerce has been tasked with facilitating relationships between the U.S. government and commercial space enterprises, such as Lockheed Martin, Northrop Grumman, SpaceX, Blue Origin and Boeing. He announced the formation of a new Space Bureau within the Department of Commerce to facilitate application of commercial space technology to government programs.

For his part, NASA's Bridenstine focused on the to-do list his organization has, and at the top of that list is a new challenge issued by U.S. Vice President Mike Pence to return to the moon (a man and a woman, it was noted repeatedly) by 2024, followed by a sustainable U.S. presence on the moon by 2028. This would be followed, soon after, by a moon-to-Mars mission. Bridenstine says NASA is up to this task — again, with help from the commercial sector. The only thing NASA does not have is the funding for this enterprise. Yet.

The message here is clear: The human tendency to assert control and authority over new domains is as pronounced in space as it is on Earth, and as technologies are developed to enable and ease delivery of people and cargo into space, there will be a new battle for control of the resources space provides. It appears, as Shanahan said, that space has become the next battleground for the next generation of warfighter.

JEFF SLOAN — Editor-In-Chief

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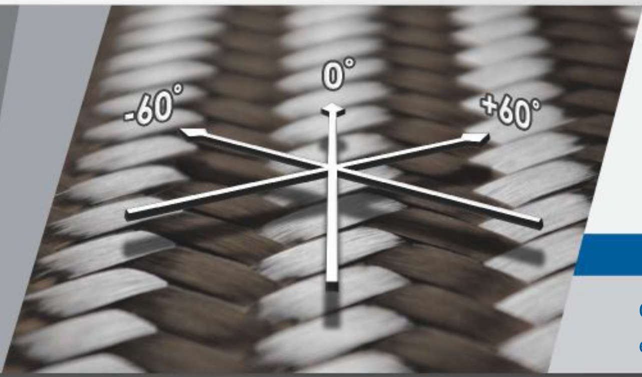

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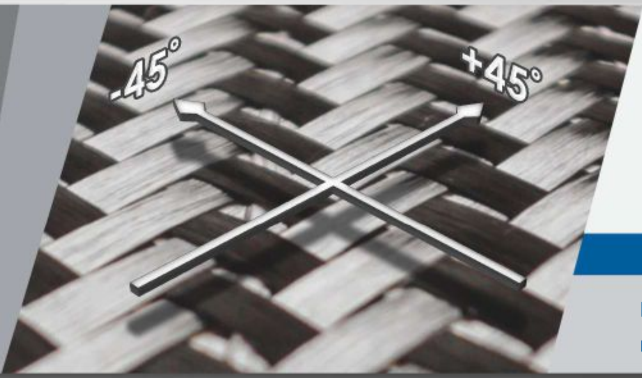

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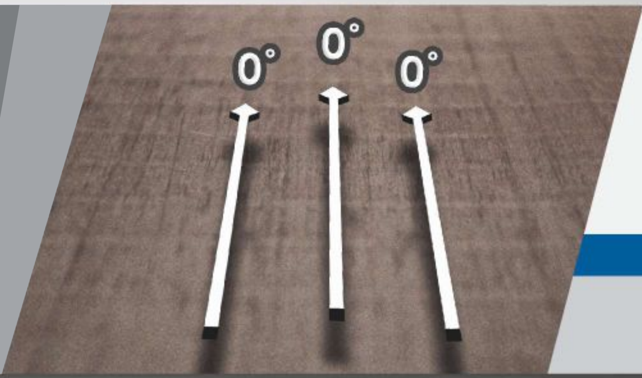

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Composites: Irrational exuberance?

» Another March has passed, and with it the 2019 edition of JEC World. Per JEC, 1,300 exhibitors saw more than 43,000 people come through the exhibition, once again demonstrating that Paris is "the place to be" as winter turns to spring, especially if you are in the composites industry. I witnessed strong attendance at the various presentations and events across the show floor over the three days, numerous new products being introduced and novel automation solutions being performed during live demonstrations. It is clear that the overall health of the industry is good and sales are growing, and the number of countries represented on the floor indicate strong global optimism for the future.

In December 1996, then U.S. Federal Reserve Chairman Alan Greenspan delivered a speech to the American Enterprise Institute during which he introduced the term "irrational exuberance," referring to investor enthusiasm that propels stock prices to levels not supported by fundamentals. He was referring to U.S. share price/earnings ratios well above historical norms. In early 1998, the NASDAQ index stood at 1500, and in early 2000, the famous dot-com boom drove it to 5000, more than tripling the index in only two years. Internet companies with little to no revenues (remember Pets.com?) attracted huge investments from initial public offerings, spectacularly crashing in 2000 and taking the NASDAQ back to 1500 in only a year. It took another *14* years for the NASDAQ to again break through the 5000 point barrier.

> We can remain optimistic, but we also need to redouble our efforts to make composites the obvious choice.

My own portfolio at the time contained a handful of tech stocks, but I was careful to own only those that made *real products*, with real revenues and real profits — companies like Sun Microsystems, Cisco Systems and Applied Materials, which produced hardware that built the backbone of the internet. Certainly, I was safe, right? Unfortunately, when a large number of the dot-com enterprises went bankrupt, they liquidated all their hardware, causing an interruption in the equipment supply chain and dragging down the share prices of the "real" companies I owned in my portfolio. Fortunately, these companies recovered, and most of my holdings were restored, but not to the levels of early 2000.

So how does this relate to JEC World, or even to composites? As I wandered around JEC this year, I could not turn a corner without seeing a composite automobile component on display — body panels like hoods, fenders and deck lids, carbon fiber wheels, structural crossmembers or subframes, and entire monocoque structures. Similarly, albeit less in number, were aircraft fuselage and wing structures, many featuring thermoplastic materials or out-of-autoclave thermoset solutions. And it wasn't just the U.S.- and European-based company stands: such parts were also pervasive on Chinese, Japanese, Korean and other countries' displays. By my estimate, over 90 percent of the auto and aero parts on display were either prototypes or proof of concept, *not production components*. In other words, these parts are not generating revenues or profits, like the many dot-com companies of 1999-2000.

So, the question is, have we reached a point of *irrational exuberance* in the composites industry? Are we being unrealistic about what the future holds for these applications and how quickly that future will arrive? I hope not, as there is still a lot of work to be done to reduce costs and cycle time to realize significant auto penetration, and new aircraft programs willing to incorporate novel materials and technologies are few and don't come along very often.

I am a persistent cheerleader for the composites industry, having spent 35 years in it. But I also keep an ear to the ground and know that entrenched material providers remain vigilant against new entrants. I did see applications at JEC that I think are poised to see rapid adoption and in substantial volumes. One is the maturation of pultruded carbon and hybrid carbon/glass fiber spar caps for wind turbines. These have the potential to be cost-neutral to infused glass fiber spar caps, enabling longer and lighter blades. Another is composite battery enclosures for electric and hybrid electric vehicles, which are forecasted to see high growth rates. The attributes of composites make our materials ideal for this application.

We can remain optimistic, but we also need to be realistic and redouble our efforts to make composites the obvious choice for transportation, energy generation and infrastructure. While the dot-com bust set the internet back for a period, e-commerce and information delivery via the internet is today an undeniably major economic force. It took focus on ideas that could generate revenue, time and scale to achieve. We can replicate that in composites, I believe, if we do the same. CW

ABOUT THE AUTHOR

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

Measuring thermoplastic prepreg tape quality for part process control

» Both the aerospace and automotive industries are interested in applications using thermoplastic prepreg tapes. As might be expected, the quality of the finished parts is significantly affected by the quality of the raw material for the laminate. Though thermoplastic prepreg tapes have been used for decades, the push for quality has intensified as many seek to consolidate in-situ, without further application of pressure or heat. The French engineering and advanced manufacturing R&T organization Cetim (Nantes, France) has developed a system for quality assurance of these materials, which in turn, increases quality control for finished parts.

Tape quality necessary for in-situ consolidation

Cetim has developed several technologies for producing thermoplastic composite parts. One comprises a laser filament winding machine for thermoplastic prepreg tapes. The goal for the machine is to manufacture tank and tube applications that, until now, were limited to metallic and thermoset composite materials.

This thermoplastic winding process is based on the same concept as thermoset filament winding, but with a different, in-situ, consolidation step. For thermoplastic composites, a laser heats a specific area of the tape to increase the thermoplastic matrix to its melting point. In this melt temperature region, consolidation of the tape is achieved while the matrix is molten with pressure applied by a drum. Successive layers of the part are stacked and consolidated during winding.

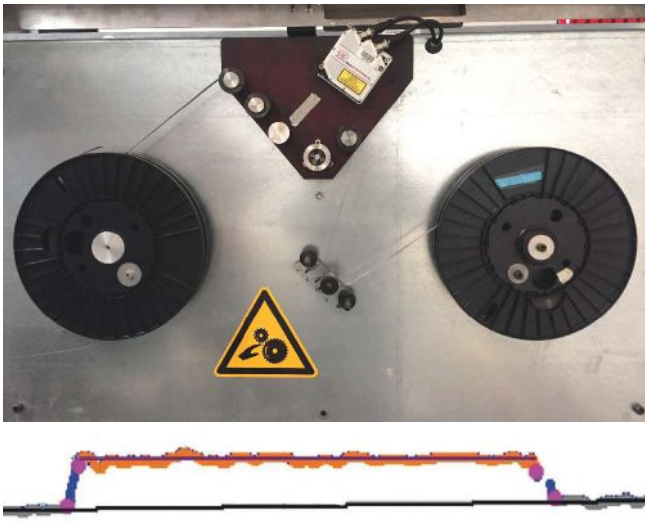
However, as the industry has discovered during development of automated placement methods over the past decade, in order to produce parts with reliable properties and performance, it is necessary to understand the thermal and physical-chemical behavior of these thermoplastic tapes. For example, the tape must have constant dimensions and very low porosity to avoid temperature fluctuations during application that could result in poor consolidation between layers.

Thus, to succeed in its thermoplastic composite process development and to efficiently evaluate the quality of in-situ consolidated parts, Cetim has developed four quality assurance checks over the entire manufacturing cycle: dimensional (as received), thermal (as heated), inline (as consolidated) and the energy required to peel tape layers apart after consolidation.

Dimensional control

This first check takes place before use. Its aim is to quickly evaluate tape thickness and width along its length. The testing machine is equipped with a laser, a camera to catch the reflected laser signal and a sensor to measure the unrolled length of tape. The process comprises unwinding tape from the as-shipped spool onto an empty spool. During this process, the laser and camera provide light data across the width of the tape and along its complete measured length. The processing software interprets the data and shows, in real time, a graph of variation in tape width along the x-axis and in tape thickness along the y-axis (Fig. 1). This makes it possible to visually detect width or thickness defects, and the machine software automatically shows alerts when dimensional tolerances are exceeded. After test completion, data of tape width and thickness variations is easily retrieved (table in Fig. 1), and it is also possible to apply statistical processing.

(A)



(B)

	Provider 1	Provider 2	Provider 3	Provider 4	Provider 5	Provider 6	Provider 7
Thickness average (µm)	234.06	141.95	146.61	151.52	195.80	292.69	149.51
Thickness standard deviation (µm)	5.85	3.65	6.77	3.25	6.89	11.66	1.99
Width average (mm)	12.60	12.46	12.60	12.90	11.90	12.82	12.68
Width standard deviation (mm)	0.03	0.10	0.03	0.14	0.15	0.04	0.03

(C)

FIG 1 CETIM's tape dimensional control machine (A) produces a graph (B) of data (C) obtained during the testing process.

Thermal and micrographic controls

The second check evaluates defects that affect the tape's thermal behavior during heating (in this case, by laser) including dimensional change, adhesion/delamination between fibers and matrix,

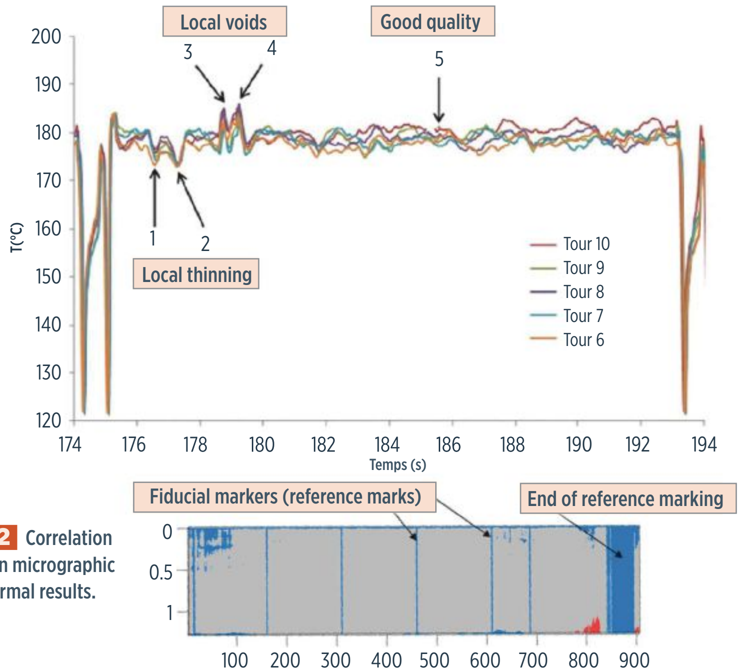


FIG 2 Correlation between micrographic and thermal results.

porosity and surface condition *before* manufacturing. The technique comprises scrolling the tape in front of a low-power laser and using a thermal camera to capture an image of the temperature variations generated. These inhomogeneities in heating identify defective areas where porosity, dry fibers or surface roughness modify the local thermal behavior. After data processing, it is possible to obtain images that show a spatial representation of the tape's thermal response (Fig. 2), including deviations, where red represents areas that are warmer and blue represents areas that are cooler than the desired processing temperature.

It is also possible to show a graph of process time (x-axis) versus tape temperature (y-axis, Fig. 2). Cetim has correlated these results to porosity measurement from micrographs of tape sections. These are sections of tape as it is received and/or sections of final parts that are observed under a digital microscope, providing qualitative information such as fiber distribution, specific type of defects, porosity, etc. Though helpful to establish the correlation between tape temperature response and part quality, these micrographic inspections are expensive, destructive and only allow the tape to be analyzed section by section, not continuously over its entire length. However, Cetim did complete this investigative work, correlating results from the tape's temperature response test with micrographic section results. These tests show the effectiveness of this rich control for thermoplastic tapes.

Inline control

This control consists of determining whether the part being produced is compliant directly, inline during the manufacturing process. This operation is based on direct monitoring of essential manufacturing parameters such as measured temperatures, laser power, tape speed and roller pressure on the tape. The digital processing of this data provides a visual and automatic synthesis of manufacturing quality.

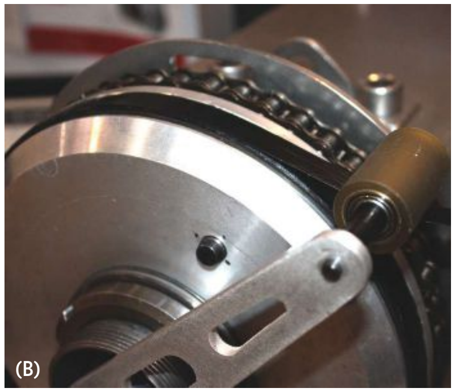
CETIM has developed a dashboard to give an overview of the process parameters during the whole fabrication. Data analysis is done with MATLAB software and enables implementation of an alert threshold as well as zooming in on the out-of-scope area for analysis of the origin of deviation (for example, tape quality or geometric mismatch).

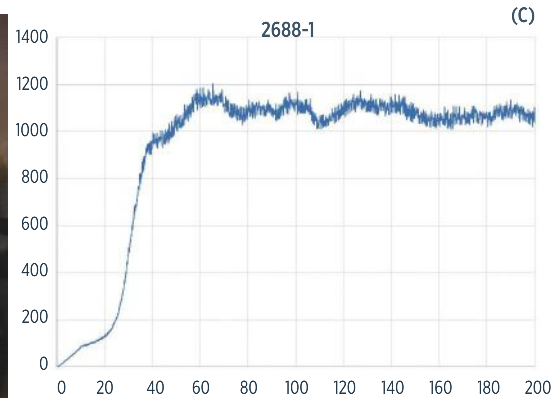
It is said to be particularly effective for monitoring production of parts with simple geometries (for example, a plate, tube or ring); however, it is more complex to generate for complex geometry parts.

FIG 3 Cetim's peel test machine (B) produces a graph of test data (C). A CF/PEEK tape comparison performed with control data is also displayed (A).

(A)

	C/PEEK 1	C/PEEK 2	C/PEEK 3
ΔWidth	0.03 mm	0.06 mm	0.05 mm
ΔThick.	3 µm	14 µm	6 µm
ΔTemp.	1.8°C	5.0°C	1.3°C





Peel test

This final check has been developed by Cetim in collaboration with test bench specialist LF Technologies (Saint-Hilaire-de-Riez, France). It enables, in just a few minutes, the assessment of interlayer adhesion of the tapes. Measurements are made on specimens called "rings," which are manufactured by winding and in-situ consolidating several rounds of tape around a simple tube. These consolidated rings are then placed on the left drum of the test machine (Fig. 3) and unwound using the right drum. Multiple parameters may be adjusted including speed and peel angle, the latter via an arm with a roller at its end. Once the test is completed, an automated data processing system extracts the change in peel energy over the length of the unwound tape and graphs the data. This test enables a relatively quick and low-cost evaluation of optimal manufacturing parameters.

Increasing product and process control

Controlling the quality of thermoplastic prepreg tape enables composite part manufacturers to control the quality of their products. Non-compliance in one of these controls makes it possible to determine the origin of the problem and therefore to correct it effectively and quickly.

With these checks, Cetim can efficiently complete material benchmarks to select the most suitable tapes for a given application. Cetim is still developing an evaluation of low-cost tape for the development of thermoplastic composite hydrogen storage tanks for fuel cell vehicles. Cetim is also engaged in R&D projects that evaluate the relative advantages of thermoplastic compared to thermoset composite pressure vessels. Cetim works within the frameworks of private research agreements with several companies worldwide to develop application of thermoplastic in-situ consolidation. CW

ABOUT THE AUTHORS

Damien Guillon joined Cetim in 2009 after earning an aeronautical engineering degree and a Ph.D. on the crash behavior of composite materials. He was manager of the testing laboratory and a composite design expert before becoming R&D manager of the polymers & composites team.

Yoann Le Friant and Luc Poitevin joined Cetim as R&D project managers, in 2018 and 2017, respectively, after earning Master's degrees in mechanical engineering. Le Friant's current work includes lifetime prediction of polymer parts and control of thermoplastic tape quality. He is also in charge of Cetim's material choice consultancy. Poitevin works on parts development for the space industry using thermoplastic processes and integration of complex functions.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Index shows modest expansion on production and supplier delivery activity

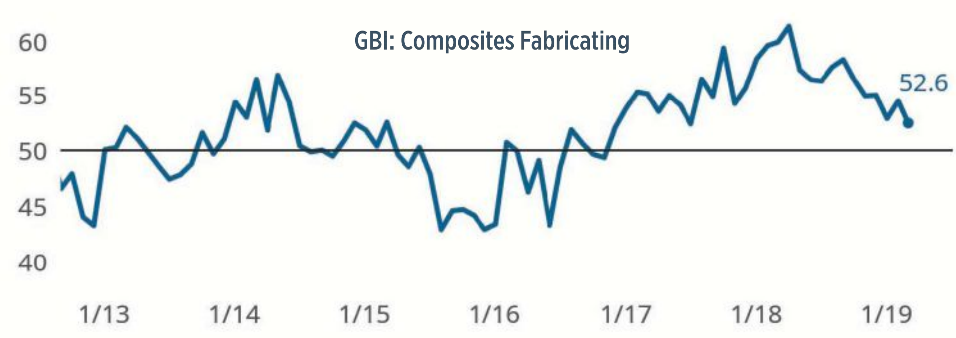
March 2019 — 52.6

» The March GBI: Composites Index moved lower as a significant slowing of new orders activity combined with an increase in production activity resulted in the sharpest contraction in backlogs since June 2016. The latest reading is 13.0 percent lower compared to the same month one year ago when the Composites Index was only one month away from reaching its all-time high in April 2018. Gardner Intelligence's review of the underlying data indicates that the Index was sustained by production, supplier deliveries, employment and new orders. The Index — calculated as an average — was pulled lower by exports and backlogs, both of which contracted during the month.

February's surprise expansion in new orders activity did not carry into March, as the latest reading for new orders fell nearly five points. Between January and March, the new orders reading experienced a net 2.5-point increase. Exports registered a fourth month of either contracting or flat activity, which further weakened order activity. The recent activity in new orders and exports combined with a small increase in production activity resulted in backlogs contracting at the steepest rate in more than two years. CW

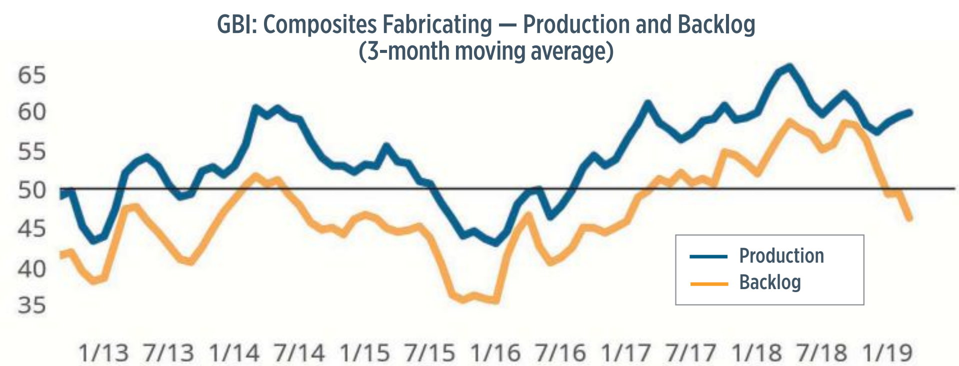
ABOUT THE AUTHOR

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



Highest expansion comes from production

Production was the fastest expanding component in March, followed by supplier deliveries, employment and new orders.



Slower new orders expansion and increased production reduced backlogs

Slower activity in new orders in March, after February's sharp uptick, combined with modestly greater production activity, resulted in the steepest contraction in backlogs since mid-2016.

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JEC World 2019 had on display a sample of trending technologies across industries, a Massachusetts-based startup launches a fabric with z-direction reinforcement and more.

Massachusetts-based startup raises funding for fabric with z-direction reinforcement

Boston Materials (Bedford, Mass., U.S.) has announced the development of its patented Carbon Supercomposite, a carbon fiber fabric that features milled carbon fibers magnetically aligned in the "z" direction to provide uncommon ply-to-ply strength. The company has raised $1.75 million in seed funding led by the Clean Energy Venture Fund with participation from Sabic (Pittsfield, Mass., U.S.) and the Clean Energy Venture Group (Cambridge, Mass., U.S.).

Boston Materials is working with Sabic to integrate Carbon Supercomposite with polyetherimide (PEI) and polycarbonate (PC), but says the fiber is resin agnostic and compatible with any thermoset or thermoplastic resin matrix. The company says the technology improves toughness and strength and allows for enhanced electrical and thermal conductivities. According to Anvesh Gurijala, founder and CEO of Boston Materials, Carbon Supercomposite can increase compressive toughness by as much as 300 percent and compressive strength by 35 percent compared to traditional prepreg systems.

While the material has potential in a variety of end markets including pressure vessels, wind energy, automotive and aerospace, the company is initially targeting sporting goods and overmolding applications and aims to launch its first Carbon Supercomposite product in summer of 2019.

Trends from JEC World 2019

JEC World 2019, which took place in Paris from March 12-14, 2019, showcased a range of the latest composites technologies across industries. Here are a few of the trending technologies at the show. Go to **short.compositesworld.com/JEC2019** and **compositesworld.com** for *CW*'s full coverage on these and more.

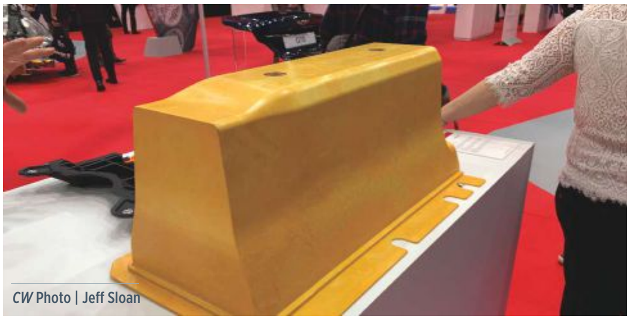
CW Photos | Jeff Sloan

Automotive curing agents and epoxies

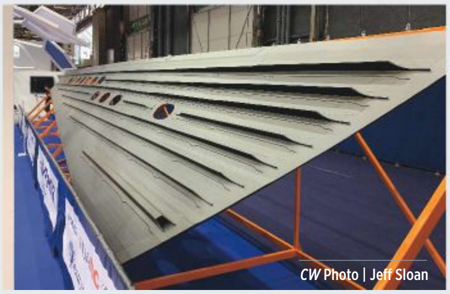
Evonik (Parsippany, N.J., U.S.) introduced its VESTALITE S styrene-free curing agent for high-performance epoxy sheet molding compound (SMC). Parts on display included a carbon fiber/epoxy SMC wheel (right) for an electric multi-purpose city vehicle (450 kilograms without battery), and a glass fiber/epoxy SMC developmental lift gate (left) fabricated for a South Korean automotive OEM.

EV battery enclosures

Hexion (Columbus, Ohio, U.S.) featured several products at the show, including a phenolic SMC designed specifically for heat and fire resistance in battery enclosures for electric vehicles (EV).



CW Photo | Jeff Sloan


CW Photo | Jeff Sloan

New technology for fabricating large aerostructures

Hexcel (Stamford, Conn., U.S.) displayed the largest part at JEC World 2019, an A380 empennage structure developed by Hexcel with FIDAMC (Getafe, Madrid, Spain) and MTorres (Torres de Elorz, Navarra, Spain). The MTorres machine used to fabricate the part, says Hexcel, has a laydown rate of 100-150 kilograms/hour and can place tapes up to 2 inches wide, enabling efficiencies heretofore not seen in aerospace manufacturing. The goal of the project was to demonstrate fabrication speeds possible with state-of-the-art fiber placement systems and materials.

Thermoplastic composite radomes

Porcher Industries (Eclose-Badinières, France), featured a thermoplastic 5G SATCOM radome structure developed in cooperation with aerospace composites fabricator Meggitt. Porcher created a glass fiber-based composite material designed for high impact resistance and efficient processing that provides the ability to tune the dielectric constant (Dk) for optimizing 5G air-to-ground transmission.

CW Photo | Jeff Sloan

CW MONTH IN REVIEW

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

Kaman launches composite blade development program for K-MAX helicopter
The multi-year program consists of design, manufacture, test and qualification of an all-composite blade for Kaman's intermeshing rotor system.
3/8/19 | short.compositesworld.com/K-MAX

SpaceX crew capsule returns to Earth after successful flight test
The SpaceX *Crew Dragon* successfully parachuted to Earth on March 8, 2019, marking the end of Demo-1, NASA's first commercial crew flight test.
3/8/19 | short.compositesworld.com/SpaceX_CD

TenCate Advanced Composites changes its name to Toray Advanced Composites
The new name was announced at JEC World 2019. TenCate Performance Composites, a subsidiary of TenCate Advanced Composites, will subsequently change to Toray PMC.
3/12/19 | short.compositesworld.com/Toray

Boeing and SAMPE announce strategic partnership
The partnership is meant to promote leading-edge materials technology and access to professional development and growth opportunities for Boeing engineers.
3/13/19 | short.compositesworld.com/B_SAMPE

Mitsui Chemicals to establish long glass fiber-reinforced PP facility in China
The facility will become Mitsui Chemical's third manufacturing base for the material and is expected to increase its production capacity to 10,500 tons per year.
3/15/19 | short.compositesworld.com/GF-PPChina

Solvay and Airborne to partner on developing automated processing
The partnership aims to identify solutions to the industrialization challenges facing the composites industry.
3/18/19 | short.compositesworld.com/S_Apartner

Hexion introduces two-component epoxy solution for aerospace composites
The solution is based on Hexion's EPIKOTE system and uses a metering and mixing agent from Hübers.
3/18/19 | short.compositesworld.com/Hex2Kepoxy

AeroLas targets carbon fiber yarn industrialization
Munich-based AeroLas specializes has used air-bearing technology to develop a system that enables discontinuous carbon fiber to be spun with thermoplastic fibers.
3/19/19 | short.compositesworld.com/CF_yarn

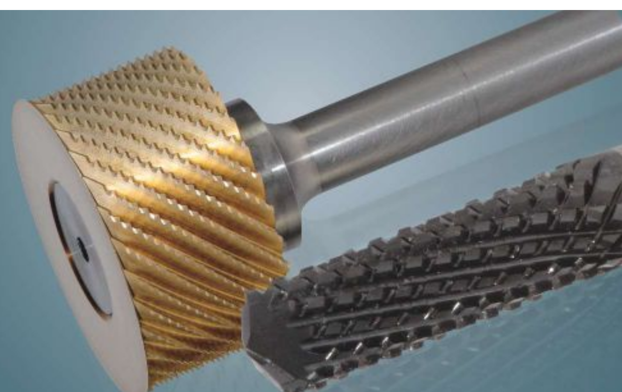
SAERTEX, Scott Bader to partner on fire protection material system
The partnership targets production and distribution of a fire protection line of materials combining multiaxial noncrimp fabrics and a specifically designed resin system.
3/20/19 short.compositesworld.com/Saertex_SB

Arkema Inc. builds U.S. PEKK production plant
The plant, located near Mobile, Ala., will produce Kepstan PEKK materials targeted toward carbon fiber-reinforced parts in next-generation aircraft.
3/25/19 | short.compositesworld.com/ArkemaPEKK

Composite rebar for construction

Olin Epoxy (Midland, Mich, U.S.) displayed carbon fiber-reinforced rebar developed with its alkali-resistant epoxies, in partnership with No Rust Rebar Inc.

CW Photo | Scott Francis



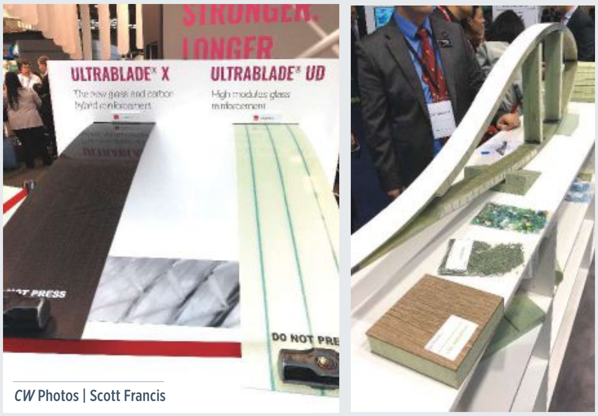
CW Photo | Scott Francis

Carbon fiber dog handle

In the Sports & Lifestyle Planet, **Refitech** (Waalwijk, Netherlands) exhibited its carbon fiber guide dog handle, produced for the Royal Dutch Guide Dog Foundation (KNGF). The handle is said to improve comfort and stiffness as well as reduce weight by more than 50 percent compared to the previous metal version.

LPG tanks

Hexagon Regasco LPG composite cylinders are produced via filament winding for both industrial and home gas storage.



CW Photos | Scott Francis

High-modulus fabrics and recycled foam core for wind turbines

Owens Corning (Toledo, Ohio, U.S.) displayed its Ultrablade X and Ultrablade UD composite fabrics (left) for use in stronger, longer wind turbine rotor blades. Benefits are said to include high modulus and up to 20 percent greater resistance to long-term fatigue loads compared to other materials. **Armacell** (Thimister, Luxembourg) displayed its recycled PET foam cores and demonstrated its use in wind turbines among other applications (right).

CW Photo | Scott Francis

Multi-material composite bike frames

On display in the Sports & Lifestyle Planet, Santa Cruz Bicycles (Santa Cruz, Calif., U.S.) exhibited an additively manufactured carbon fiber-reinforced bicycle frame (pictured in the foreground in the image) custom-built for professional cyclist Danny Macaskill. Epsilon Composite (Gaillan Médoc, France) showcased its wood and carbon fiber composite bicycle (pictured back left).

Fusing waterjet, laser for efficiency in CFRP/CMC machining

Laser MicroJet technology offers high accuracy and speed without heat issues, burring or replacement of cutting tools.

By Ginger Gardiner / Senior Editor

» As carbon fiber-reinforced polymer (CFRP) and ceramic matrix composite (CMC) materials proliferate in aircraft engines, space components and hypersonic applications, machining becomes an issue where precision and efficiency can alter program outcomes. Trying to machine high-reliability and high-accuracy features into CFRPs and CMCs can be challenging due to their hardness and abrasiveness, resulting in slow machining rates, undesirable effects on material properties, inability to meet parts specifications and high operational costs, including recurring tool replacement.

To meet this challenge, a range of laser technologies have been developed for machining such advanced composites. While lasers offer the potential for increased efficiency and elimination of recurring tool costs, the heat generated dissipates into the material, creating potential for microcracking and material change. Lasers also cut at the focal point of the light beam, resulting in V-shaped cuts that can be problematic for precise tolerances.

Laser MicroJet technology developed by Synova (Duillier, Switzerland) creates a laser beam that is entirely contained within a waterjet. The laser is reflected at the air-water interface, similar in principle to an optical fiber, while the water cools the cutting zone and washes debris from the kerf. Advantages of the Laser MicroJet compared to conventional lasers reportedly include no burning or thermal degradation, fewer burrs for smoother surfaces, straight-sided cuts and higher precision.

CW first encountered the Laser MicroJet in its 2017 tour of GE Aviation's Asheville, N.C., U.S. production plant for CMC engine components (see Learn More). Here, it is used to machine holes in CMC shrouds for LEAP aircraft engines. "This technology helps to maintain a high level of accuracy in the hole diameter," says Ryan Huth, GE Aviation's manager for CMC production. "The MicroJet can drill these holes in two minutes versus one hour with conventional machining," says Huth. *CW*'s sister magazine, *Modern Machine Shop*, has also published an informative article on the Laser MicroJet (see Learn More).

Machining CFRP laminates

Using laser pulses contained within a waterjet, the Laser MicroJet demonstrates its capability to produce 3-millimeter-diameter holes in a 2.7-millimeter-thick CFRP laminate at a speed of 1440 mm/min with high quality and precision. Source | Synova

The power of water and light

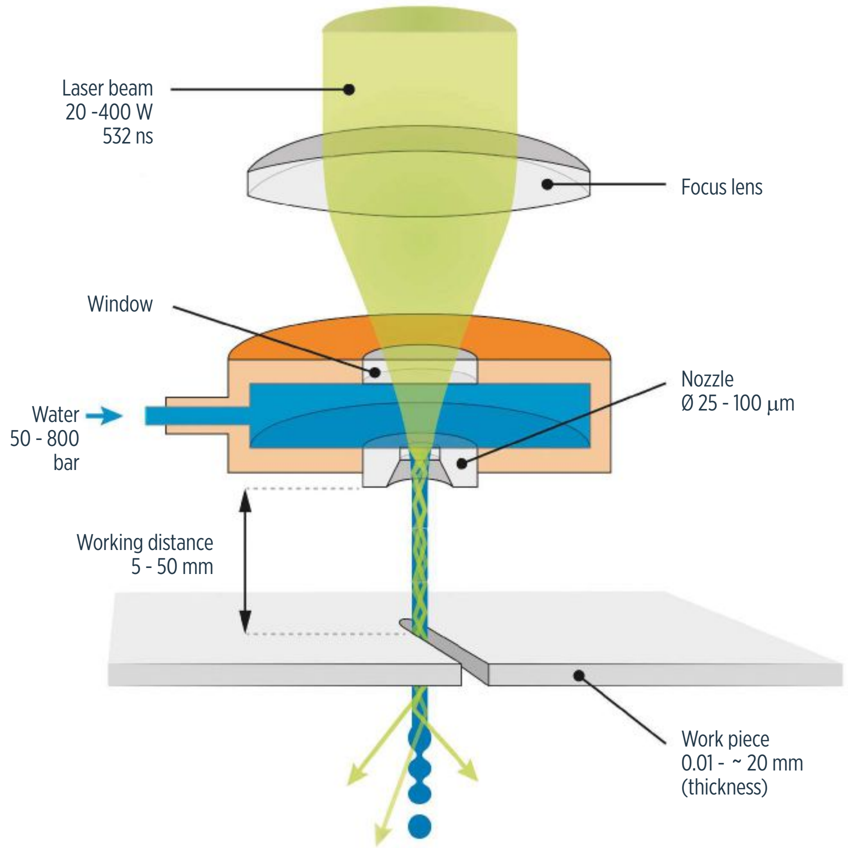
Synova was founded in 1997 by Dr. Bernold Richerzhagen, who patented Laser MicroJet technology after his research at the Federal Institute of Technology (EPFL, Lausanne, Switzerland) in the 1990s. The technology was broadly adopted for semiconductor wafer dicing in 2001. Synova then established local subsidiaries in the U.S., Japan, India and Korea in 2003. These have been expanded to now include micromachining centers, with near-term expansion planned for Taiwan and China. In 2009, Synova established a cooperative development partnership with Makino Milling Machine Co. Ltd. (Tokyo, Japan), introducing a new machine series and advancing these for the machining of medical devices, watch mechanisms, gas and jet engine turbine blades, semiconductor devices and cutting tools from superhard materials.

In the Laser MicroJet system, a laser beam passes through a pressurized water chamber and is focused into a nozzle. The lasers are a common industrial type — solid state Nd:YAG — with a power of 10-200 watts and a wavelength of 1,064 (infrared), 532 or 355 nanometers. The hair-thin jet — diameter of 50-70 microns — of filtered, deionized water is used at a low pressure of 200-650 bar. This results in low water consumption, on the order of 2-3 L/hr, and a negligible force of less than 0.1 newton exerted on the material.

How is it possible to achieve efficient laser ablation within water? "The laser is pulsed roughly 10,000 times per second," explains Jacques Coderre, Synova business manager for the U.S. "For each laser pulse, a plasma is generated that pushes the water upwards, enabling ablation to occur. At the end of the pulse, the plasma collapses and the water now cleans the surface and dissipates the heat." He notes the waterjet also eliminates the complexity and process variations of maintaining the laser in focus typically required with dry laser systems. "This enables cutting thick or non-flat parts without having to worry about being in focus," says Coderre. "The technology also produces a cylindrical laser that creates perfectly parallel walls with tight kerf widths."

Configuring for composites

The Laser MicroJet performs well not only for CMCs, but also for CFRP and stacked laminates. During testing, it produced 3-millimeter-diameter holes in a 2.6-millimeter-thick carbon fiber-reinforced plastic (CFRP) laminate at speeds up to 1,440 mm/min. "With a conventional laser, you »



■ **Fusing water and light for performance**

The Laser MicroJet pulses a solid state laser 10,000 times per second, ablating even the hardest materials with each pulse, while the waterjet cleans and cools the surface in between each pulse. The Laser Microjet is used by GE Aviation to machine holes in its CMC shrouds for aeroengines (bottom). Sources | Synova (above) and GE Aviation (bottom)

■ **Wide range of machines**

Synova has integrated its Laser MicroJet into a range of machines such as a gantry machine for parts larger than 2 meters by 3 meters and its five-axis XLS 1005 with a table for large work pieces (pictured). Source | Synova

have to slow down because of heat," notes Coderre. "Conventional mills can achieve similar speeds but have higher operating costs due to required tool replacement."

The Laser MicroJet can cut 1-inch-thick CMC laminates. "The speed is based on a pretty constant ablation rate of 1 mm^3/min," Coderre observes.

Synova has a range of machines, introducing its five-axis CNC LCS 305 system last year. "This machine excels at high-accuracy 3D cuts and is well-suited for small, CMC parts," Coderre explains. "But it is not a good fit for large CFRP parts." For this, Synova has integrated its Laser MicroJet into a gantry machine, capable of machining parts larger than 2 meters by 3 meters. "It is also easy to integrate with robots and easy to program," he adds. For 2D cuts, the MicroJet software converts a CAD file into machine code. Once verified, the operator simply presses a button and the machine performs the cutting routine. For 3D cuts, Coderre explains that a postprocessor extracts the necessary 3D data from the CAD file and formats it for the Laser MicroJet.

For Factory 4.0 capability, a laser power meter, positioning sensor and automatic jet angle correction are integrated into the Laser MicroJet system. "It is very flexible," says Coderre, "easy to incorporate into parts production as a standalone system or as part of fully automated lines for operator-free, high-volume production." The technology has already been proven in CMC parts for the LEAP aircraft engines, he continues. "For composites, it offers lower manufacturing costs, achieved through faster production speeds, reduced operational costs, higher reliability and higher yields." Such efficiency is indeed what composites need as new materials, markets and competitive metals technologies continue to evolve. CW

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Read this article online | short.compositesworld.com/w-jetlaser

Read more about the Laser Microjet in *Modern Machine Shop* | gbm.media/waterlaser

Read about GE Aviation's use of Laser MicroJet for CMCs | short.compositesworld.com/GEATour

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Reusable vacuum bags go digital

CAD-guided casting boosts precision, utility of reusable vacuum bags.

By Karen Mason / Contributing Writer

■ CAD-directed geometry

Using casting, Industrial Technologies creates reusable vacuum bags that closely conform to the geometries of the components they are servicing. Shown here are bags designed for a high-temperature autoclave application.

Source | Industrial Technologies

» "A lot of our ideas about how vacuum bags work come from our own experience," says Max Caprez, technical sales manager at Industrial Technologies (Akron, Ohio, U.S.), as he recounts the company's history. Starting out more than 20 years ago as a fabricator of composite tools, Industrial Technologies experienced firsthand the challenges of maintaining vacuum integrity across a component, as well as consistency from component to component, in both autoclave and resin infusion applications. As it developed solutions that helped to reduce material costs, labor costs and fabrication time associated with vacuum bagging, the company also leveraged its reusable vacuum bag (RVB) technology to market RVB products to other composites fabricators.

Today at Industrial Technologies' 25,000-square-foot facility, the company produces silicone reusable vacuum bags, as well as cauls, intensifiers and mandrels, as one of its main product lines. The majority of the company's customers come from composites fabrication and maintenance, repair and overhaul (MRO) operations for the aerospace industry. Industrial Technologies continues to make RVB products from conventional silicone materials — semi-cured and cured silicone sheet — but has also advanced RVB technology to a patent-pending cast vacuum bag system. *CW* sat down with Caprez to learn more about the company's cast bags and to glean some advice for composites fabricators as they work with various vacuum bag systems.

CAD-guided manufacturing

Aside from Industrial Technologies' cast vacuum bagging, most reusable vacuum bags are produced using one of two hand-fabrication techniques. The first involves seaming of silicone sheet stock. The second, and more common, method is to use a dedicated spray machine, which creates a silicone film directly on the mold or, in some cases, on a dummy part in the mold, depending on the required fit. Multiple layers are built up to the desired RVB thickness, typically 1 to 10 millimeters. Although each RVB maker has its own silicone formulations, processing parameters and performance characteristics, RVBs generally are successfully providing composites fabricators with a means for a cleaner, more cost-effective molding of production parts, with a return on investment achieved in as few as 10 molding cycles.

Caprez asserts that conventional RVBs are sufficient for a significant number of Industrial Technologies customers. But not long ago, the Industrial Technologies team also recognized that a new approach would be needed to better meet the needs of some customers. The notion of using cast manufacturing arose, Caprez recalls, as the company serviced the needs of the MRO industry. "We were making precision cast parts out of silicone and urethane for MRO applications, and we identified a need for a reusable bag made just as precisely, designed on a computer," Caprez says.

To produce cast RVBs for a customer, Industrial Technologies first taps its engineering team, which develops the RVB CAD model in-house or in collaboration with the customer's design engineers. With computer modeling, the team is able to design offsets into the RVB so that the vacuum bag fits closely over the layup, and the vacuum seal is generated by these bag systems without an external frame. "It lays down right where it needs to be," Caprez says. Compared to cast RVBs, says Caprez, conventional RVBs made from silicone sheets leave a larger gap between the part surface and the bag. "The pull-down to the surface places a lot more stress on the silicone," Caprez notes, "and you don't get the best properties."

Applying the CAD model, a closed-cavity mold in which the RVB will be cast is CNC machined. With closed-cavity molding, cast

RVBs can be produced not only with precise offsets but also with varying thickness, so that the consolidation force generated by the bag can be tailored to the layup of the specific component. Unlike conventionally produced RVBs, cast RVBs can be made with virtually any thickness, and Industrial Technologies has produced cast RVBs as thick as 40 millimeters. The size range of cast RVBs is also noteworthy; Industrial Technologies has cast small parts measured in grams and large parts weighing as much as 500 pounds.

Once the mold for the RVB is built, Industrial Technologies is able to quickly manufacture the needed bags, filling new orders with a 24-hour turnaround. To make each bag, the proper amount of silicone is cast (poured) into the mold, where chemical cure takes place. Casting into a closed-cavity mold enables the company to produce bags that closely fit complex shapes and undercuts much more easily and effectively than hand-manufactured conventional RVBs.

"Everything is very precise," Caprez declares, "to the point where there can initially be over-consolidation of the component with our product." He explains that the more precise offsets provided by the cast RVBs results in greater force generated on the component. "This shows how much more performance you can get from designing something to the right offset and thickness," he concludes.

Integral seal

Operators handling cast RVBs should be trained to prevent scratches or mars, especially on the integral seal, for maximized vacuum performance. Shown here is a debulk bag made from high-elongation silicone. Source | Industrial Technologies

The when and how of RVBs

Caprez acknowledges that some composites fabrication projects are not well suited to *any* RVBs, while others are best serviced by conventional RVBs. "Big parts with low production volumes are not a good fit for our system," he says. The cast manufacturing method makes it simple to manufacture more RVBs, so larger programs that need multiple bags experience a significant cost savings with cast RVBs compared to conventional RVBs. In fact, Caprez says, even the initial cost of the first cast RVB for a project » typically is comparable — and often is less (by as much as 75 percent) — than conventional RVBs.

Most customers of Industrial Technologies' cast vacuum bag system are making a high volume of parts — up to 100,000 annually. Medium-volume applications, primarily in aerospace, may use cast RVBs when the component would be time-consuming to bag with conventional RVBs or disposable systems. The form-fitted geometry of the cast bag means it can be positioned more quickly and easily. The cast system also makes sense for a lower-volume part when it is relatively expensive and requires the precision offered by cast RVBs. Caprez explains, "If the part has large material costs or labor costs, then they want the safest and lowest risk cure operation possible. They get that from our cast system."

LEARN MORE

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

What should fabricators be prepared for when they are applying an RVB for the first time to a particular component? Caprez reports that the most common issues have to do with the overall assembly. In autoclave operations, for example, fabricators sometimes need to make adjustments to the vacuum monitoring equipment that goes inside the bag.

The primary point of focus when installing a vacuum bag system is, of course, vacuum integrity, and Industrial Technologies prides itself on its expertise in finding and eliminating leaks. "When you're bagging," Caprez emphasizes, "the surface where the bagging system is sealing off is critical." This is where the reusable bag should have no scratches or mars that would compromise the seal. Caprez notes that, in general, operators must be trained to handle RVBs with appropriate care — though the RVB is relatively sturdy, scratches (which can be easily overlooked) can render the bag less effective.

Addressing the issues of RVB implementation returns Industrial Technologies to its roots as a composite tool manufacturer. The company continues to draw on its past experience, Caprez says, even as it continues to advance RVB technology for a growing number of composites applications. CW

ABOUT THE AUTHOR

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■ **Process for reusing thermoplastic tape scrap**

Van Wees UD and Crossply Technology BV has developed a high-speed process technology that enables converters and part manufacturers to reuse thermoplastic tape and thermoset scrap to produce chip-based laminates that still offer half the flexural strength and modulus of continuous-fiber tapes in the same material/fiber configuration.

Source | Van Wees UD and Crossply Technology BV

Zero-waste: New process, equipment recycles prepreg, tape offal

Technology provides sustainable approach to reusing valuable thermoplastic scrap in chips-based laminate.

By Peggy Malnati / Contributing Writer

» One challenge of kitting prepreg fabrics or unidirectional (UD) tapes is figuring out what to do with trimmings that are too small or whose fibers are incorrectly aligned for reuse in another project. Although nesting software and cutters have reduced scrap significantly, trimmings still often go into a landfill, which adds to material and part costs as well as environmental burden. However, a Dutch company, Van Wees UD and Crossply Technology BV (Tilburg, Netherlands), is helping improve sustainability by developing a new technology — and the machines that make it possible — to reuse thermoplastic tape and thermoset offal.

Textile roots

Founded in 1945 and with deep roots in the textile industry, Van Wees is a full-service provider that designs, produces, installs and commissions machines and production lines to produce advanced composites (thermoset or thermoplastic, carbon or glass fiber) with a focus on high-quality, high-volume production methods. The company makes prepreg impregnation lines (including creels) — primarily for epoxies on the thermoset side and for materials ranging from polypropylene (PP) to high-temperature polyamides (PAs) on the thermoplastic side — as well as crossply and multiaxial UD tape placement machines, which can process either thermoplastic or thermoset tapes. A sister company, Eltra Engineering BV (also in Tilburg) specializes in industrial automation technology and supplies electrical controls and software for Van Wees machines.

At its Research and Technology Center (R&TC), Van Wees maintains production-scale equipment for its own process development as well as for customers considering a Van

From scrap to sheet

During die-cutting operations to produce net-shape preforms from tailored-fiber laminates in thermoplastic UD tapes prior to molding, scrap is collected and segregated by resin and fiber type. Irregularly shaped and sized scrap is then further chopped to produce chips with a maximum size of 50 by 50 millimeters (above), and the chips are pressed into a consolidated sheet via compression or vacuum molding (right).

Source | Van Wees UD and Crossply Technology BV

Wees system, or who are learning to operate equipment while waiting for their machines to be built. This allows customers to produce material that they can evaluate or, in turn, offer to their own customers for evaluation. For example, at the R&TC, tows can be pulled from a creel and fibers spread and impregnated to produce tapes, which then can be fed through the company's crossply or multiaxial UD machines to produce laminates with a variety of ply layers and fiber orientations. (Crossply laminates have at least two plies oriented at 0/90 degrees and multiaxial UD laminates have at least two UD plies oriented at angles *other than* 0/90 degrees.) Laminates exiting these machines are tacked together for ease of handling. They may next be die-cut into net-shape preforms that are then ready for processing into a composite part. Although Van Wees' equipment focus with the crossply and multiaxial UD equipment is on production of UD *thermoplastic* tapes, the machines can be used to produce tapes with thermoset matrices and/or with fabric rather than UD reinforcements.

Interestingly, it was Van Wees' own scrap problem from making these products for customer testing, as well as customer requests, that led company researchers to develop a "zero-waste process" to recycle chips/offal from preform production using tailored-fiber blanks. As a service, the company is offering customers the opportunity to evaluate these chip-based thermoplastic blanks and already has developed equipment to commercially produce them at high production volumes.

> The 100-percent recycled, zero-waste tailored blanks provide good and orthotropic stiffness and strength.

Waste not, want not

During die-cutting operations to make net-shaped preforms (which Van Wees calls "patches"), scrap material is collected and segregated by resin and fiber type. This scrap is irregularly shaped and sized, so die cutters are designed to produce "chips" with a maximum size of 50 by 50 millimeters. Chopped chips are then pressed into a consolidated sheet (via compression or vacuum molding), resulting in a laminate with randomly oriented, discontinuous fibers. No additional resin is needed to make the sheet, and only chips with chemically compatible resins are mixed together, although both glass and carbon fiber-reinforced chips may be combined depending on properties desired in the final part that will be formed from the chips-based laminate.

Because fibers in individual chips within the laminate can be up to 50 millimeters long, and fiber orientation across the sheet is random, the 100 percent recycled, zero-waste tailored blanks provide good and orthotropic stiffness and strength — particularly compared with short-fiber injection molding compounds. However, since fiber weight fractions for the laminates' discontinuous fiber bundles can run 50-70 percent — with initial formulations on the high end of that range — the material can barely flow in a compression press. To fill »

■ No signs of performance loss

A study conducted by Van Wees compared the properties of UD tailored-fiber laminates (second from top) in several resin and fiber configurations as well as chips-based laminates (top) from scrap produced creating preforms from the UD tailored-fiber laminates vs. a fabric-reinforced organosheet to produce door crash beams (B-side of molded part third from top and A-side of part, bottom). The researchers saw little difference in performance between the part in continuous/UD-fiber laminates vs. a hybrid of the chips laminate in the core and continuous/UD-fiber laminates in the skins.

Source | Van Wees UD and Crossply Technology BV

2.5D or 3D geometry, the chip-based laminate must be overmolded with short fiber or even neat resin in an injection molding machine, or it could be co-molded with a continuous-fiber material in a compression press. Either way, the laminate does need to be preheated prior to molding. Van Wees has found that the chip-based panels still provide half the bending strength and modulus of its high-performance, continuous-fiber crossply panels in the same fiber and resin configuration.

Concept prove out

To showcase the capabilities of its zero-waste tailored blanks, Van Wees has conducted several demonstrator projects. One was a stiffening/crash beam for door inner panels on a passenger car. This effort was based on the Lipa Series project, which developed lightweight composite parts for series production for a range of industries. The now-inactive consortium based in Büsslingen, Switzerland, built on core technologies involving preforming continuous-fiber organosheet/glass-mat thermoplastic (GMT) composites and then back filling with fiber-reinforced resin in an injection molding machine.

High-speed process

The zero-waste process is designed to operate at high production speeds to match other company equipment. For the door crash beam, researchers estimated that with just one multiaxial UD machine (capable of producing 1,800 preforms/hour), the system could easily meet project goals of 2 million parts/year. By adding the additional equipment to convert scrap to chips-based laminates, production volumes would increase 30 percent to 2.6 million parts/year with no waste. Source | Van Wees UD and Crossply Technology BV »

Van Wees' demonstrator beam (a part used to pass side impact/intrusion regulations) was approximately 650 millimeters long, 110 millimeters wide, had a nominal wall of 3 millimeters, and weighed roughly 450 grams in the benchmark material, which was a 3-millimeter glass fabric-reinforced PA6. The part also featured a domed structure in the center that was 40 millimeters high. The organosheet crash beam did not provide sufficient energy absorption to meet application requirements, so Van Wees researchers attempted to improve overall performance in the same wall thickness (since existing tooling was used), in a cycle time of less than one minute and with zero waste.

Van Wees produced UD tapes in-house using several polymers and reinforcements — including glass fiber/PA4/10, glass fiber/PP, carbon fiber/PP, and glass + carbon fiber/PP. Matching short-fiber injection overmolding compounds were produced by the resin suppliers. Simulation was used to evaluate the number and orientation of individual UD plies for tailored blanks in order to meet or exceed performance requirements. Next, tapes were used to produce continuous-fiber laminates, from which the crash beams were produced. Computer-aided engineering (CAE) results predicted the glass fiber/PA4/10 tailored blanks would provide the best properties at lower cost than the fabric/organosheet, and physical testing confirmed this.

To further explore opportunities to reduce waste and cost, researchers reused scrap (approximately 30 percent cutting losses) generated from producing continuous fiber laminates to produce crash beams, recycled that material into chip-based laminates that were 1-millimeter thick, and used that product as a core layer (replacing three UD plies) between "skins" of more UD material made on the multiaxial UD machine. Interestingly, in preliminary tests with a limited sample size, they saw little or no loss in performance for the hybrid laminates with a mix of continuous and discontinuous reinforcement compared to the full continuously reinforced laminates.

Additional calculations conducted by the team indicated that it would be possible to meet Van Wees' production goals of 2 million crash beams per year, using the 1-minute composite overmolding process developed by the Lipa Series team. Given the speed at which the Van Wees tailored-blank production lines operate (1,800 patches/hour on the multiaxial UD machine and 1,260 patches/hour on the crossply machine), adding additional equipment to convert scrap into chips-based laminates would create a zero-waste production system and increase production volumes 30 percent to 2.6 million parts per year. Ironically, the injection molding machines would be the rate-limiting step in this production

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Read this article online | short.compositesworld.com/recycledTP sequence — something that doesn't often happen.

Another rapid-turnaround project that company researchers conducted was to develop composite-faced door handles for the conference room at Van Wees headquarters. Final composite inserts were available for attendees to view at last year's Composites Overmolding conference (presented by *CW*).

"Co-development and innovation are the driving forces of modern industry," notes Rien van den Aker, Van Wees' director. "We believe that joint development with all the players in the composite chain is of prime interest. Metals are the competitors of our industry and are made in the most rational way. Therefore, it will only be with intelligent processes and equipment that we can introduce lightweight composite products into high-volume applications." He emphasizes that it will take a joint effort among supply chain members to make zero-waste production of thermoset and thermoplastic composite parts possible. "Van Wees is happy to assist interested parties with product and process development," he adds. CW

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The still-promised potential of basalt fiber composites

Although the long-anticipated market surge in basalt fiber-reinforced polymer composites remains largely in the future, basalt fiber manufacturers are making headway over the technical and market hurdles toward large-scale application.

Basalt in sporting goods

Kayak paddles are one among many sporting goods applications that benefit from basalt fiber's combination of "give" and strength. Source | Nimbus Paddles

By Karen Mason / Contributing Writer

If you quarry rock originally formed from the rapid cooling of magnesium- and iron-rich lava, and find a way to produce fibers from this rock, it should come as no surprise that the fiber would exhibit excellent thermal insulation and fire resistance properties, as well as very high service temperatures. These key properties have made basalt fiber a standard material for insulation products in high-temperature applications, such as industrial furnace lining and fireproof rope. Basalt fiber producer Kamenny Vek (Dubna, Russia), for example, is supplying a large amount of its product to the U.S. automotive industry for exhaust system insulation, and also to producers of heat-resistant materials for industrial applications.

In addition to its thermal properties, basalt fiber's combination of strength, impact resistance and chemical inertness also have made it an attractive candidate for composites applications. So the question remains: When will basalt fiber-reinforced polymer composites (BFRP) enjoy significant market penetration?

The inside joke, reports James Streetman, manager at Advanced Filament Technologies (Houston, Texas, U.S.), is that BFRP applications "have been five years away from a major breakthrough for the past 15 years." Advanced Filament Technologies offers the trademarked Sudaglass basalt fiber, originally made in Sudogda, Russia, and now produced by GBF Basalt Fiber Co. (Zhejiang, China). All kidding aside, cautious optimism may best describe Streetman's mood — and more generally, the mood of many BFRP stakeholders. For example, Nick Gencarelle, principal at Smarter Building Systems (Newport, R.I., U.S.), describes the BFRP market as "very slow, flat — but in the last two years, things have started to open up a bit. Structural engineers are beginning to more fully understand the need for BFRP."

One clear sign that BFRP may be poised for growth is the recent investment of $20 million to build the first basalt fiber production facility in the United States. Relative newcomer Mafic (Kells, County Meath, Ireland) is building the facility in Shelby, North Carolina, and expects to "go hot" in the third quarter of 2019, reports Jeffrey Thompson, Mafic marketing manager.

It would seem that the appeal of basalt fiber's performance characteristics and the potential for considerable BFRP market penetration are strong. As a result, basalt fiber manufacturers continue to pursue this market resolutely and are ironing out the technical and market issues that so far have kept the breakthrough from occurring.

■ **Price-performance sweet spot**

Recognizable because of its unique color, basalt fiber more importantly provides a unique combination of performance characteristics that place it within the price-performance gap between E-glass and carbon fibers. Source | Kamenny Vek

The appeal of basalt

The notion of creating fiber from basalt is not new; the first patent for basalt fiber manufacture was issued in 1923, and application to military hardware was researched extensively in the 1950s and 1960s. Even major producers of glass fiber explored basalt's potential, though they abandoned this focus in the 1970s to concentrate R&D efforts on better-performing glass fiber, including S-2 glass. While interest in developing basalt fiber-reinforced composites has waxed and waned over these decades, it has persisted and grown in recent years.

A June 2015 MarketsandMarkets Research (Pune, India) report estimated near-term overall growth in the basalt fiber market, including composite and non-composite applications, to be substantial. According to the report, the basalt fiber global market in 2020 will reach $200 million, with a compound annual growth rate (CAGR) of 13.1 percent between 2015 and 2020. "We are in the process of updating our existing study on the basalt fiber market," says Pankaj Kumar Tiwari, MarketsandMarkets associate manager, "as we have witnessed significant changes in this market in 2018." As contributors to the market change, he cites growing use of basalt fiber in hybrid composites, an increasing demand from the automotive market and the appeal of basalt's recyclability combined with its strength (said to be greater than that of E-glass). Tiwari mentions two specific events, as well. In 2018, Owens Corning (Toledo, Ohio, U.S.) acquired Paroc Group (Helsinki, Finland), maker of basalt insulation fibers; also, Mafic and fiber sizing manufacturer Michelman (Cincinnati, Ohio, U.S.) announced a partnership focused on basalt fiber composites.

Basalt fiber's thermal properties are of interest beyond non-composite insulation applications. BFRP opportunities are opening up in applications demanding high and/or wide-ranging service temperatures. Another property, impact resistance, differentiates basalt fiber significantly from glass and carbon. A preliminary study by the Aachen Center for Integrative Lightweight Construction and the Institut für Textiltechnik der RWTH (Aachen, Germany), for example, demonstrated approximately a 35 percent higher specific energy absorption capacity of a basalt hybrid yard woven fabric (HYWF) with polyamide 6 resin compared to glass HYWF/polyamide 6, and 17 percent higher compared to carbon HYWF/polyamide 6.

Basalt rock's iron and aluminum oxides create other favorable characteristics. For example, basalt fiber provides better corrosion and fire resistance than that provided by E-glass. Additionally, a recent study by Mafic in collaboration with the Fraunhofer Project Center (London, Ontario, Canada) confirmed a higher tensile modulus, tensile strength and interlaminar shear strength, a 40 percent higher specific strength and a 20 percent higher specific stiffness for basalt fiber/epoxy test panels compared to E-glass/epoxy panels made with the same resin and fabrication process. Kamenny Vek reports similar results.

Basalt fiber features low water absorption, important in construction and pipe applications. Basalt fiber is electrically nonconductive. As a naturally occurring material, it is also inherently »

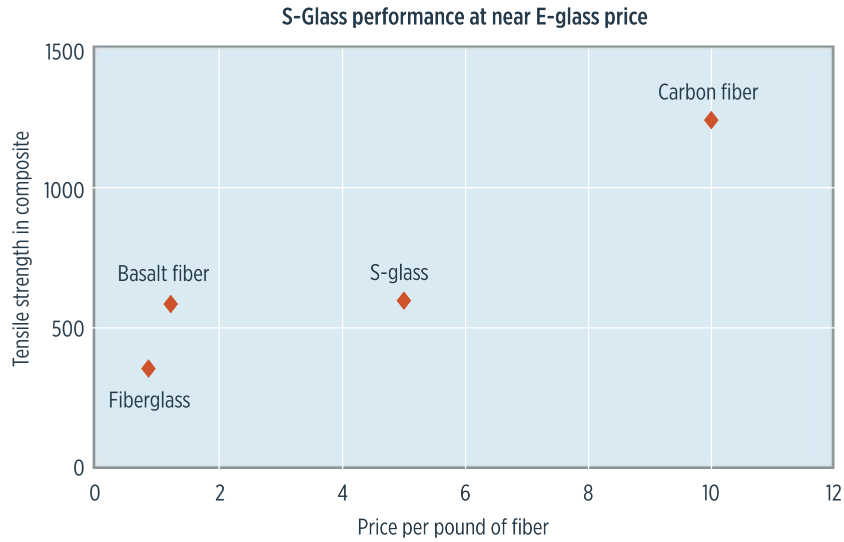
■ **Basalt fiber source material**

Rapidly cooled lava forms basalt rock, which helps explain basalt fiber's excellent thermal properties. Basalt fiber producers seek out basalt sources with consistent composition and properties.

Source | Mafic

■ **Filling the gap**

Data indicate that basalt fiber offers tensile strength comparable to that of S-glass at a cost closer to that of E-glass. Source | Mafic



more recyclable than other reinforcing fibers, a factor that automotive and other industries take into consideration. In sum, Gencarelle refers to basalt fiber as "leaner, greener and meaner" and more impact-resistant than other reinforcement choices. These characteristics point to a sweet spot for BFRPs in the performance window between E-glass and carbon fiber composites. As Thompson expresses it, "We find ourselves to be filling the cost and performance gap between carbon and glass fiber. That market segment has been hungry for a product to fill that space."

A move from carbon fiber to basalt is reportedly an easier business case to make than a move from E-glass to basalt, but both cases can be made. Regarding carbon fiber, cost savings are typically the primary justification for a switch to BFRP; applications for which carbon fiber overshoots performance requirements can be served at the cost-performance point offered by basalt. Also important in some applications are the differing failure modes of carbon and basalt. While carbon fiber, when damaged, tends to "shatter" catastrophically and sometimes in more than one place, basalt fiber experiences what could be characterized as a gentler failure mode. Streetman illustrates: "When a carbon composite prosthetic leg fails, the user falls down; with a basalt composite prosthetic, the user would sit down."

While basalt fiber's relative cost has decreased as production methods have become more efficient, it is still more expensive than E-glass — as much as double the price in large-volume applications — so for an application to absorb this cost increase, it must be adequately counterbalanced by improvements in performance characteristics critical to the application. Characteristics that may come into play include added mechanical performance such as stiffness and strength, resistance to impact, chemicals, corrosion and water as well as a difference in failure mode compared to glass, which tends to splinter more than basalt.

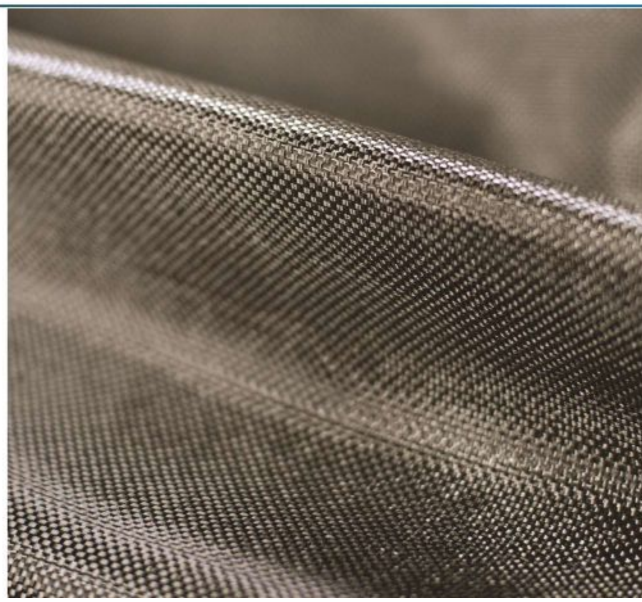
The hurdles for basalt

The basic manufacturing method for basalt fiber is straightforward enough: Much like glass fiber production, basalt fiber is extruded into filaments from the melted raw material, in this case mined basalt rocks. Material efficiency for basalt fiber is enhanced by the fact that no secondary materials are needed to create the fiber, or as Gencarelle puts it, "One pound of rock becomes one pound of fiber." The melt point for basalt of 1,500°C is also comparable to glass, for which the melt point ranges from 1,400 to 1,600°C. Because basalt is opaque, it is more difficult to uniformly heat than glass is, and this has created a need for production enhancements such as keeping the molten product in a reservoir for an extended period, the immersion of electrodes in the bath, or a two-stage heating scheme. These advancements have been made and are well-established technology in basalt fiber plants.

The fact that the raw material for basalt fiber is naturally occurring leads to one major technical hurdle: inconsistent raw material properties. That is, rock mined from different locations varies in the specific quantities of iron, magnesium and other constituents. Key parameters have varied by as much as 10 percent. Pointing out that fiberglass has faced the same challenge regarding raw material variation, Streetman reports, "We have been making headway in providing a standardized product."

In years past, the variation in basalt fiber properties served as a setback to potential applications. "When basalt has been shown to be the best fiber for the application," Thompson explains, "the inability of the customer to rely on material availability, quality and consistency meant that the application would not be commercialized at that time." In overcoming this variation, "the raw material is simultaneously the most important and the least important aspect of our process," Thompson declares. "Once you've identified a consistent source, it's no longer a problem." Mafic uses a European source for its Irish facility. It will use this same source when it begins U.S. production, but the company is also targeting an undisclosed U.S. source for future supply to the U.S. plant. All fiber makers carefully select the source ore and prequalify it, and this along with production process improvements has resulted in greater consistency.

Historically, basalt fiber manufacture has been manually controlled, but fiber makers are advancing their product's quality and consistency with the addition of automated controls. Gencarelle reports that the basalt fiber factory he represents »



Basalt textiles

Basalt fiber producers have developed sizing and fiber handling technologies sufficient for the creation of a full spectrum of fabrics for composites applications. Source | Mafic

is ISO 9000 certified. “They emphasize quality control from the raw materials all the way through the process,” he notes. He believes that the lower limit for variation is around 3 percent which, admittedly, may be too high for aerospace structural applications. But other market opportunities abound, including applications in the sporting goods, prosthetics, cryogenics and energy industries.

In terms of the market, basalt fiber manufacturers report that the biggest hurdle today is regulatory. “Many areas in the construction industry,” Streetman explains, “can only use materials that have been accepted into the code.” He mentions the Florida Department of Transportation as one body that has been “more forward-thinking” and is closing in on standards for acceptance of basalt composites. Gencarelle also points out that the American Concrete Institute has recognized that basalt rebar meets the institute’s requirements for rebar applications. Still, work lies ahead before construction and other industries achieve widespread code acceptance for basalt composites.

Finally, and perhaps most significantly, basalt fiber producers find themselves in a market “Catch-22,” especially with respect to current E-glass applications. The large volume of many such applications means that current fiber use is greater than the current capacity that basalt fiber manufacturing facilities could begin to meet. Even if basalt fiber is technically the best fit for an application, composites manufacturers don’t want to commit to a BFRP design unless they know they can get enough product. Conversely, since it takes two to four years to commission a large basalt fiber plant, basalt investors want assurances that market demand will be there when the plant comes online.

BFRP activity

If basalt fiber providers can point to one application that portends particularly well for BFRP growth, it would be rebar. Like fiberglass rebar, basalt rebar is considerably lighter than conventional steel rebar, "over 70 percent lighter, in fact," Gencarelle says. "One person can easily lift a 100-meter coil of 10-millimeter basalt rebar." Advantages over glass rebar include basalt's natural resistance to rust and corrosive liquids and chemicals, he continues. This makes it well-suited to marine applications, chemical plants and other potentially corrosive environments. "Also, moisture penetration from concrete does not spall, so it needs no special coating like fiberglass rods," he adds. Gencarelle also highlights the match between basalt rebar's and concrete's coefficient of thermal expansion. The fact that it is nonconducting makes basalt rebar a good option for buildings that house MRIs or data-intensive operations.

Gencarelle reports some work being done to bring basalt rebar pultrusion factories to the U.S., noting that such a move would help grow basalt's market share both by avoiding tariffs and by allowing these factories to compete for projects that specify U.S.-made rebar.

Work on the regulatory front continues. Basalt rebar is included in the national construction codes and is widely used in the construction industry of countries like Russia, Ukraine and China. "In some other countries, like the United States, Canada, the United Kingdom, Italy and Poland, basalt rebar is widely used in applications where certification is not required, such as swimming pools and garden paths," says Oleg Kuzyakin, commercial director for Kamenny Vek. Major basalt rebar certification efforts are underway in these countries. "In some European countries like Germany and France, this process is more expensive, long and complicated than in others," Kuzyakin adds, "but we see rising interest in basalt rebar in these countries, too."

More sporadic activity characterizes other applications and market segments. Streetman notes, for example, that automotive companies have employed BFRP panels consisting of chopped fiber and thermoplastic matrix to improve impact and corrosion resistance. These programs have come to an end, though, and Streetman is not aware of any current BFRP work in production automotive applications. Kuzyakin confirms, "Customers want to use our fiber for production of different types of panels for trucks, and in car parts made with polypropylene or polyamide resin, but these are not commercial projects yet."

In India, Russia and Korea, Kamenny Vek chopped basalt fiber is used to make brake pads. The company also reports a significant amount of its fiber being used in compressed natural gas (CNG) cylinders for buses and trucks as well as residential applications.

Another growing application area is in composite pipes. Wavin Ekoplastik (Kostelec nad Labem, Czech Republic) has developed a polypropylene (PP) pipe with a basalt fiber-reinforced layer that exhibits as much as a 50 percent improvement in pressure » resistance at high temperatures and 20 percent improvement in flow rate compared to the baseline glass fiber/PP pipe.

Kamenny Vek's Australian partner Basalt Fiber Tech (Melbourne, Australia) is supplying basalt fabrics for marine applications, and numerous sporting goods applications are also using the company's fiber, though Kuzyakin notes that these currently are not high-volume markets. "Of greater potential in terms of volume is wind energy applications," Kuzyakin reports. "Wind is one of the most prominent applications. We consider it strategically important but long-term because of the *very* long, complicated and costly procedures of certification and qualification."

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Prosthetics and orthotics, as mentioned earlier, benefit from basalt fiber's greater "give." A November 2018 *CW* story reported one such application by Coyote Designs (Boise, Idaho, U.S.). Some of the company's customers found carbon fiber polymer composites to be uncomfortably stiff, and the prosthetics suffered from a high rate of cracking failure. Interestingly, another factor that made the switch to basalt attractive was that, unlike manufacturing with basalt fiber, manufacturing with carbon fiber involved masks, protective gear and dust collection systems for health and safety. BFRP improved the prosthetic's flexural properties and reduced the failure rate significantly.

In sporting goods, often a hybrid carbon-basalt design is used to gain the advantages of each fiber type. The digital magazine *Basalt Today* is replete with examples, including Wilson (Chicago, Ill., U.S.) badminton rackets, Niche (Holladay, Utah, U.S.) snowboards and Nimbus Paddles (Heriot Bay, B.C., Canada) kayak paddles.

The future seems near

Though a substantial BFRP breakthrough has not yet materialized, progress seems to be occurring on all the necessary fronts: manufacturing efficiency and capacity, global presence, product design and development and regulatory activity. "We think we're in a fantastic place today," Thompson declares, "and our customers have been showing us that they believe it too, by their level of investment and their desire to see our U.S. facility come online."

Anticipating significant developments in the next 12 to 24 months, Thompson concludes, "We're excited to be an additional composite tool in the toolkit." CW

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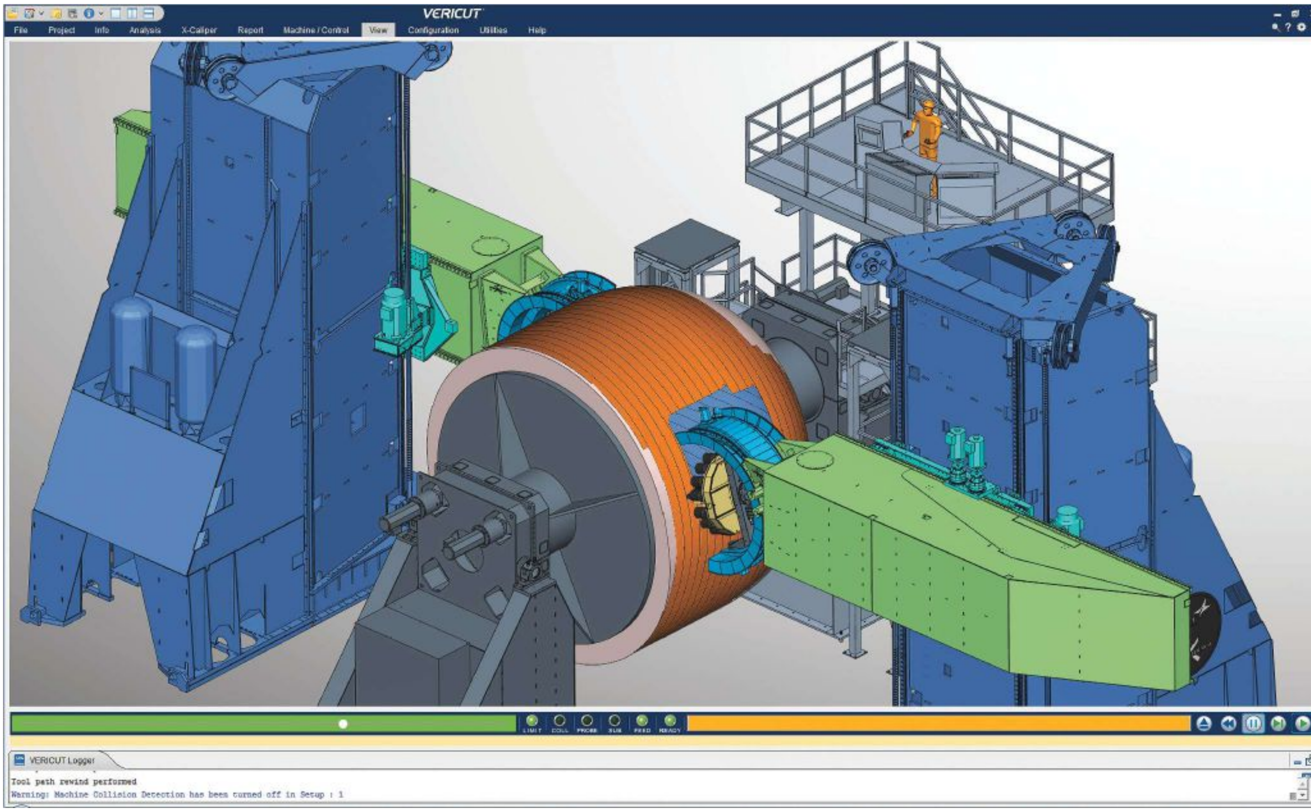


Smarter, integrated data for ATL/AFP

More than helping to eliminate dry runs and costly errors, AFP/ATL software is beginning to benefit the whole product lifecycle through the interconnectedness of the digital thread.

By Karen Mason / Contributing Writer

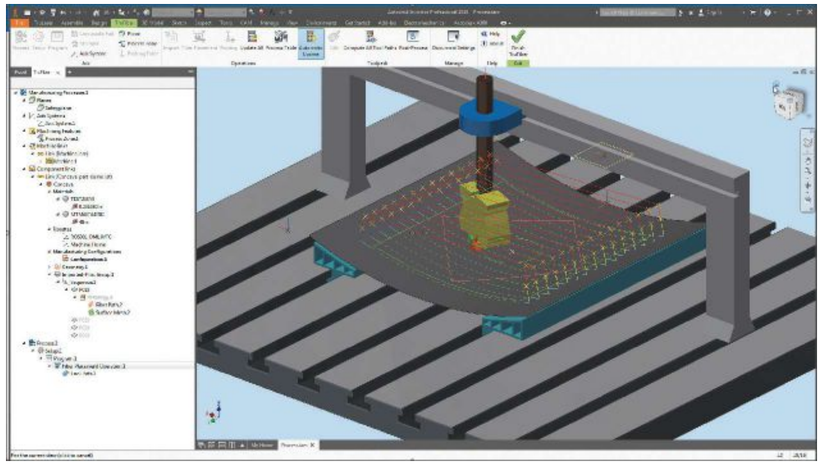
Digital value

With multi-million-dollar machines building multi-million-dollar components like composite fuselages, programming and simulation play an essential role in AFP/ATL operations. Early entrant CGTech developed the first machine-independent program, VERICUT Composites software, in 2005.

Source | CGTech

» "Too often, designs are thrown over the wall to manufacturing." Neatly summarizing a common yet undesirable state of affairs, Robert Yancey, director of manufacturing and production industry strategy and business development at Autodesk (San Rafael, Calif., U.S.), goes on to talk about the "convergence of design and manufacturing" to which his company is devoting significant resources. Such efforts are a crucial element in the build-out of the digital thread, which is meant to provide the communications framework that ultimately will connect functions throughout a product's lifecycle.

Variously called "smart manufacturing," the "Industrial Internet of Things (IIoT)," or "Industry 4.0" (alternately, "Industrie 4.0"), the digitalization of today's manufacturing operations is well underway in many sectors. In some instances, like the fully automated Siemens (Munich, Germany) Simatic programmable logic controller (PLC) factory in Amberg, Germany, or the Composites Technology



Optimizing operation

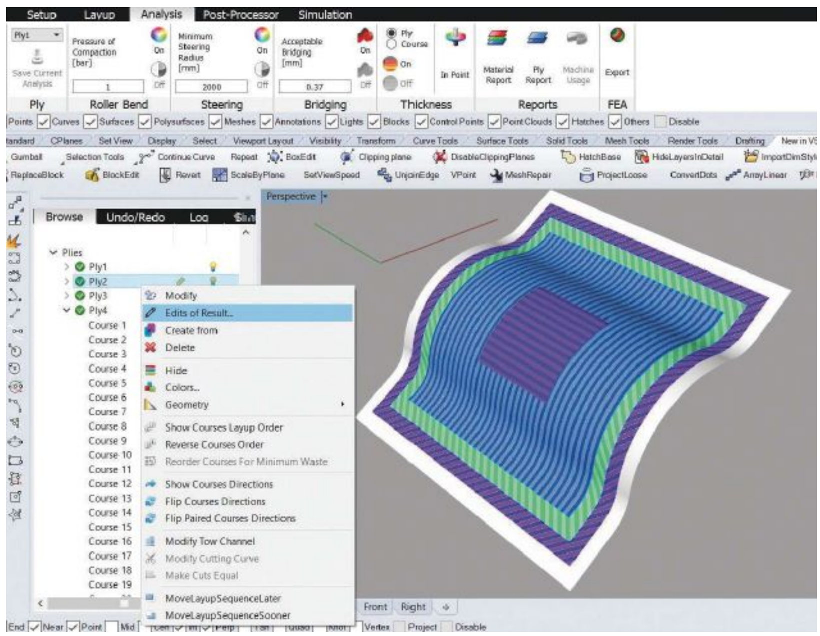
Maximizing efficiency while ensuring that design requirements are met, Autodesk's TruFIBER software optimizes operational parameters and generates NC code for AFP/ATL manufacturing.

Source | Autodesk

Center (CTC, Stade, Germany; a subsidiary of Airbus Operations GmbH), full digitalization has been deliberately implemented from near-clean sheet design (see Learn More). Much more commonly, though, manufacturers must transition incrementally from existing operations to the fully digital future.

In the case of automated fiber placement (AFP) and automated tape laying (ATL) systems, digitalization of composites fabrication is lagging a few steps behind other manufacturing operations — and with good reason. "Composites manufacturing is radically different and not as mature as metal cutting," notes Andre Colvin, composites products manager at CGTech (Irvine, Calif., U.S.), adding, "Machine builders and users all hold their cards close to the chest. They want to maintain every advantage possible over the competition."

Yet discernable progress is occurring in AFP/ATL digitalization on two fronts. First, machine-independent software continues to mature, enabling a composites manufacturer to use the same software package on different AFP/ATL brands. This maturation also means developing support for new AFP/ATL or similar technologies within the software package. Second, software developers are working to implement the digital thread so that different functional groups within design and manufacturing communicate and interact more directly and efficiently. »



Navigating curves

Digitally building out an AFP program ply by ply, MikroPlace and other AFP/ATL software packages analyze fiber paths to effectively traverse curved surfaces while placing material with acceptable fiber orientation, overlaps and gaps. Source | Mikrosam

AFP/ATL digital automation pieces

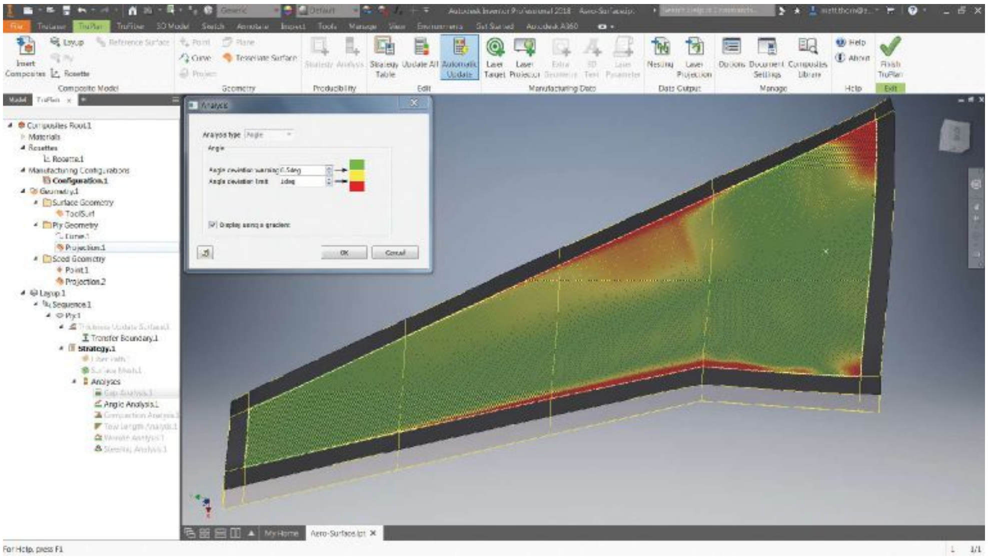
To optimize the efficiency of an AFP/ATL or similar system, fabricators strive to achieve the dual objectives of (1) running the machine at the maximum feed rate as often as possible, while (2) minimizing production errors by slowing down in areas of the layup where multiple material cuts and adds take place repeatedly or in areas of high contour. Described in the 2017 CGTech whitepaper "Roadmap to Automated Composites," these objectives are prompting ongoing developments in the machines themselves, from the end effectors laying down the material to robotics and novel high-speed continuous-fiber preforming approaches. Of equal importance, though, is ongoing development of the software that enables the machine to produce the component as designed, or to alert designers of needed changes for manufacturability.

AFP/ATL manufacturing software consists of multiple modules. Machine control software — the numerical code (NC), most commonly "G-code" — directs the machine's movements and operational settings. Machine programming software, or path-planning software, provides operational data to the controller, via postprocessing, for each component to be built. This software dictates the direction and position in which the material will be placed. It is designed to optimize tool paths, feed rates and other operational parameters. Simulation software, working in concert with machine programming, takes the engineering of a production run offline and enables manufacturers to visualize production on-screen. It does so by processing the G-code that the postprocessor has generated. Digital simulation replaces dry runs on the actual production equipment, saving significant time and cost. "These are high-value machines, and the material being laid down is expensive," Yancey says. "So any activity on the machine that is not making the product is costly."

Machine independence

The basic goal of AFP/ATL software is to read composite part design data from the CAD system, then create and simulate an NC program for the automated layup machine. Getting from CAD to an NC program is an iterative, multi-step process. Of course, even before the CAD file is sent to manufacturing software, multiple steps typically occur within design, including laminate and ply design, analysis and simulation. Next, a tool surface is designed using the CAD data, generating information that is as essential to the layup machine as the part information. Machine programming imports part and tool information and creates the NC paths. Some iteration occurs at this point: paths that meet the requirements of the material and of the AFP/ATL process are fed back to the CAD program to ensure that the design can be produced. This process accounts for factors such as material steering limits, the curvature of the tool, overlaps and gaps and minimum tow length.

Once the machine programming and design modification have reached a satisfactory result, a postprocessor generates code specific to the AFP/ATL machine being used. "For each step in creating these part programs comes the possibility



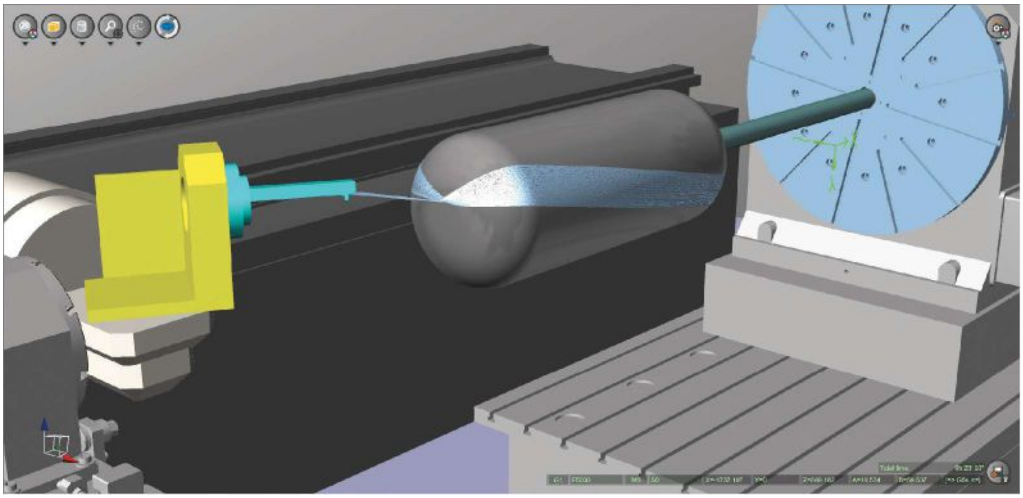
Fiber path analysis

AFP/ATL software packages include analysis of fiber orientation, which deviates from the ideal as the layup head negotiates curved surfaces and complex geometries. Autodesk TruPLAN software here indicates in red the areas in which deviation exceeds manufacturing tolerance.

Source | Autodesk

of introducing a mistake," Colvin notes. "If there is a missing tow or material is placed somewhere other than where you were expecting, it is very expensive to have to scrap the component." Therefore, the NC code is used to simulate the layup process via the manufacturing simulation program.

As the number of companies offering similar production technology grows, OEMs and other large manufacturers do not want their engineering teams to have to learn and maintain multiple software packages from machine to machine, so demand for *machine-independent* software has grown. This is how CGTech first became involved in AFP/ATL software development. In 2004, as The Boeing Co. (Chicago, Ill., U.S.) implemented AFP technology for major 787 *Dreamliner* components, it was clear that multiple AFP/ATL machine types would be employed by Boeing internal »



■ **Simulating different machines**

NCSIMUL software was first applied to filament winding, then to AFP/ATL simulation, while other software providers expanded their composites manufacturing portfolio after starting with AFP/ATL. Source | Hexagon

teams as well as its tier suppliers. For this reason, CGTech developed its software in a way that would enable it to work with *any* AFP/ATL system.

The 2005 release of VERICUT AFP/ATL met Boeing's requirements as it successfully programmed and simulated Electroimpact (Mukilteo, Wash., U.S.) AFP machines but was customizable to work with other systems. Soon after, the company released its VERICUT Composites Applications with two modules: VERICUT Composite Programming (VCP) and VERICUT Composite Simulation (VCS). VCP reads CAD surfaces and ply boundary information and creates fiber-placement paths to fill the plies according to user-specified manufacturing standards and requirements. Layup paths are linked together to form specific layup sequences and are output as NC programs for the AFP machine.

VCS reads CAD models of the layup tool and fixtures, and simulates the layup sequence directly from NC program files. Tow material is applied to the layup form via NC program instructions in VERICUT's virtual CNC simulation environment. The simulated material applied to the form can be measured and inspected to ensure the NC program follows manufacturing standards and requirements. A report showing simulation results and statistical information can be automatically created.

Just as the VERICUT composites application family is designed to work with any AFP/ATL machine, VCS can also simulate directly from VCP or from other composite layup path-generation offline programming applications.

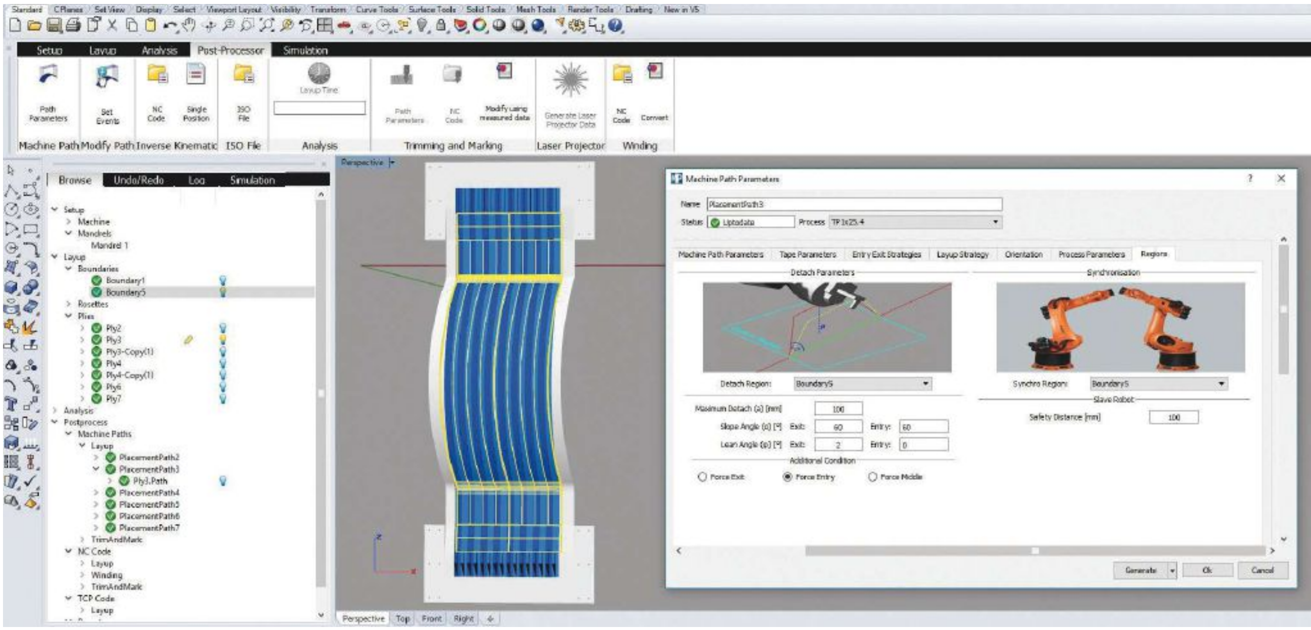
Prior to developing software for composites fabrication, CGTech built its reputation through its VERICUT metal machining software, for which Boeing has been a customer since 1989. Another company, the maker of NCSIMUL software now owned by Hexagon Manufacturing Intelligence Division (Boston, Mass., U.S.), also developed its composites manufacturing package on the foundation of CNC machining software. Created in 2014, NCSIMUL Composites focuses on the simulation function in AFP/ATL (as well as filament winding) programming, including NC program analysis, material layup simulation and results analysis.

NCSIMUL added composites manufacturing simulation after a customer asked for the capability to simulate wire winding. Branching into an additive process from CNC machining, the company seized the opportunity and expanded the program to include composite tow layup. "The two technologies were similar, except that the fiber had to be treated as rectangular (that is, accounting for width)," explains Silvère Proisy, general manager for Hexagon's production software business. "The challenge was to understand how to deposit material, instead of taking it away. We needed to know a lot about the technology the placement head was using."

Not all composites fabrication software started with metal machining, though. Instead of working from a CNC software foundation, the TruComposites suite of software tools branched into automated composites manufacturing initially from cutter nesting and laser projection software. The suite, created by Magestic Systems (Westwood, N.J., U.S.) and now owned by Autodesk, includes AFP/ATL-relevant modules: TruPLAN analysis and optimization software, which includes fiber path generation for AFP/ATL applications; and TruFIBER, which optimizes AFP/ATL operational parameters and generates NC codes for manufacturing.

In 2009, Makidea (Prilep, Macedonia) beta tested its MikroPlace software package, which was written for use with a then-new AFP machine from sister company Mikrosam (Prilep, Macedonia). MikroPlace was modularly constructed from the start, so that it could accommodate other AFPs and ATLs. MikroPlace version 4.0, now offered by Mikrosam, supports filament winding and 3D printing as well as AFP/ATL, and also supports multiple machines or robots working on different aspects of the same project.

These production software developers have emphasized the advantages of machine-independent software, noting that the metal-cutting industry experienced a similar move from software »



Programming multiple machines

AFP/ATL software continues to evolve and add capabilities to keep up with AFP/ATL hardware. MikroPlace version 4.0, for example, supports multiple machines or robots working on different aspects of the same project. Source | Mikrosam

created by the machine tool builder to software developed separately.

Colvin agrees that manufacturers are free to select the best machine for a specific part, family of parts or manufacturing process, without having to introduce a different piece of software into the engineering process for each brand of machine. He adds, "When software is separate from the machine and applied in a variety of applications, the software increases efficiency and agility of the overall manufacturing process."

Of course, some AFP/ATL manufacturers have maintained their proprietary software. Automated Dynamics (Niskayuna, N.Y., U.S.) is one of several AFP/ATL manufacturers that chose to keep software development in-house. The company's FPM (Fiber Placement Manager), which supports planning, development and simulation of an AFP-built composite structure, and FPS (Fiber Placement Software) automation machine control are Windows-based programs to provide ease-of-use for the proprietary suite. One advantage of proprietary software developed by the machine builder is that all troubleshooting is the responsibility of one supplier.

Whether proprietary or machine-independent, AFP/ATL software is primed for fuller integration with other software systems, working toward a complete digital thread.

> There is a need for communication between functions in the design-to-manufacture cycle.

Functional data integration

Building out the *digital thread* in AFP/ATL operations entails integration not only of the manufacturing software modules but of the full product lifecycle, from design to manufacturing and inspection of each component, and ultimately to assembly and MRO (maintenance, repair and overhaul) operations through the life of the final product. The primary challenge to this integration is what the smart manufacturing community refers to "traditionally siloed" functions. That is, design functions have developed and evolved separately from manufacturing functions such that moving information from one to the other is by no means automatic. A fully functional digital thread will erase the communication barriers between functions and make application development a much more streamlined process.

However, there are two factors that make interconnectedness more difficult for the manufacture of composite components than for metal, plastics and other materials. First is that AFP/ATL is still a relatively young technology. Further, AFP/ATL hardware is still evolving, with a great deal of customization, Colvin notes. "In order to be successful, companies often need customization on the machine to fit their parts and process — every machine has something custom. And everyone's process is different: different rollers, separate debulks and more."

Second, the relatively large number of variables in composites design and manufacture, due to composites' anisotropic and heterogenous nature, has led to more functional silos than for manufacturing with metals and other isotropic, homogenous materials. "With metal cutting, it doesn't matter how you got there, as long as the part matches the final design," Colvin says, "but different procedures in composites programming will lead to completely different parts."

There is an obvious need for communication between functions in the design-manufacture cycle. Software providers are working diligently toward this end. "We are getting a better representation of what can be manufactured, and going back to ensure it meets design specifications," Yancey continues. "This is allowing us to reduce overdesign to account for laps and gaps, for example, and to make a lighter weight composite structure."

Yancey points specifically to Autodesk's introduction of Fusion 360, a cloud-based common data environment connecting design and manufacturing workflows. Initially, Fusion 360 is supporting CNC machining for manufacturing, "but additive manufacturing is next to be addressed," Yancey says. This includes AFP/ATL programming as well as 3D printing software. Currently under development at Autodesk is Fusion Production, an additional product that will enable manufacturers to plan, monitor and optimize production performance.

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short.compositesworld.com/AFPATL2009

Similarly, CGTech has partnered with Siemens PLM Software (Plano, Texas, U.S.), integrating VERICUT with Siemens Teamcenter digital lifecycle management software. According to the companies, this integration enables CGTech users to seamlessly interact with technology designed to enhance product development decision making and produce better products. Following historic trends in the same way that Fusion 360 has, VERICUT metal-cutting software is currently being integrated with Teamcenter; CGTech reports that VERICUT Composites software is not yet integrated with Teamcenter.

Yancey expects not only a convergence between design and manufacturing but also a convergence in manufacturing methods. "If we have a robot cutting material, what can we learn from that and apply to a robot laying down material?" He foresees hybrid workflows and greater ability to investigate tradeoffs with different manufacturing methods. CW

ABOUT THE AUTHOR

CW contributing writer Karen Mason focused academically on materials science and has been researching and writing about composites technology for more than 25 years.
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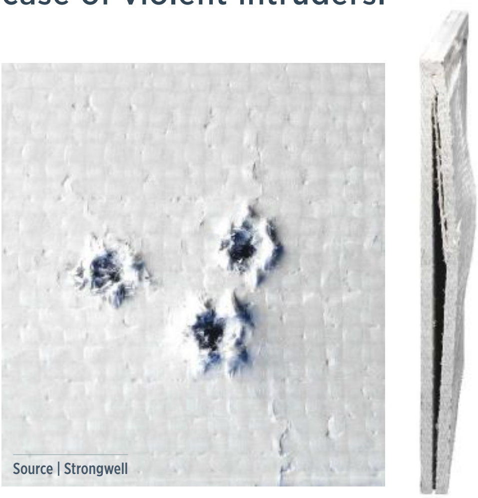
Ballistic panels protect school

A composites manufacturer has developed military-grade pultruded panels that are being used to protect schools in case of violent intruders.



Source | Strongwell

It's an unfortunate fact of modern life that many school districts across the U.S. feel the need to protect themselves from violent intruders. In addition to training, schools have begun to implement a huge array of smart technology and materials to fight security threats, which the Washington Post (Nov. 13, 2018 issue) has estimated could represent a $2.7 billion market.

One composites manufacturer is a part of this growing market. Strongwell's (Bristol, Va., U.S.) pultruded HS Armor panels, which were first produced as a military product application, are designed for ballistics resistance. The monolithic (non-cored) panels are pultruded using multiple layers of woven mat — with the number of layers dependent on the performance requirements — wet out with a proprietary (non-epoxy) resin matrix and cured in a controlled cycle. Panels are typically 4 ft. wide, in lengths ranging from 8 to 12 ft. When struck by a bullet or other projectile, HS Armor panels delaminate in a way that absorbs the energy while stopping the projectile. They have been independently tested to Underwriter's Laboratory (UL) 752 (Levels 1 through 8) and National Institute of Justice (NIJ) Ballistics Specifications (Levels 1, 2A, 2 and 3A) and meet the UL 94 V-0 flammability rating.

A school in Tennessee with almost 1,200 students underwent a renovation during the 2018 summer break to secure its main entrance using Strongwell's panels. The school district procured more than forty HS Armor panels to provide UL Level 8 protection, which means they are capable of withstanding multiple shots from a military-style assault rifle. A wall between two classrooms was taken down, and a new, secure entry room was created by the contractors. The HS Armor panels were hung and installed, just like drywall, on the four walls of the new entry room. Standard drywall panels were then placed over the composite panels and finished in a matter of days. The entire area was completed, including paint, trim and electrical wiring, in less than four weeks. According to Strongwell, both the contractor and school were surprised with the ease of installation and quality of the armor panels. CW

Composites Events

April 29-May 2, 2019 — Long Beach, Calif., U.S.
AeroDef 2019
aerodefevent.com

April 29-May 2, 2019 — Chicago, Ill., U.S.
AUVSI XPONENTIAL 2019
xponential.org

May 6-8, 2019 — Beijing, China
SAMPE China 2019
sampechina.org

May 20-23, 2019 — Houston, Texas, U.S.
AWEA WINDPOWER Conference 2019
windpowerexpo.org

May 20-23, 2019 — Charlotte, N.C., U.S.
SAMPE 2019 Technical Conference and Exhibition
nasampe.org

May 21-23, 2019 — Detroit, Mich., U.S.
Rapid + TCT 2019
rapid3devent.com

June 5-7, 2019 — Metz, France
ICWAM 2019 - International Congress on Welding, Additive Manufacturing and Non-Destructive Testing
icwam.com

June 9-11, 2019 — Annapolis, Md., U.S.
ACMA Composites Executive Forum
s1.goeshow.com/acma

June 12-13, 2019 — Stade, Germany
CFK-Valley Stade Convention 2019
CFK-Valley.com

June 13, 2019 — Rosemont, Ill., U.S.
Additive Manufacturing Workshop for Plastics at Amerimold
additiveconference.com

June 17-23, 2019 — Paris, France
Paris Air Show
siae.fr/en/

June 18-19, 2019 — Santa Clara, Calif., U.S.
MT360
mt360conference.com

June 19-20, 2019 — Chicago, Ill., U.S.
JEC Chicago 2019
jec-chicago.events

July 3, 2019 — Vigo, Spain
MATCOMP19
matcomp19.com

July 22, 2019 — Kelowna, British Columbia, Canada
CANCOM 2019
CANCOM2019.ca

Aug. 11-16, 2019 — Melbourne, Australia
ICCM22 — The 22nd International Conference on Composite Materials
iccm22.com

Aug. 27-29, 2019 — Austin, Texas, U.S.
Additive Manufacturing Conference and Expo
additiveconference.com

Sept. 4-6, 2019 — Novi, Mich., U.S.
SPE Automotive Composites Conference and Exhibition (ACCE)
speautomotive.com/acce-conference

Sept. 10-12, 2019 — Messe Stuttgart, Germany
Composites Europe
composites-europe.com

Sept. 23-26, 2019 — Anaheim, Calif., U.S.
CW CAMX 2019
thecamx.org

Oct. 1-3, 2019 — Tampa, Fla., U.S.
IBEX 2019
ibexshow.com

Nov. 19-21, 2019 — Knoxville, Tenn., U.S.
CW Carbon Fiber 2019
CarbonFiberEvent.com

Nov. 26-28, 2019 — Copenhagen, Denmark
WindEurope Offshore 2019
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New Products

Source | Airtech

» CURING ACCESSORIES

High-temperature vacuum valve

Airtech (Huntington Beach, Calif., U.S.) introduces its VacValve 429 SS HTR, designed for high-temperature cures in situations where standard valves with silicone rubber seals fail. VacValve 429 SS HTR is to be used for direct connection to vacuum hoses instead of complex and expensive coupling systems. It is said to be usable up to 900°F (482°C) in combination with new high-performance graphite seals. This valve can be directly screwed to the company's Airflow 800 or BBH1080 hoses, which are said to provide safe connections for high-temperature processes for materials such as thermoplastics. Graphite seals for high-temperature use can be ordered separately.

According to the company, the valve provides a simple, low-space connection to vacuum hoses, and its high-temperature gasket improves sealing performance, reducing the risk of vacuum leakage. **airtechonline.com**

Source | Cygnet Texkimp

» FILAMENT WINDING

Four-axis filament winding machine

Cygnet Texkimp (Northwich, U.K.) recently launched its four-axis filament winder. The new winder, meant to complement the company's 3D Winder and robotic filament winding machine, is said to add an accessible option to a wider cross-section of the market but retaining specialized features like optimized geometry, reduced contact points and accurate surface finishes.

The winder's launch comes two years after the company unveiled its robotic 3D winding machine, the 3D Winder, to create complex composite parts for the automotive and aerospace markets in high volumes and at high speeds. It is also a year since the launch of the company's robotic filament winding machine. **cygnet-texkimp.com**

Source | Harper International

» FURNACES & OVENS

Next-generation oxidation oven system

Harper International (Buffalo, N.Y., U.S.) announces the release of its next-generation oxidation oven system, as well as enhancements to its high-temperature (HT) furnace systems.

The 3-m-wide production-scale oxidation oven includes enhancements such as better thermal and air velocity uniformity, said to demonstrate up to 30% improvement in production efficiency. The stainless steel interior of the advanced oxidation oven design is said to enable a range of precursors to be produced throughout all line sizes, from research to production scale. Additionally, this most recent design reportedly yields longer equipment life, improved corrosion resistance and increased carbon fiber quality.

The proprietary oven design is said to nearly eliminate chimney effect, while also providing optimal thermal and velocity uniformity at the fiber entrance and exit points. The patented supply nozzles are said to provide consistent velocity across the width, length and height of the oven for maximum uniformity across the tow band throughout the fiber processing volume. Independently adjustable louvers are provided internal and external to the end seal, enabling operators maximum energy efficiency and minimum fugitive gases. Harper's end seals also feature a maintenance door on both sides of the chamber, enabling quick and convenient service actions.

Enhancements to Harper's HT furnace systems for fiber manufacturing include improvements to the entrance throat section, including on-line cleaning capabilities. According to Harper, debris and filament buildup impedes and disrupts smooth gas flow in a carbon fiber HT furnace, resulting in non-uniform properties across the tow band. The debris needs to be removed periodically during the operation of a fiber production line. Traditional cleaning techniques require reduction of HT furnace temperatures in order to gain access for cleaning, resulting in reduced furnace run times. Harper's new on-line cleaning system, located in the entrance section, is said to enable cleaning while the furnace is hot, resulting in increased run-time.

In order to prevent exposure of the HT furnace to an air atmosphere, the on-line cleaning feature is self-contained and sealed with an incorporated nitrogen purge. Additionally, Harper's on-line cleaning system includes sight-ports that permit the operator to see into the process chamber in order to assess the level and location of the debris. The on-line cleaning feature offers Harper HT furnace users improved fiber thermal uniformity and increased furnace utilization. **harperintl.com**


Source | TCS

» PREPREG MATERIALS

Epoxy prepreg for aerospace interiors

Total Composite Solutions (TCS) Ltd (Havant, U.K.) introduces its epoxy prepreg solution to the aerospace interiors sector. The material range developed and manufactured by Microtex Composites Srl (Prato, Italy), TCS's prepreg partner, are said to enable substitution of traditional phenolic systems with these materials, while exceeding the requirements of industry standard FAR 25.853.

Advantages are said to include improved finished part quality, reductions in potential rework and resulting commercial or supply chain gains in manufacturing. The material can also be oven cured, enabling flexibility for manufacturing large structures without autoclave cure. All test properties achieved to date, the company says, have been produced from oven-cured laminates. The company sees potential for this material to be used for lighter weight structures with enhanced fire performance properties. **totalcompositessolutions.com**

» RESIN SYSTEMS

Flow media for resin infusion

SWM International (Alpharetta, Ga., U.S.) announces the introduction of Naltex flow media for resin infusion processes. This flow media is engineered to retain up to 15% less wasted epoxy resin than is commonly trapped in media grid apertures after processing, while maintaining high flow rates compared to current technology. Designed for wind energy, marine and aerospace composite vacuum-assisted resin transfer molding (VARTM) processes, Naltex resin infusion media also features a soft, flexible edge that is reportedly safe for use with sensitive vacuum bags that are prone to abrasion and puncture.

The Naltex family of diamond net flow media includes a variety of resin material options, engineered to withstand high temperatures, improve drapeability, increase flexibility and reduce the amount of retained resin within the media apertures. Configurations are also available for applications that require low, medium and high flow rates. **swmintl.com**


Source | KRC Machine Tool

» CUTTING & KITTING

Configurable machine tool system

KRC Machine Tool Solutions (Independence, Ky., U.S.) introduces its KRC Fusion VI high-performance machine tool, a modular, large-format gantry system capable of being parametrically configured for a range of sizes and configured for specific or multiple processes. According to the company, the system's high stiffness structure has been developed over several years of Dynamic Finite Element Analysis and verified through virtual and actual machine modal analysis.

The primary vertical mast configured for milling is capable of five-axis, high-speed, high-volume material removal and precision drilling, routing and countersinking. The secondary mast executes precision six-axis abrasive waterjet trimming, powered by Flow ultra-high waterjet intensifiers and cutting heads. Multiple quick-change kinematic cutting heads are available to meet complex geometries.

With the company's integrated metrology package, the Fusion VI is also said to perform complex part alignments, inspection, spring back compensation and tool path correction. This configuration is tailored for the complete processing of composite aerostructures, reportedly saving manufacturers time and money while delivering high part quality.

All of the Fusion VI machines can be provided with either FANUC or Siemens controls, flexible or dedicated tooling and fixtures, multiple machine bed options and automation. Each system is tailored as a turn-key solution and configured to match the specific process requirements of each customer.

krcmachinetoolsolutions.com

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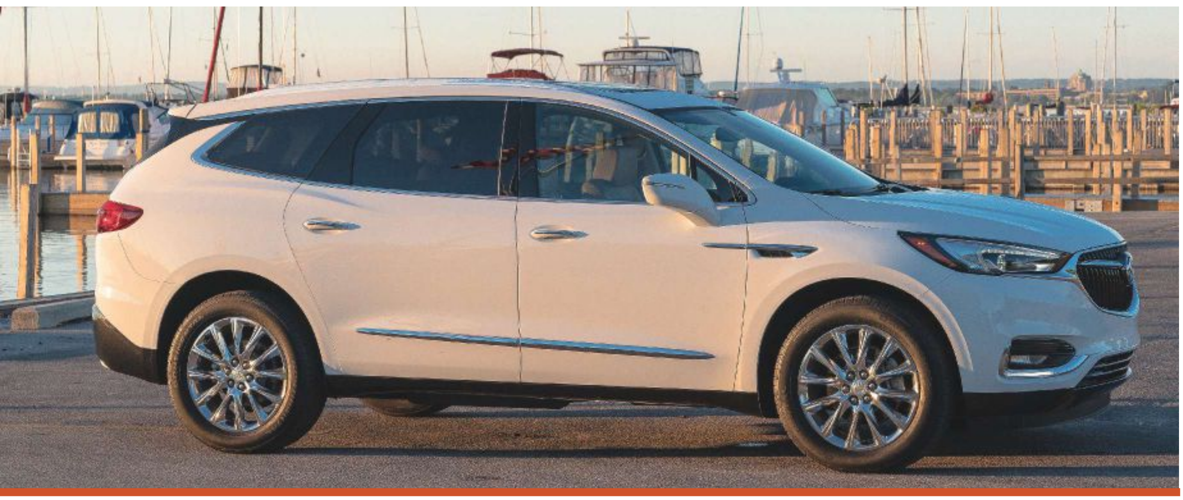
SHOWCASE

ADVERTISING INDEX (continued)

Autocomposites: Impact shield protects 12-volt battery in severe crash

GMT protection buys time for offboarding emergency services call before battery shorts out.

By Peggy Malnati / Contributing Writer



Even better battery protection

In response to even tougher federal vehicle safety standards, General Motors Co. is developing new, stronger battery trays as well as battery impact shields for distributing crash loads over a greater area.

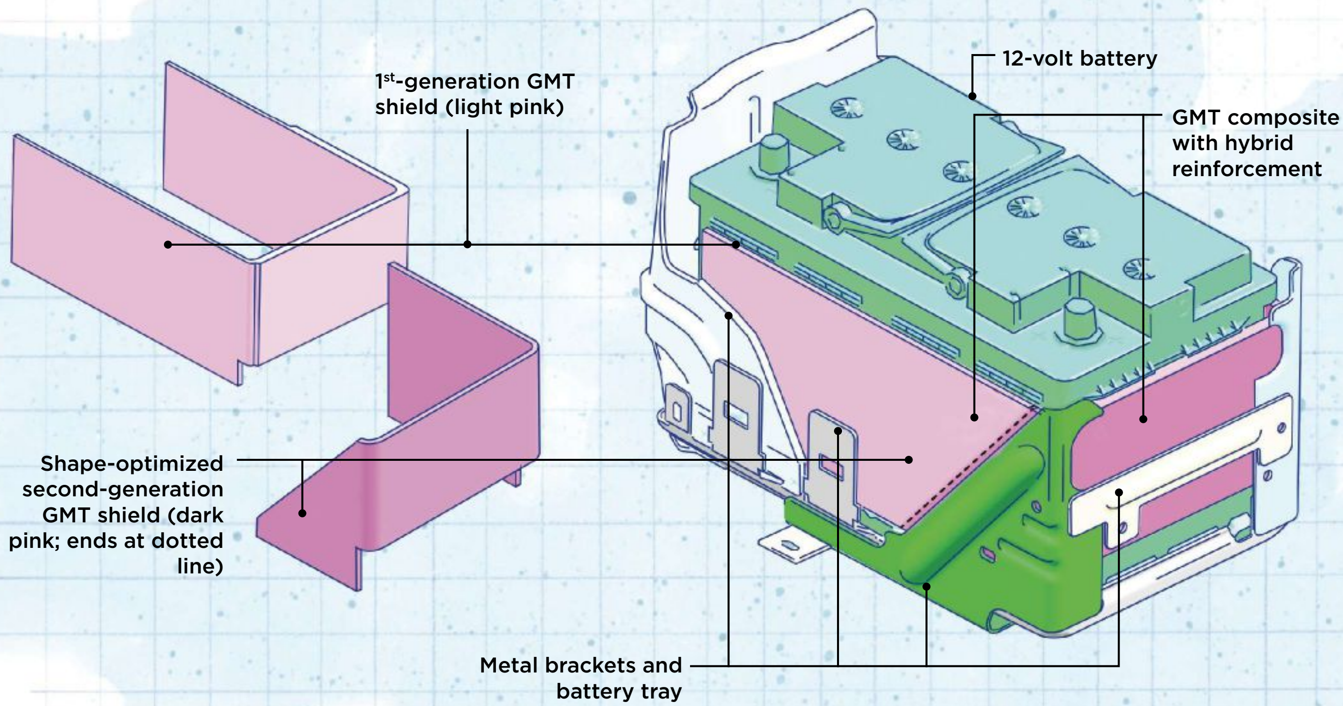
Source | General Motors Co.

» As conventionally powered passenger vehicles become more electronic and need bigger batteries to run onboard systems, protecting cells during severe crashes becomes more difficult. While the structure around batteries already is high strength and provides adequate protection for normal crashes, during severe crashes the protective structure itself can deform and puncture the battery, rendering it inoperable. In such cases, additional battery protection is desired, but ideally without sacrificing design or other safety features, without adding much weight or cost, *and* without impeding battery service or replacement during the vehicle's life. As a result, a new part, called a battery impact shield, has been developed to protect larger 12-volt batteries in severe crashes and is a growing application for composites.

Tough test gets tougher

The already difficult U.S. Federal Motor Vehicle Safety Standard (FMVSS) 208 now requires automakers to test at a 30-degree offset during frontal-barrier testing. The test's impactor is designed to completely miss frame rails so that a corner of the bumper takes the full hit before being pushed into the engine bay. The severe crash loads this test simulates have led General Motors Co. (Detroit, Mich., U.S.) to beef up battery trays and to develop battery impact shields, which serve the purpose of distributing crash loads over a greater area, thereby protecting batteries longer from being punctured and shorted out by surrounding components as the vehicle front end is crushed. This buys enough time for onboard diagnostics to detect the crash and send an "offboarding" safety call to first responders before the battery stops working — a feature that saves lives when occupants are unconscious or pinned and unable to make a call. These shields are designed to sit on metallic battery trays and wrap around those portions of the battery nearest engine bay components that crash simulation has identified as most likely to damage the battery in a severe crash. In use, control modules and other components connected to the battery hang off the shield and hold it in place so there are no noise/vibration/harshness issues. The shield is simply removed during maintenance or battery replacement and put back afterward.

The team working on the 2018 model year Buick *Enclave* sport utility vehicle (SUV) found late in the development cycle that the steel shield designed to protect the truck's 12-volt battery wouldn't pass required crash tests. Extensive computer-aided engineering (CAE) analysis after barrier and drop-silo testing had already led engineers to develop a challenging performance requirement for the part. To prevent costly start-of-production (SOP) delays,



DESIGN RESULTS **12-volt battery impact shield**

- Large C-section is thermoformed/hot stamped from hybrid fabric/chopped glass-reinforced GMT composite.
- C-section molding is then placed in waterjet fixture and geometry for six shields are cut.
- Shield fits around battery and sits on battery tray. When battery needs servicing or to be replaced, shield is simply lifted away and replaced once work is done.

Illustration / **Karl Reque**

GM's Advanced Materials & Development team was brought in to *quickly* find a replacement technology — and quick it was.

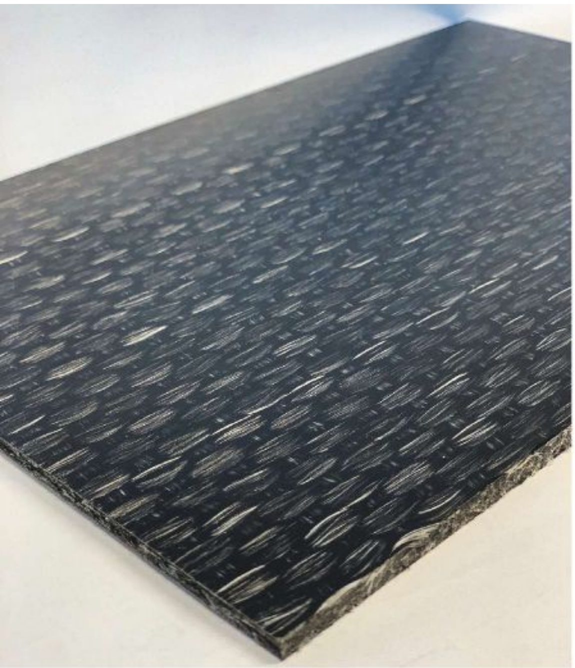
Crash course

It was early December and there was one more vehicle crash test scheduled before the holidays that was necessary to certify the SUV, which was due to launch in less than three months. A new shield design, material and tool had to be created and validated *before* that final vehicle crash test. GM engineers reviewed earlier crash test results and calculated loads and impact forces that the metallic design had experienced. Several additional CAE models were evaluated for additional load cases and inputs were used in a 6∑ Pugh matrix analysis to develop key metrics for materials evaluation. The new candidate would need to meet or exceed all federal safety regulations, including flammability requirements (FMVSS 302), and also meet GM's total system cost targets.

Given the short timeframe, researchers screened six commercial structural sheet molding compound (SMC) grades reinforced with chopped fiberglass at fiber weight fractions (FWF) of 42-49 percent in vinyl ester/unsaturated polyester matrices and with specific gravity values of 1.5-1.9. Material was obtained, plaques were molded, standard test coupons were cut and materials were tested. Given the severity of the 30-degree offset-barrier test, materials showing high impact strength and puncture resistance on instrumented (Dynatup) impact tests were prioritized. During impact testing, the impactor fell at 6.6 m/s and tests were conducted at -40°, 23° and 125°C. High glass loadings in the structural SMC grades made it difficult to maintain good wetout. When researchers examined broken samples by microscope, they found significant glass pullout from the matrix, but no broken glass. The 3∑ data spread was characterized as "noisy and wide" and didn't provide required safety margins. Since there was no time to reformulate, researchers turned to different technology — glass-mat thermoplastic (GMT) composite.

Novel, not new

Three commercial grades of GMTex glass fabric-reinforced composite with a polypropylene matrix from Quadrant Plastic Composites AG (QPC, a group company of Mitsubishi Chemical, Lenzburg, Switzerland) were evaluated. The highest-performing grade was 4.3 millimeters thick and featured multiple layers of woven, oriented glass mats (4/1 weave, 0/90 degrees) with a core of randomly oriented, 50-millimeter chopped glass. By integrating both woven and chopped fibers, the material provides »



a high-impact, consistent and homogeneous laminate, with an FWF of 61 percent. An intermediate grade was 3.0 millimeters thick and featured a woven glass fabric integrated with multiple layers of chopped glass, with an FWF of 40 percent. The third grade was 1.8 millimeters thick and combined woven fabric with chopped glass in a thinner laminate, with an FWF of 40 percent. Although fabric-reinforced GMT is not new, and has been used commercially in the automotive industry for decades, this was the first time that either GM or molder Continental Structural Plastics (CSP, a Teijin Group company, Auburn Hills, Mich., U.S.) had worked with these next-generation hybrid-mat GMT composites combining both fabrics and chopped glass mats.

■ Integrating woven *and* chopped fibers

The material chosen for the battery shield is a 4.3-millimeter thick laminate from Quadrant Plastic Composites AG that features multiple layers of woven, oriented glass mats with a core of randomly oriented, 50-millimeter chopped glass. The integration of both woven and chopped fibers provides a high-impact, consistent and homogeneous laminate.

Source | Quadrant Plastic Composites AG

"The two higher-performing grades worked, the 3∑ data spread was narrow and the thickest material gave us a significant safety factor, which is what we wanted," explains Kestutus "Stu" Sonta, GM material engineer-advanced materials electrification, who was materials lead on the shield redesign project.

Next, small-scale test results were validated using full-size parts to increase confidence before the final full-vehicle crash test. A non-optimized C-shaped design had already been developed to evaluate SMC and GMT materials via simulation. This model was used to rapidly cut a prototype aluminum tool at GM to mold preliminary test parts in the 4.3-millimeter-thick grade (GMTex X103F61-4/1-0/90°). These parts were then subjected to sled testing, which drops a mass from two stories at a speed designed to simulate the loads seen in the 30-degree offset-barrier test. The impacted structure is a greatly simplified chassis consisting of rails, axles and wheels, a battery tray, an instrumented but non-powered 12-volt battery, engine-bay components predicted via simulation to damage the battery in a severe crash and the GMT shield — all in the same relative position they would be in on a real vehicle. Many rounds of sled testing were completed and the team recorded very similar loads to those measured with earlier full-vehicle crash tests, which validated both concept and the material/process combination.

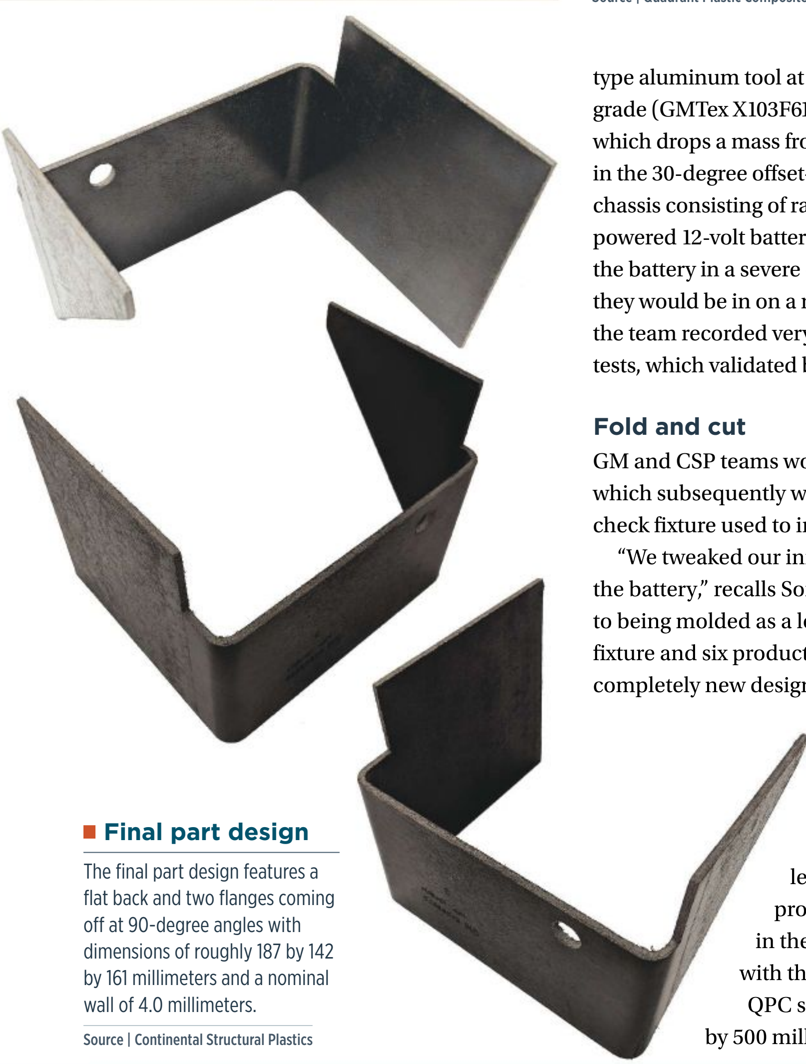
Fold and cut

GM and CSP teams worked together to further optimize the C-shaped shield's design, which subsequently was used to produce the production tool, waterjet fixture and check fixture used to inspect finished parts.

"We tweaked our initial design to allow for clearances, wire routing and fitment to the battery," recalls Sonta. "For process economics, the part's geometry lends itself to being molded as a long C-section channel, which can then be placed in a CNC fixture and six production parts cut from it via waterjet." He emphasizes this was a completely new design, optimized for composites, not a metals design into which composites were force-fit.

"We also modified the design to improve draft angles on those deep-draw vertical walls, as well as to incorporate locators for *waterjetting*, and to balance the charge," adds Dale Armstrong, CSP engineering manager and processing lead on the project. "Molding was straightforward. It was programming the waterjet to create all the geometry we needed in the net-shape part that was a bit challenging. We're doing things with this material that the supplier never envisioned."

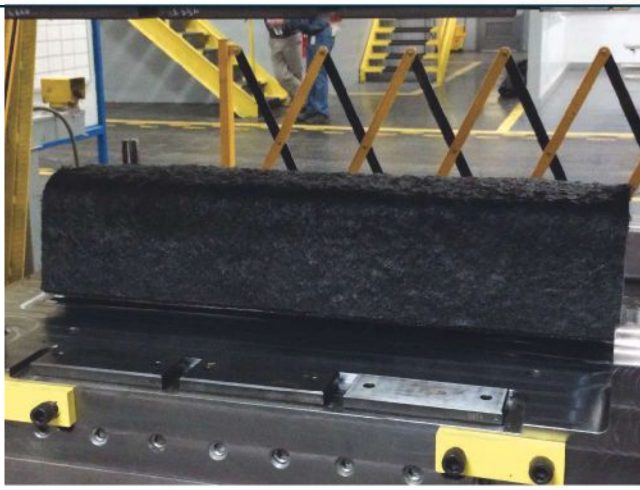
QPC supplies the material as a precut blank of approximately 930 by 500 millimeters. A single blank is used each molding cycle to form



■ Final part design

The final part design features a flat back and two flanges coming off at 90-degree angles with dimensions of roughly 187 by 142 by 161 millimeters and a nominal wall of 4.0 millimeters.

Source | Continental Structural Plastics



Compression-molded material

A blank of GMT material has been preheated and draped over the tool in a compression press prior to molding (left). The as-molded C-channel is ready to demold (right). The round "buttons" shown at the top are molded locators for the CNC fixture. Source | Continental Structural Plastics

the C-section channel from the full geometries of six individual production parts will subsequently be cut via waterjet. The material first runs through a four-stage infrared oven at CSP's Conneaut, Ohio, plant and is transferred to a neighboring, low-tonnage compression press. When heated, chopped glass fiber in the consolidated blank lofts approximately twice its previous thickness owing to a phenomenon called glass springback — in this case, the blank going into the tool is almost 9 millimeters thick and is reconsolidated during molding. Button-to-button cycle time is around a minute. No modification (via flame retardants or foils) were required for the part to pass FMVSS 302.

One of the interesting features of this GMT material is that, owing to both high glass loading and the textile layers, it has limited flow. Because of that, it's not technically compression molded but rather is thermoformed (or hot pressed) under low forming pressures. "Given the nature of this material, we need very little pressure to reconsolidate it," adds Armstrong. Since forming pressures are low and there's little material flow, no shear edges were needed on the tool.

CNC machining the final shapes

The C-channel is placed in a CNC fixture and a waterjet is used to cut out six separate battery impact shields from the single molding.

Source | Continental Structural Plastics

By keeping part and tool designs simple, a tool to mold a large C-channel, from which six production parts are waterjet cut after molding, kept the project on track and held down costs. Prototypes and early pre-production parts were molded on the aluminum tool, but given vehicle production volumes, GM opted for P20 steel on production tooling for longevity. Laval International (Tecumseh, Ontario, Canada) produced that tool.

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Not lost in translation

The final part has a flat back and two flanges coming off at 90-degree angles with dimensions of roughly 187 by 142 by 161 millimeters and a nominal wall of 4.0 millimeters. Best estimates are that the composite design weighs 75 percent less and costs 60 percent less than a comparably performing metal shield. Despite the speed with which the project proceeded, the team agrees that both process and design worked as expected, and the new shields passed crash testing with flying colors, providing extra protection to key safety systems.

"This program showcases how nimble we can be with the help of our suppliers," says Sonta, who adds that core concepts learned during this project have been translated to several other platforms globally. 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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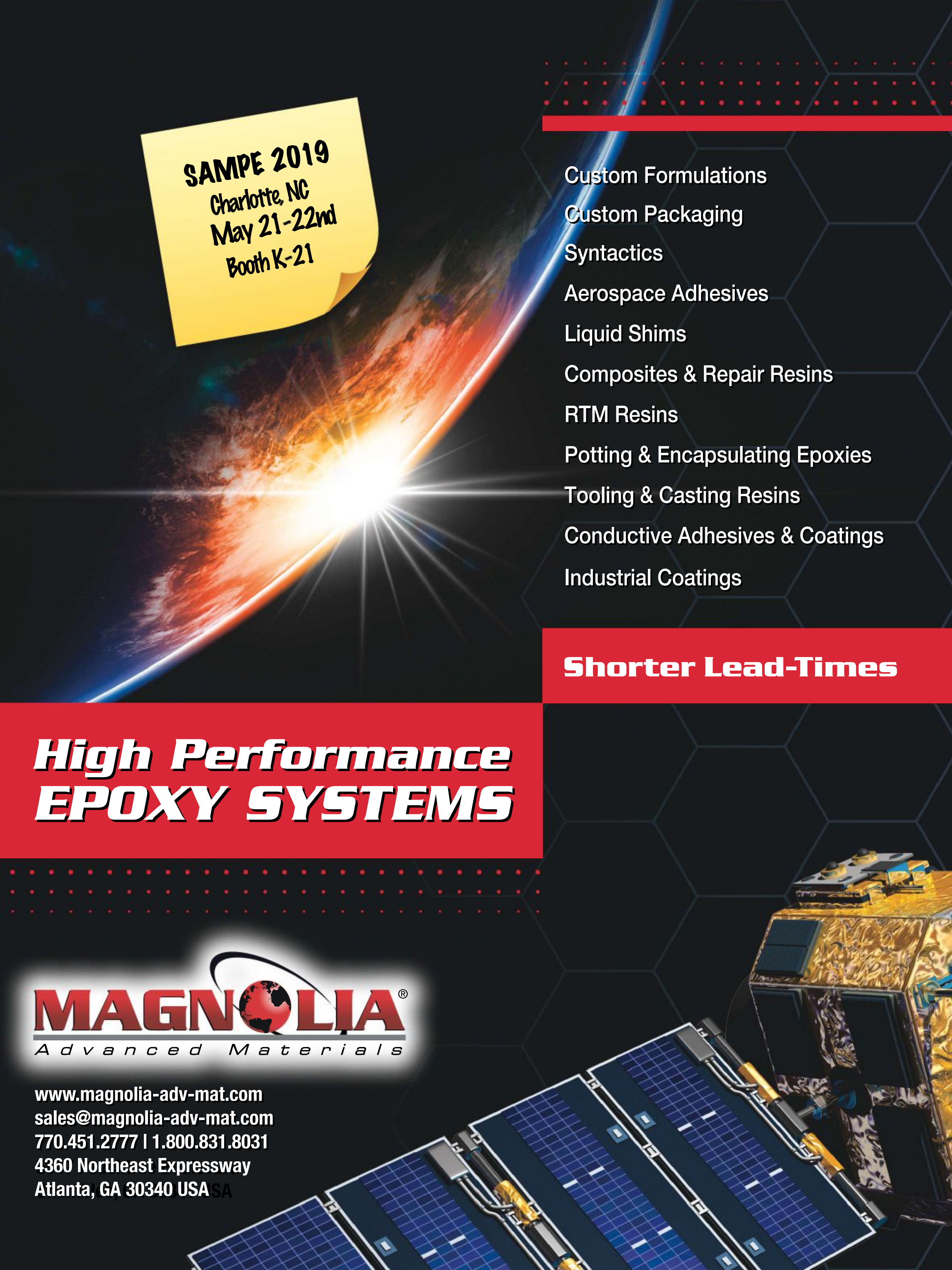
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