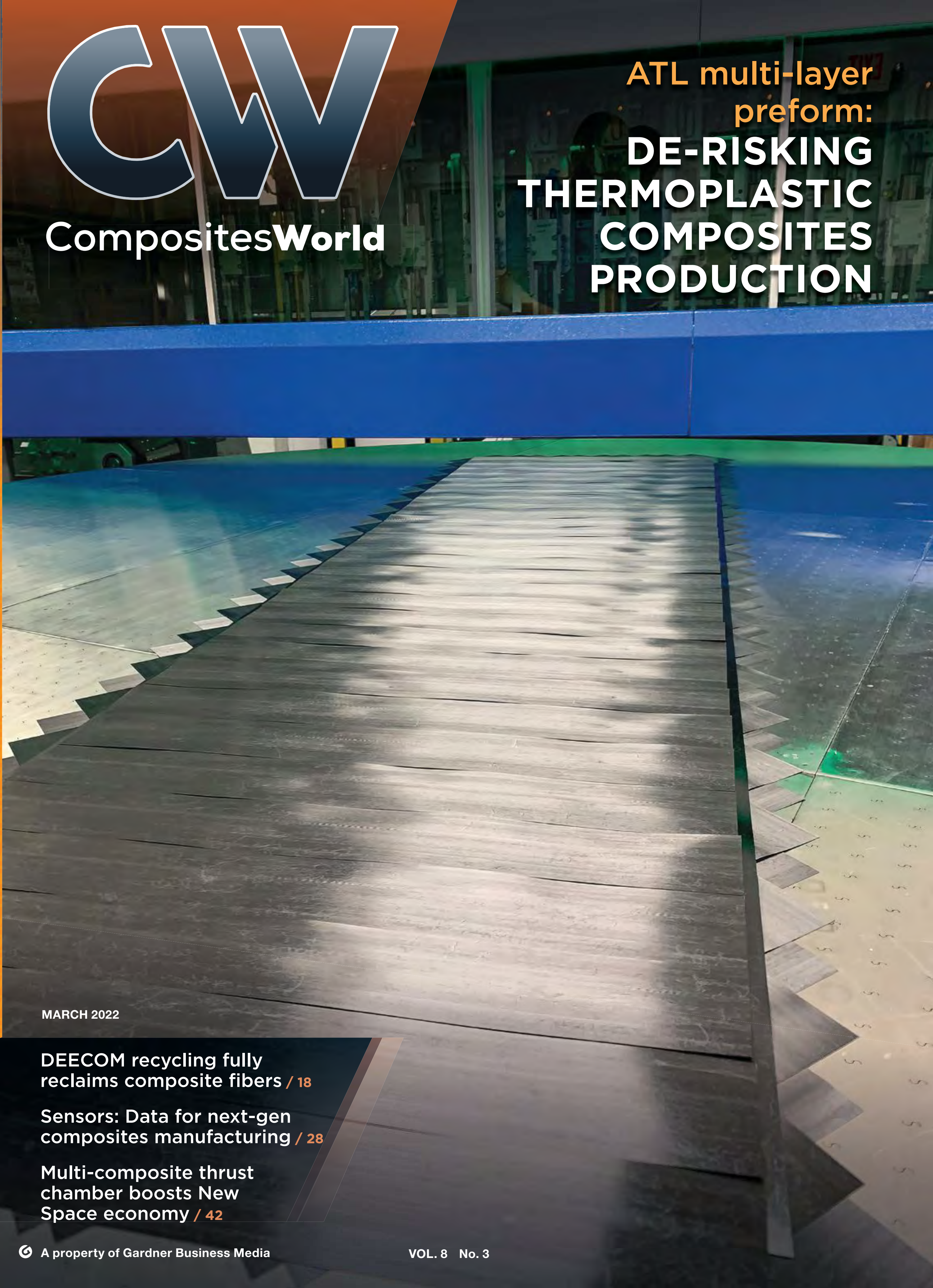

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ATL multi-layer preform: DE-RISKING THERMOPLASTIC COMPOSITES PRODUCTION

MARCH 2022

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VOL. 8 No. 3

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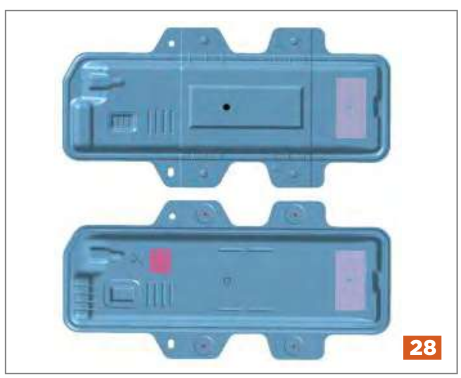
COLUMNS



DEPARTMENTS

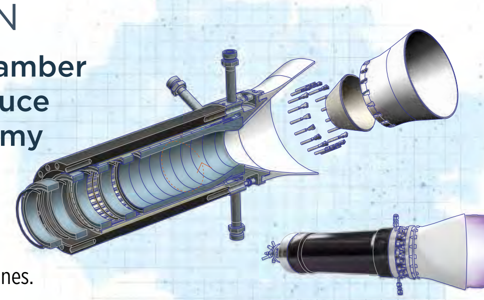
FEATURES

ON THE COVER

Inside an enclosed ATL cell, this tailored blank line produces carbon fiber/PAEK preforms at Victrex Composites Solutions' Bristol, R.I., U.S., facility. The line includes a robotic spool change-out and creel, two rapid tape dispensers and ultrasonic spot welding. The preform, shown here, is then placed on a rotary table to be tack welded. The process enables near-net shape layups and minimizes material waste. See p. 22.

Source | Ginger Gardiner, *CW*

FOCUS ON DESIGN



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» In a social setting — say, a family holiday dinner or a cocktail party or in idle conversation with a stranger — one of the questions we like to ask each other is, "So, what do you do?" The answer is almost always interesting and can lead to further discussion. If you work in the composites industry, however, answering that question can be a challenge, particularly if your interlocutor is a non-technical person. Simply referencing composites manufacturing is almost always meaningless to the listener. Carbon or glass fiber might have some meaning, but only in an abstract way. I will sometimes reference applications like concrete or wind turbines — everyone has seen those — and then explain that fiber-reinforced composites are analogous to rebar-reinforced concrete and that the blades on wind turbines are made with fiber-reinforced composite materials. And that's usually about as far as it goes.

CW introduces a new "Predicting Failure" column series.

A few months ago, I ran across a definition of composites manufacturing that, for those of us who are technically or scientifically inclined, makes good sense. The definition actually came from a column *CW* published late last year, written by Navid Zobeiry, an assistant professor of Materials Science & Engineering at the University of Washington (Seattle, Wash., U.S.).

His definition was this: *Processing fiber-reinforced polymer (FRP) composites is a complex and multi-physics problem of heat and mass transfer, thermo-chemical phase transitions and highly nonlinear and time-dependent viscoelastic stress developments.*

Perfect. Or, at least, it perfectly captures the complexity that is composites manufacturing. This single sentence nicely summarizes the hurdles that can make composites manufacturing so daunting: "multi-physics problem," "heat and mass transfer," "thermo-chemical phase transitions," "viscoelastic stress developments."

Of course, the physics of composites fabrication is not just a manufacturing challenge. It's a design challenge as well. All of the CAD tools composites designers use must account for these variables and enable intelligent deployment of tools to help optimize and maximize fiber orientation to meet the mechanical loads of the application. The designer then relies on physical testing of the finished part to provide an ultimate assessment of the design's performance. And, in a worst-case scenario, in-service failure can also inform the validity of a design.

In any case, any designer would likely agree that the ability to *predict* failure of a design *before* that failure occurs — whether in test or in service — is the optimum path to design optimization. It was with this idea in mind that a few months ago we here at *CW* wondered if we couldn't develop a series of columns through which to explore best practices and strategies for designers to use to predict and then mitigate failure in composite parts and structures.

We engaged Hexagon Manufacturing Intelligence (Cobham, U.K.) to help us develop a new series of columns called "Predicting Failure." As the name implies, the goal is to explore the design flaws that lead to structural failure and identify solutions to avoid such failure. Hexagon's design experts will help us in this effort.

The first Predicting Failure can be found in this issue, on p. 6, and is titled, "How to validate 3D-printed composite part performance." It chronicles the design optimization of a 3D-printed bracket used to lift heavy cast metal components during CNC machining. The bracket integrates chopped and continuous fiber reinforcement, optimally placed to avoid performance failure. Manufacturing was performed with a Markforged (Cambridge, Mass., U.S.) 3D printer. You can look for additional Predicting Failure columns in other issues throughout 2022, and beyond.

More importantly, the Predicting Failure column provides an opportunity for you to explore your own failure challenges. If you have a design, part or concept that exhibits a failure mode you would like to see addressed, let me know and we will consider it as a topic for a future column. You can reach me at my email, jeff@compositesworld.com. I hope to hear from you soon.

JEFF SLOAN — Editor-In-Chief


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How to validate 3D-printed composite part performance

» Danfoss Power Solutions (Ames, Iowa, U.S.) wanted to reduce cost and lead time challenges with a machined aluminum bracket by redesigning it to use carbon fiber-reinforced plastic (CFRP) made with its Markforged (Watertown, Mass., U.S.) 3D printer. The bracket is used to lift heavy cast metal components during CNC machining and assembly (Fig. 1).

In 2019, Markforged and MSC Software Corp. (MSC, Irvine, Calif., U.S.) announced a partnership to connect Markforged material and print information with MSC finite element analysis (FEA) simulation, enabling simulations of fiber-reinforced 3D-printed parts to predict mechanical and structural performance. A simulation workflow was developed, comprising Markforged's Eiger design software and Digimat material and process modeling software from e-Xstream engineering (Käerjeng, Luxembourg), a division of MSC. Both are now part of Hexagon Manufacturing Intelligence (Cobham, U.K.), which traditionally dealt with metrology and inspection after production, but now has capability to feed that information back into design and manufacturing optimization. This 3D-printed composite simulation workflow was validated on the Danfoss bracket, and potential for failure was investigated.

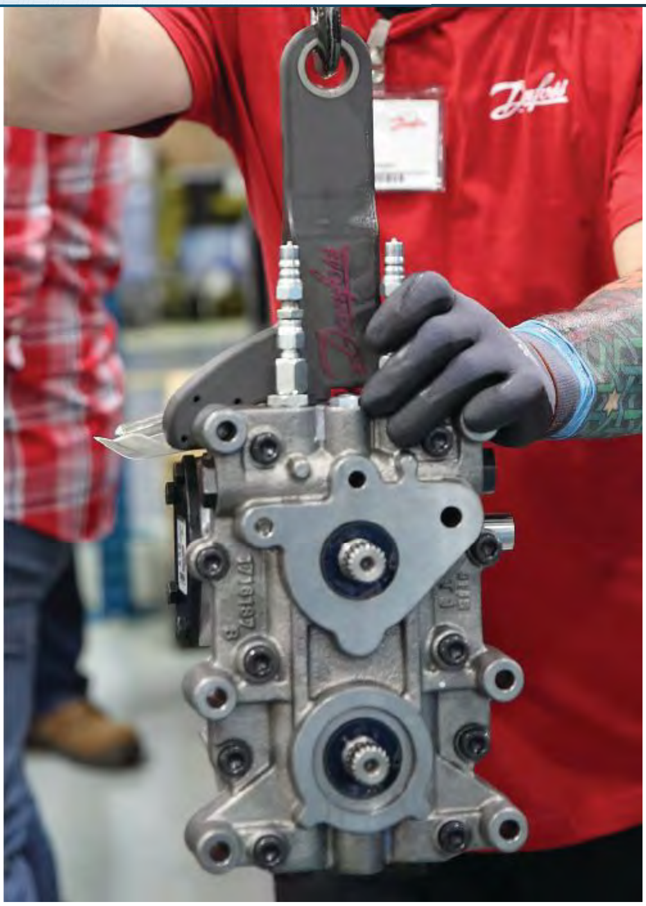


FIG. 1 3D-printed composite lift fixture

Danfoss worked with Markforged and Hexagon to predict the performance of this lift bracket, redesigned from machined aluminum to 3D-printed composite.

Source (all images)| Danfoss, Markforged, Hexagon

Integrated Computational Materials Engineering (ICME)

ICME is an approach that Hexagon has industrialized to simulate composite part performance. For example, Digimat is used to perform injection molding simulations, deduce the fiber orientation throughout the part and run a coupled FEA simulation using the as-manufactured material microstructure to derive the actual mechanical behavior in the part. Through the partnership with Markforged, ICME has now been adapted for 3D-printed composites. Key steps include:

- Define the part's toolpaths/fiber paths in Eiger and build an FEA model in Abaqus, Ansys, etc.
- Export toolpath data from Eiger into Digimat.
- Perform material testing and modeling to calibrate the Digimat material model.
- Run FEA to evaluate as-manufactured part performance.

Eiger software

The composite bracket was designed to roughly maintain the shape of the previous aluminum part, but converted the multi-part assembly into a single printed piece that was lighter weight thanks to fiber paths tailored to align with in-service loads. After importing the CAD file into Eiger, two designs were created. One used only Markforged's Onyx short fiber-reinforced polyamide 6 (PA6) filament. A second design added five layers of continuous carbon fiber, for example, to reinforce the outer planes of the part, the lifting ring at top and twin pin openings at bottom. In both designs, an infill pattern printed with Onyx filament was used where possible to reduce printed material and weight. Eiger can also design areas of isotropic properties and tailor section modulus to meet deflection requirements.

Map print toolpaths to FEA

An FEA model was created with in-service loads and boundary conditions using Ansys, Abaqus or other standard FEA software. The next step was to export the 3D print toolpath data from Eiger to Digimat using the proprietary interface developed by Markforged and Hexagon. This step maps the filament material data (Onyx and continuous carbon fiber) along with fiber orientation from the 3D print toolpath onto the FEA structural mesh. A Markforged webinar on this case history gives more detail on how this

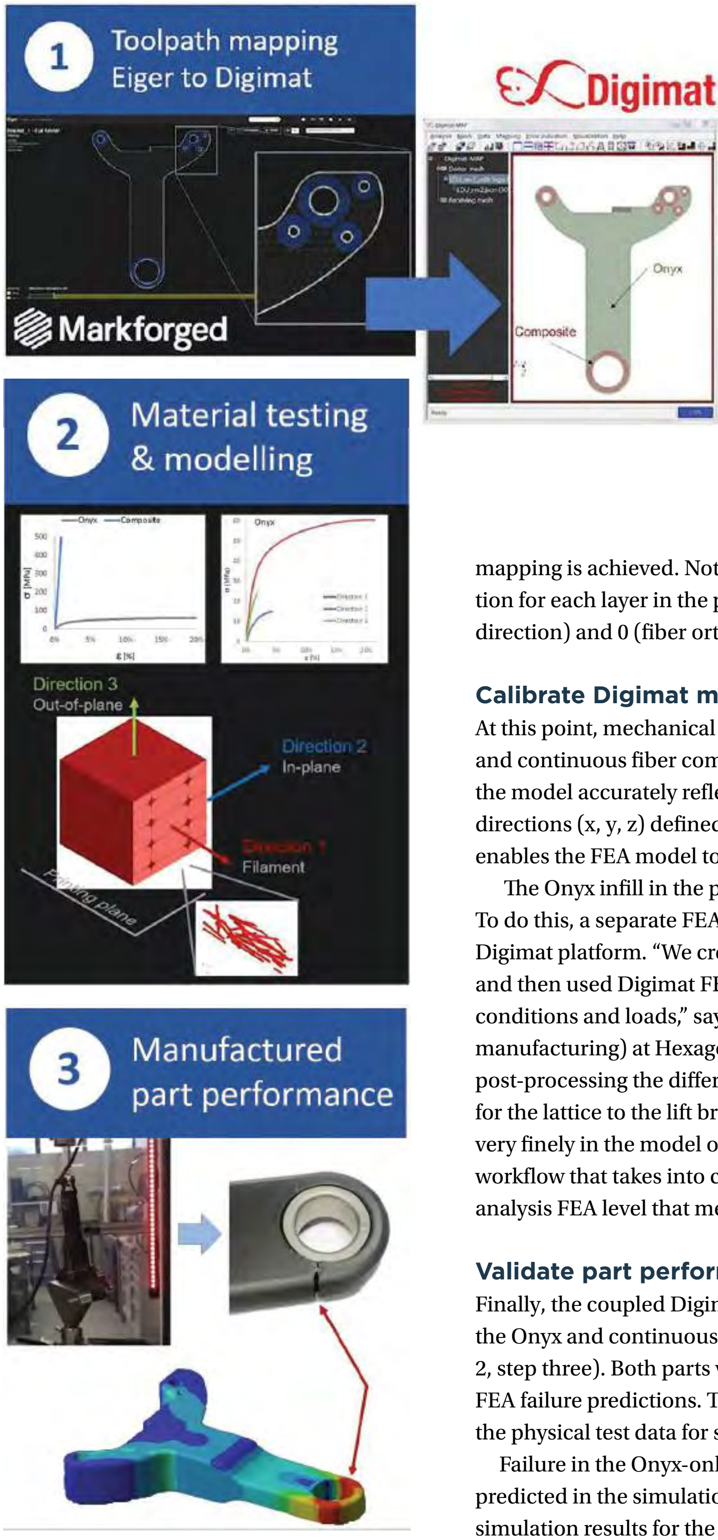
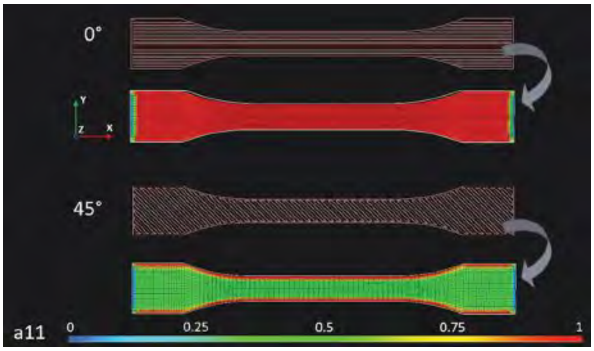


FIG. 2 Validated failure prediction

The final three steps in ICME are shown here, ending with an FEA simulation that predicted maximum strain at the top lifting ring, validated by physical testing and addressed by adding continuous carbon fiber.



Mapping Eiger to Digimat

Fiber orientation for each layer is valued between 1 (aligned, red) and 0 (orthogonal, blue), with 45° shown as green, and some blue at the ends where orthogonal fiber has been placed.

mapping is achieved. Note in the second image for step one of Fig. 2 that fiber orientation for each layer in the part can be valued between 1 (fiber aligned with the principal direction) and 0 (fiber orthogonal to this direction).

Calibrate Digimat material model

At this point, mechanical testing was performed on 3D-printed tensile coupons for Onyx and continuous fiber composites to calibrate the Digimat material model. This ensures the model accurately reflects the mechanical properties achieved in the characteristic directions (x, y, z) defined by the 3D printing toolpath in each printed plane, which enables the FEA model to reflect the as-manufactured part.

The Onyx infill in the printed lift bracket also needed to be accurately represented. To do this, a separate FEA was created and solved using Digimat FE, a tool within the Digimat platform. "We created a representative unit cell of the triangular infill geometry and then used Digimat FE to help automate assigning material behavior, boundary conditions and loads," says Olivier Lietaer, business development engineer AM (additive manufacturing) at Hexagon. "We then ran the analysis on the infill model and, after post-processing the different results, we exported an equivalent macroscopic response for the lattice to the lift bracket FEA model. In this way, you don't have to mesh the infill very finely in the model of the as-printed part. Thus, we have enabled a multi-scale workflow that takes into consideration the as-printed microstructure at the structural analysis FEA level that mechanical engineers need."

Validate part performance

Finally, the coupled Digimat-FEA simulation was ready to run. The FEA results for both the Onyx and continuous fiber parts showed maximum strain at the top lifting ring (Fig. 2, step three). Both parts were printed and tensile tested to failure. Results validated the FEA failure predictions. There was also good agreement between Digimat results and the physical test data for strength and modulus.

Failure in the Onyx-only tensile test part was at a load 25% higher than the maximum predicted in the simulation, but this was deemed an insufficient factor of safety. Using simulation results for the second part, says Lietaer, "we were able to show that by adding only a couple of layers of continuous carbon fiber in the failure location, the stiffness was almost doubled to exceed 7 kilonewtons, meeting the required safety factor of 5." Thus, he adds, this safety factor is sufficient to account for any uncertainty in actual maximum load seen in service as well as any variability in the part manufacturing, allowing the 3D-printed part to be safely deployed in Danfoss operations. »

Optimize printed parts

The next step is to optimize printed parts. "You can use Hexagon's MaterialCenter platform," says Lietaer, "to store and track any data from the workflow presented here." This includes batch information for fiber and matrix materials, which printer was used and whether multiple parts were printed, as well as parameters such as print temperature and speed.

"It is also possible to store material test data used for simulation, but also as-printed data such as tensile tests and metrology scans for dimensional accuracy," he adds. "In this way, you centralize all of that data for wide access and use. For example, say some parts are failing prematurely. Using MaterialCenter, you can trace the parts and compare data to perhaps find the commonality in a specific batch of materials or a certain machine which needs maintenance. You can also compare the test data to identify which print parameters produce the best part performance. Thus, it is possible to optimize materials, machines and print processes, as well as designs for future parts." CW

ABOUT THE AUTHOR

Olivier Lietaer joined Hexagon (Stockholm, Sweden) in August 2016 as additive manufacturing (AM) business development engineer, where his main role is to connect the AM industry needs to the Digimat Development team, including the key tasks of accelerating new materials development, simulating the printing process and predicting the as-printed part performance. Prior to joining Hexagon, Lietaer served as R&D engineering team leader at Safran Aero Boosters (Liège, Belgium). He holds a PhD in applied mechanics from the Université Catholique (Louvain, France).

Composites industry begins 2022 with a burst of activity

January—58.9

The Gardner Business Index (GBI): Composites Fabricating increased more than two points to close January at 58.9. A greater level of activity in new orders, production and backlogs all contributed to the month's overall gain. January's supplier deliveries reading also increased; however, in the present environment, rising readings indicate weakening supply chain performance. Those Index components that posted lower readings from a month ago included employment and export orders. In both instances, January's reading fell below 50, indicating contracting activity. Of these, employment activity fell nearly five points to an 18-month low.

Over the last six months, composites fabricators have learned to do more with less. On a three-month moving average basis, production results compare similarly to those of past business cycle expansions. Unlike any past expansionary cycle, however, production readings in recent months have been restrained by both weak supply chains and a reduced labor force. Finding ways to expand production with fewer workers and limited materials will continue to restrain target levels of production. The result of this imbalance has been made evident by sharply higher backlog levels. CW

ABOUT THE AUTHOR

Michael Guckes is the chief economist/director of analytics for Gardner Intelligence, a division of Gardner Business Media (Cincinnati, Ohio, U.S.). He has been in the economics and industrial space for 20 years, with his last five at Gardner Intelligence. Guckes received his BA in political science and economics from Kenyon College and his MBA from Ohio State University.
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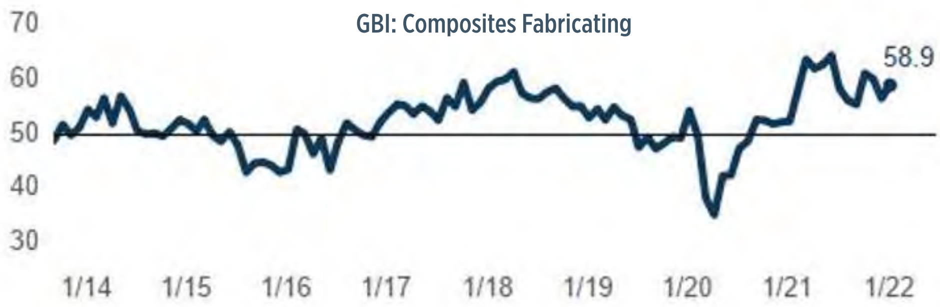
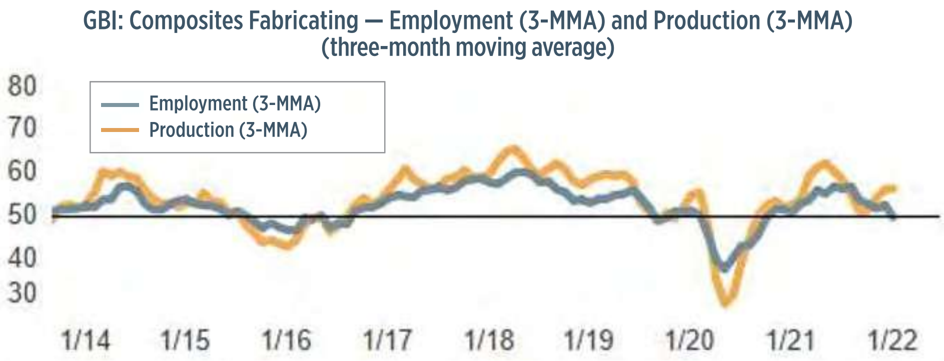


Composites Fabricating Index

Production activity has remained relatively robust in the face of a reduced labor supply and struggling supply chains.



Doing more with less

Challenging supply chain conditions throughout 2021 restrained production and thus elevated backlogs. Challenging hiring conditions likely also added to elevated backlog readings.

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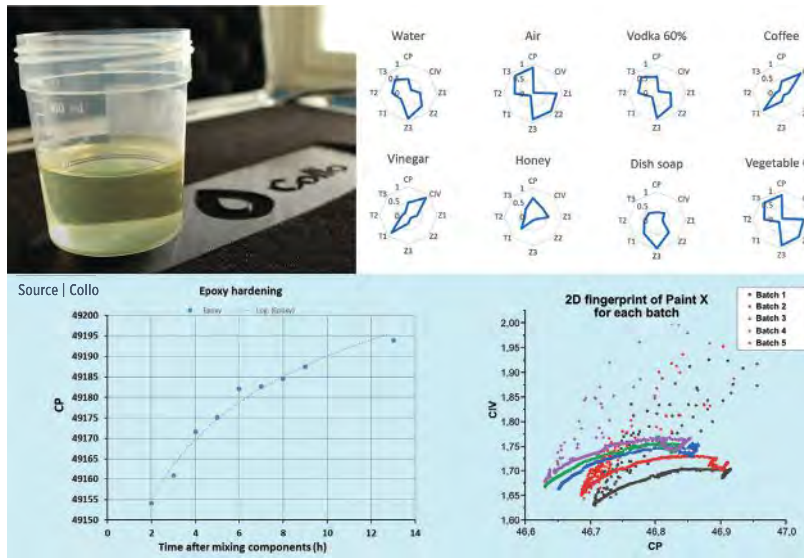
ColloidTek Oy uses electromagnetic sensors and edge analytics to optimize resin degassing, mixing, infusion, polymerization, cure and more; the *CW* 2022 Top Shops benchmarking survey is now open; Airbus will open a lifecycle service center for aircraft in China; JEC World 2022 has been postponed to May 3-5, and more.

Fingerprinting liquids for composites



Source | Collo

ColloidTek Oy (Collo, Tampere, Finland) is a spin-off from Tampere University, co-founded in 2017 by ceramicist and materials scientist, Matti Järveläinen, who is also the company's CEO. The company has developed an electromagnetic field (EMF) sensor that constantly measures a liquid being processed and analyzes how that liquid is changing. "Our combination of proprietary Collo sensors, signal processing and data analytics technologies provides a solution to measure what we call liquid fingerprints," explains Tuuli Potila, marketing manager for Collo. "Our sensors are installed directly into a process line, giving accurate, real-time data and enabling customers to see inside their processes, achieve advanced process control and improve efficiency."

"We provide continuous, contactless monitoring of liquids and how they are changing during processing with regard to chemical reactions, viscosity, homogeneity of mixed components, etc.," says Järveläinen. "We then use artificial intelligence and analytics to convert this data into a better understanding of the process. We correlate our readings to quantities that can have set limits and alarms, such as rheological viscosity, homogeneity or degree of polymerization. If you just take samples into the lab, you are only seeing a snapshot of the process. It's like driving on a motorway and just opening your eyes for one minute each hour and trying to predict where the road goes from that."

Currently, sensors are configured as either a Collo Probe, which can be immersed in a liquid, or a Collo Plate, which is installed into the wall of containment/mixing vessels or process pipes/feed lines. Collo Plate is shielded with tempered glass, enabling use at temperatures up to 130°C and is being tested for continuous use in temperatures up to 150°C.

Collo sensors can be used in all types of liquids, says Potila, including suspensions, emulsions, pastes, gels, slurries, creams, solvents, resins, adhesives, coatings and multi-component liquids, as well as for complex processes used with such liquids. "We interrogate the sensor in two-second intervals and the frequency is in the megahertz range," notes Järveläinen. "We have good control of the electromagnetic field the sensor emits and have developed it to see into the resin or paint, for example."

In fact, Collo sensors can read through any nonmetallic material, including composites. Järveläinen uses coffee as an example: "You can put your coffee mug on the sensor, and it will send and receive an electromagnetic field through the bottom of the coffee mug with enough sensitivity to recognize one grain of salt added to the coffee," he says. "For composites, then, it doesn't much matter if you have fibers, or if you have a very thick or thin medium, the sensor still has quite high sensitivity."

So would a Collo sensor be able to read through the bottom laminate of a composite joint and see into the adhesive? Or read through a composite tool to monitor the resin flow front during infusion of a composite part? According to Järveläinen, "it depends on the size and structure of the antenna and how we engineer it in the sensor unit."

Collo sensors measure two main variables — ion viscosity and permittivity. These basic dielectric properties are also measured by dielectric analysis (DEA) sensors, which apply a voltage between two electrodes in contact with a resin or adhesive and then measure the change in signal between these electrodes.

"DEA sensors need to contact the resin and are measuring it in the area between those two electrodes, which must be in close proximity to each other," explains Teemu Yli-Hallila, Collo co-founder and CTO. "The Collo sensor is just one electrode, around which the sensing electric field is formed.

This makes it easier for Collo sensors to read through nonmetallic materials and measure liquids without contacting them."

The ability for measurement without contacting the resin or composite being controlled is an advantage and why thermal flux sensors were chosen to monitor resin flow and cure for the INNOTOOL 4.0 project. However, compared to DEA and heat flux sensors, Collo has developed its technology to recognize and measure a total of eight variables. "This increases the accuracy and versatility of Collo sensors," says Potila, "and gives them very broad capabilities."

"So, the solution we are offering is real-time, inline measurement directly from the process," says Järveläinen. "Our system then converts that data into physical quantities that are understandable and actionable, like rheological viscosity, and it helps to ensure high-quality liquid processes and products. It also allows optimizing the processes. For example, you can shorten mixing time because you can clearly see when mixing is complete." Machine learning can also be used to correlate measurements to mechanical viscosity, he notes, which is key, "because our customer doesn't want to look at arbitrary data from a sensor. What they want is to understand when they can go to the next process step or how long they have to finish a layup, for example."

Tracking a single parameter is one of the three main ways that Collo's customers are using its sensor solution. ABB Finland (Helsinki) uses Collo sensors to control the viscosity of resin used in the production of electric motors. "They are linking the sensors to a rheometer to basically run their process through a laboratory measurement," says Järveläinen. "Now, they can measure it [rheological viscosity] in real-time, in-situ."

Dielectric sensor supplier Synthesites (Uccle, Belgium) is doing the same thing by using its sensors to estimate the glass transition temperature (T_g) of resin during infusion and RTM processes. This then lets part manufacturers move away from legacy cure recipes and instead exploit material state management based on in-situ resin data in real time.

Adhesives supplier Kiilto (Tampere, Finland) uses Collo sensors to also monitor other parameters, like sedimentation — a shelf-life issue where an adhesive eventually separates into a layer of low-viscosity solvent or water on top, with hardened solids at the bottom of the container.

"Another way to use Collo sensors," says Potila, "is to monitor each process phase or batch so that they can be benchmarked and compared." Fingerprinting beer production and paint manufacturing are additional studies that have been tested and successfully prove this feature.

The third use of Collo sensors, says Järveläinen, is to optimize process steps. "Our sensors can recognize when mixing is complete, for example, so waste of time and energy are avoided while quality is assured. Alarms and process equipment control can be set to only allow the next step once the specified homogeneity has been reached." Degassing resins, and use for 3D printing complex-shaped ceramics using stereolithography (SLA) are prime examples.

Obviously, Collo's solution was not developed specifically for composites. "I don't think you will find many sensor companies that only work with composites," says Järveläinen. "It's not that the composites industry is too small, it's that any one industry will be limited."

Hence, the need for sensor suppliers to work across multiple industries, which makes it difficult to be composites specialists. "Some days, I'm talking with pharmaceutical companies and with companies who are producing milk," says Järveläinen, "and other days, I am trying to speak the language of composites. I can't teach you how to make better composites, but I can tell you how our sensor is going to work, once you help me to understand your process."

Read the full article online at short.compositesworld.com/Collo

CW's 2022 Top Shops benchmarking survey is now open

CompositesWorld, in cooperation with leading media company for manufacturing, Gardner Business Media (GBM, Cincinnati, Ohio, U.S.), and Gardner Intelligence, has opened the 2022 edition of its Top Shops benchmarking surveys.

Every year, this in-depth survey is sent out to all *CW* subscribers who perform composites fabrication. By answering a series of questions about their businesses, Top Shops is able to measure a variety of manufacturing metrics for the facility in which the respondent works. Responses are compiled to create a collective overview. Each respondent is also given a custom report comparing their facility to others to:

- Assess the effectiveness and efficiency of your manufacturing operations.
- Determine the top-performing composite fabrication facilities.
- Receive input on your strategic planning processes.

Five of GBM's brands are participating this year in addition to *CW*, including *Modern Machine Shop*, *Plastics Technology*, *MoldMaking Technology* and *Products Finishing*. Like the others, Top Shops results — including recognition of the top-performing companies — will be announced in the *CW* November print/digital issue. **The survey closes on March 31, 2022**.

"In uncertain times, knowledge is power," says Justin Combs, senior marketing manager for Gardner Intelligence. "Businesses need to know where they are excelling and where they have opportunity to improve. The Top Shops program gives them the info they need to help them succeed."

The survey for composites fabricators can be completed at **gardnerintelligence.research.net/r/XTG8Q7R**

BIZ BRIEF

BTG Labs (Cincinnati, Ohio, U.S.), a company with 20 years experience in solving critical adhesion issues and developing surface inspection technologies, has evolved its capabilities, leadership and name to become Brighton Science.

BTG founder Giles Dillingham explains the path forward. "With our proven tools and expertise — and new analytic capabilities — we're offering our customers an unprecedented level of visibility and data. Bringing in Andy Reeher, a seasoned technology entrepreneur, to lead this organization to its next level of growth means we've stepped up our game and outgrown our old name." Dillingham will continue as chief science officer and lead the company's Surface Intelligence Lab.

AEROSPACE

Airbus and partners to establish aircraft lifecycle center in China


Source | Airbus

Airbus (Toulouse, France) announced it has signed a memorandum of understanding (MOU) with the city of Chengdu, China, and Tarmac Aerosave — a maintenance, repair and overhaul (MRO) company dedicated to aircraft storage, maintenance and recycling — for the development of the first sustainable aircraft "lifecycle" service center in China. This agreement will cover a range of activities, from aircraft parking and storage, to maintenance, upgrades, conversions, dismantling and recycling services for various aircraft types.

"This is another concrete contribution to the aviation industry's quest for sustainability, supporting the principle of a circular economy in line with Airbus' purpose to pioneer sustainable aerospace. This center will support the expansion of Airbus' aviation services while enabling the implementation of China's 'Green Industry' strategy," says Klaus Roewe, SVP Airbus Customer Services. "Aircraft phase-out in China is forecast to grow exponentially over the next 20 years. Airbus is committed to investing in the region and this one-stop-shop — a first in China and outside of Europe — will see Airbus well positioned on the Chinese aircraft 'second life' services market."

A formal agreement to establish and frame this industrial cooperation is planned to be signed between the partners in mid-2022, with an entry into service of the new center slated for the end of 2023, subject to relevant regulatory approvals.

Tarmac Aerosave says it will bring its 15 years of proven expertise in eco-efficient aircraft dismantling to the project. Located in the same center, Airbus subsidiary Satair (Copenhagen, Denmark) will acquire aging aircraft, and trade and distribute the resulting used parts to complete the full scope of lifecycle services. The facility will cover a surface area of 690,000 square meters and a storage capacity of 125 aircraft.

Under this agreement, Airbus continues to deploy its sustainability roadmap for the aviation industry.

JEC World 2022 postponed to May

Source | JEC Group

After thorough consultation with the exhibitors and partners of the event, JEC Group (Paris, France) has decided to postpone the 2022 edition of JEC World from its original March 8-10 date. JEC World, the world's largest composites event, will now take place May 3-5, 2022, at the same venue, the Paris Nord Villepinte Exhibition Centre in Paris, France, as well as online via the JEC World Connect digital platform.

JEC World brings together major global companies, innovative startups in the field of composites and advanced materials, experts, academics, scientists and R&D leaders. The event also offers a unique showcase of what composites can offer to various application sectors, from aerospace and marine, to construction and automotive, and what event organizers say is an unlimited source of inspiration for participants from these industries.

"We are fully dedicated to supporting the composites industry and to fostering its development via our events and media activities," says Eric Pierrejean, CEO of JEC Group. "Exhibitors and partners are strongly supporting JEC World, their leading event, and want to meet in person in 2022 to activate business, share knowledge and highlight innovations. Postponing from March to May is a way to offer improved conditions to satisfy the industry requirements for such a trade fair as JEC World."

The JEC World team has decided to postpone the event after a survey conducted of its exhibitors and partners, confirming that a large majority is in favor of the new dates in May. As already planned, the three-day event will offer a digital platform, JEC World Connect, in parallel to the in-person event in Paris for an augmented digital experience. Content will also be available via the JEC Web TV after the show, in order to extend event reach.

"Our main concern is to create the best possible conditions for our participants for successful networking, inspiration and business success. With a postponement of eight weeks we can enable this and offer to the industry the event it deserves. Taking the decision now, after consultation of all exhibitors, was necessary to give them planning and preparation visibility," adds Thomas Lepretre, VP events, sales and operations.

ENERGY

Second U.S. offshore wind project gains approval to begin construction

Source | South Fork Wind

In January 2022, the U.S. Department of the Interior's Bureau of Ocean Energy Management (BOEM) gave final permitting approval to the South Fork wind project — New York's first offshore wind farm — making it the second U.S. offshore wind project authorized to begin construction. Onshore construction of the 132-megawatt (MW) project is expected to begin soon after federal approval and, when completed in 2023, the one-dozen turbine project located 35 miles from Long Island, N.Y., U.S., will reportedly generate enough power for 70,000 homes. The construction approval follows Vineyard Wind's approval in late 2021 and continues the momentum of offshore wind power adoption in the U.S.

South Fork will install 12 SG 11.0-200 DD 11-MW supplied by Siemens Gamesa (Zamudio, Vizcaya, Spain). These feature 97-meter-long Siemens Gamesa B97 IntegralBlades and a 200-meter-diameter rotor.

Ørsted and Eversource expect the 130-MW project to be fully permitted by January 2022, with construction activities starting soon after that and the project planned to be completed and put into operation by the end of 2023.

"The U.S. now has multiple offshore wind projects in their construction phases, showcasing that a domestic industry is now coming to life. Offshore wind is a powerful and reliable renewable energy source; its development is essential to confronting climate change and meeting state and federal clean energy goals. Federal approval of South Fork — the second U.S. offshore wind project — further solidifies the U.S. as a major market and will boost needed supply chain investments," says Ross Gould, vice president of supply chain development at the Business Network for Offshore Wind (Baltimore, Md., U.S.).

Pressurized steam-based composites recycling for full fiber reclamation

Longworth's DEECOM process for composites recycling claims to produce intact fiber and reclaimed resin with near-virgin properties.

By Hannah Mason / Associate Editor

■ **Before and after: DEECOM recycling process**

U.K.-based Longworth originally developed its pressurized steam-based DEECOM process for cleaning polymers from metal. Now, the process has been shown to effectively separate resins and fibers from composite waste or end-use parts (like the panel shown at top) leaving high-quality fibers and, potentially, resins for reuse (middle and bottom). Source (all images) | Longworth

»Today, companies face more pressure than ever to adopt a recycling or reuse solution for manufactured components at the end of their lifespans, including waste-free production processes or a way to reuse manufacturing scrap. For composite components, the recycling question is inherently complicated, since the manufacture of composite parts involves a combination of two very different materials. Is it possible to reclaim the fiber and resin materials out of a finished composite component? If so, what properties do they exhibit, and what could they be used for? If not, how can entire composite components be recycled, and what are their properties and uses?

To date, the most common methods of recycling composite components and materials are pyrolysis (flame-based) or thermolysis (heat-based), solvolysis (chemical-based), hydrolysis (water-based) or some type of mechanical process (chopping or shredding whole parts for reuse, etc.). The end product for most of these processes is a fiber with reduced mechanical properties (the resin having been burned or chemically melted off), suitable for chopping up for potential reuse as a filler, in a nonwoven, a mat or perhaps in injection molding or spray-up applications.

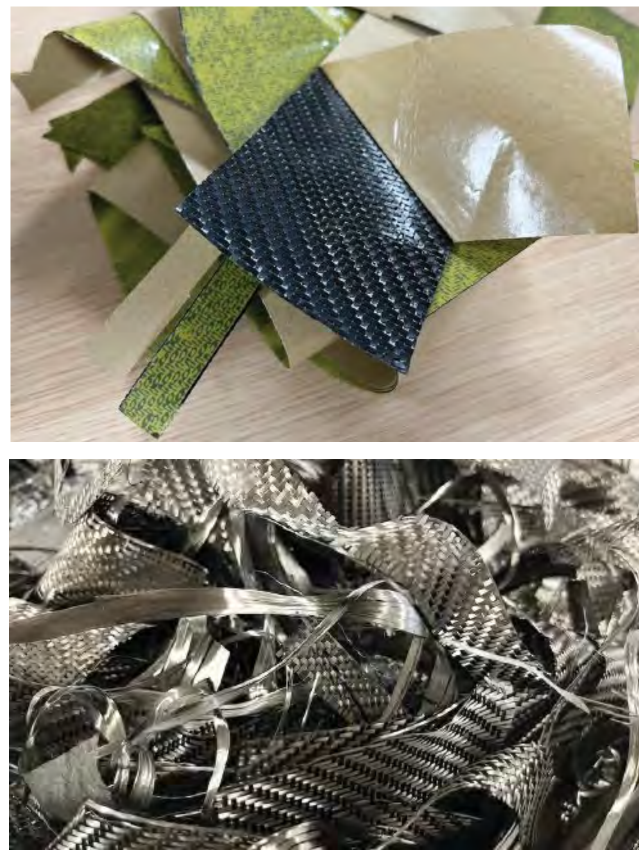
Longworth (formerly B&M Longworth, Blackburn, U.K.) is one company promising a new method for reclaiming both near-virgin-grade fibers *and* resins. Called DEECOM, the process uses high-temperature steam and pressure to separate and reclaim materials. After a decade of development and proving out the technology, the company is ready to launch DEECOM commercially for composites recycling this year.

Developing DEECOM: From parts cleaning to composites recycling

Since the 1970s, Longworth has provided cleaning solutions for the polymer manufacturing industry. For decades, the reigning solution for cleaning polymers from metal manufacturing components like stainless steel fine mesh filters employed the use of solvents like triethylene glycol (TEG). In the early 2000s, company

■ **Clean, intact carbon fibers**

These microscope images show that the carbon fibers from recycled X-ray sheets showed no leftover residue after DEECOM processing.



■ **Medical X-ray panel recycling**

These prepreg carbon fiber X-ray sheets are shown before (top) and after (bottom) processing via the DEECOM process, virtually intact.

chairman John Norris, his son Peter Norris and the Longworth team realized that many of the chemicals used in the company's cleaning systems were difficult for customers to dispose of properly and could be dangerous if released into water supplies or other improper channels. The company decided there should be a way to remove solidified polymer melt from metal components without the use of harsh chemical solvents.

The process Longworth patented in 2004 was called DEECOM — for "decompression" — and uses a combination of high-temperature steam and a pressurized chamber to clean polymers from steel without the use of chemicals, just water and steam energy.

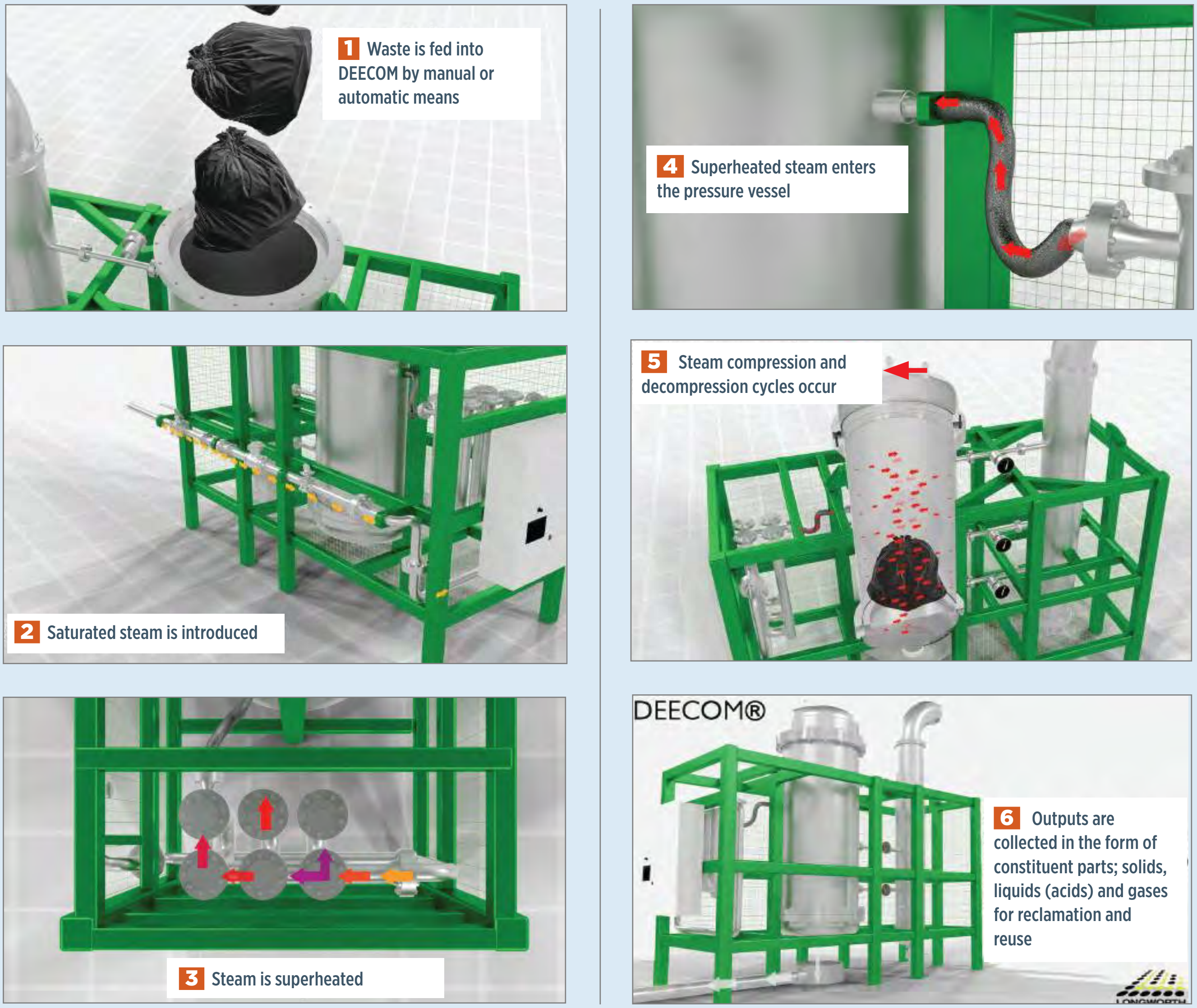
According to Jen Hill, director at Longworth, the process worked better than expected. Longworth originally thought DEECOM would be able to melt *some* of the polymers off the metal, which would mean *less* TEG or other chemicals would be needed to remove any remaining materials. "But it completely cleaned it, and there was zero damage to [the steel mesh]," Hill says. "We started applying DEECOM throughout that industry for that application, and we were quite happy with the results. It's given us a competitive advantage for 20 years, with customers around the world."

Then in 2007, Professor Peter Millington from the University of Manchester (U.K.) was visiting Longworth's facility and opened the company's eyes to DEECOM's potential application in composites recycling. "He said, 'You're completely overlooking the fact that this isn't just a cleaning solution, you're actually *reclaiming*, you're separating polymer from whatever else happens to be in the chamber,'" Hill recalls.

Longworth began connecting with composites industry leaders and OEMs to assess interest in the technology. In 2011, the company started collaborating with Boeing's Charleston, S.C., U.S., facility, for which Longworth ran trials of the DEECOM technology using carbon fiber composite fuselage sections from the 787. The results were then tested and validated by Clemson University (S.C., U.S.). Though the results have not been made public, Hill says this was the first time Longworth realized just how well its process worked for composites recycling, producing an end fiber with mechanical properties comparable to the original virgin, aerospace-grade carbon fiber.

Still new to the composites industry, Longworth spent the next several years on in-house R&D, testing and optimizing a version of its DEECOM process specifically for use in composites recycling. The company applied to patent DEECOM as a waste recycling process in 2012, and this was first accepted in China in 2017 and subsequently in other territories such as the U.S. and Europe.

Most recently, Hill says Longworth has been working to further validate the results of its process, through U.K. government-funded projects and partnerships with universities and research organizations like the National Composites Centre (NCC, Bristol, U.K.). "You need extra validation from the industry when you're entering with something very innovative, and when you're going up against technologies that have been invested in and relied on for decades. It's not a case of taking our word for it anymore," she says. »



The DEECOM process

The first iteration of the DEECOM system is set up to process waste in batches. The part to be recycled is fed into the top of a large pressure vessel. Saturated steam is piped into DEECOM's heating system, superheated to at least 400°C (752°F), and then enters the pressure vessel. While the superheated steam is still present, the vessel is pressurized by at least 0.5 bar above atmospheric pressure and goes through several cycles of compression and decompression — the frequency and intensity of the cycles depends on the properties of each material. In practice, each decompression separates more of the resin from the fiber.

The resin, now a gas or liquid depending on the type of resin and its reaction to the process, drops down into a collection area, and the fibers are left as intact as they can be, Hill says: "It's not bent, damaged or burnt, it's literally just cleaned. It's in the exact same state as when you put it in, the same length and everything." The only other waste output is steam expelled via a chimney. This steam can be captured for heat reclamation if required, further reducing the process' environmental footprint. The cycle time of the overall process depends on the number of compression/decompression cycles needed for a particular part.

The three key process parameters of DEECOM are temperature, pressure and time, and these change for each mix of materials and the size of the part or material being processed. "Any mix of those three parameters gets you a very different result. We've found that even one degree of difference can completely change the results," Hill says.

In addition, the company has recently developed a continuous system to serve as an efficient alternative option to the batch process. This, Hill says, was designed during the pandemic quarantine. “The R&D team were instructed to work from home, resulting in two new patents,” she says.

In the continuous system, cured or uncured parts are continuously fed via a screw through the system, where they are moved through a series of chambers for compression and decompression according to set parameters. This more efficient option would be ideal, Hill says, for recycling facilities that need to recycle large amounts of composite scrap. The system is believed to be able to process on par with traditional pyrolysis systems — with, she notes, less environmental impact. Manufacturing facilities that do not need continuous feed capabilities may be more suited to the batch option.

The DEECOM process is generally material-agnostic; however, one challenge to all types of composites recycling is that the process is highly dependent on the chemistry of a particular resin and a particular part. “Every time a resin supplier tweaks something, or improves a curing agent, for example, it changes how it processes,” Hill says. “To achieve full circularity within this industry, we need to work *with* the resin producers to embrace a ‘design for disassembly’ ethos, rather than have sustainability and competitive advantage in conflict.”

Because Longworth wants to keep the carbon footprint of DEECOM as small as possible, the company continues to make improvements to optimize the process so that only the needed energy and water are used. Hill explains, “Because it’s a batch process, sometimes we’re not sure whether it’s finished and ready in an hour, or if it needs another three hours or whatever the case is. We have academic partners doing projects to work out at what point in the cycle the magic happens.” The process could also be made more sustainable if a customer chooses to use renewable energy to power the equipment, and if the customer captures and reuses the heat and energy that is released during the process. Future R&D will look at whether reused or desalinated ocean water can be used, as well.

Market launch and continuing R&D

Through a new partnership with global equipment supplier to the composites industry, Cygnet Texkimp (Wincham, U.K.), Longworth plans to begin selling DEECOM units in Q2 2022. Three general sizes of batch units and a continuous unit option will be available, though Hill notes that each unit ends up being different based on the customer’s needs.

The company anticipates that the technology shows the most potential for manufacturers looking to reclaim and reuse their own manufacturing scrap, and composites recyclers looking for cleaner, large-scale solutions. One key to purchasing a DEECOM system, Hill notes, is having a use in mind for the reclaimed fiber. For example, companies using chopped fibers in sheet molding compound (SMC) could find cost savings in DEECOM’s recycled carbon fiber (rCF). An ongoing life cycle analysis (LCA) project is being performed to identify additional applications.

For recyclers, DEECOM could be an alternative to pyrolysis, or it could be used alongside pyrolysis. From the results shown so far, Hill says that Longworth is optimistic that DEECOM could help a fiber to be reused for two to three lifecycles before its usefulness is diminished. She acknowledges, however, that Longworth’s system is just one of many options, and the ideal solution may depend on the material.

In addition, Longworth is looking to partner with customers interested in reclaiming both fiber *and* resin. “Most people don’t want us to [reclaim the resin] because the value is in the carbon. But what we’d like to see is somebody truly interested in reclaiming the resin as well, because that brings us to true circularity, which was the point of the innovation,” Hill says. As with fiber, the value of reclaimed resin will depend on the value of the virgin resin, thus higher performance and aerospace-grade resins will be most attractive initially.

Meanwhile, Longworth will continue to work on evolving DEECOM. For example, the company is involved in several projects to understand the full value and to evaluate use cases for reclaimed fibers and resins. “We know [the fibers] come out anywhere between 80-100% clean and free from resin. We know we can leave the sizing or remove the sizing as required. What we don’t know is what of those uses are the most feasible in terms of commercial value, and which are most low-carbon, to serve as an alternative to people who really don’t need to use virgin fiber and pay the premium.”

Hill is also involved with the British Standards Institute (BSI, London, U.K.) committee writing new standards to allow for novel recycling processes in the U.K., since DEECOM doesn’t fall directly under other types of recycling like pyrolysis, solvolysis or hydrolysis.

There is a lot of work still to do, Hill admits, but she’s sure DEECOM has a role to play in advancing composites recycling. She says, “For composites it certainly seems like the entire industry is ready for some new innovation. It knows it shouldn’t be pyrolyzing everything or landfilling everything and it knows that there is a worldwide shortage of carbon fiber and there will continue to be. There is an appetite for [more composites recycling], there is a hunger for it, but it needs to make sense commercially. The more uses the industry can find for consistent, high-quality rCF, the cheaper and more readily available it will become through less pressure on the virgin fiber supply chain. For manufacturers employing this technology onsite to convert their own waste, they’ll effectively have access to high-grade, consistent recycled feedstock free of charge. It’s a no-brainer.” CW

ABOUT THE AUTHOR

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Plant Tour: Victrex Composites Solutions, Bristol, Rhode Island, U.S.

Supporting a new supply chain

Victrex Composites Solutions is producing thermoplastic composite overmolded parts from its 5,000-square-meter production facility housed within a building it shares with long-time partner, Tri-Mack Plastics. Source | Victrex

De-risking thermoplastic composites at an industrial scale via hybrid overmolding.

By Ginger Gardiner / Senior Editor

» When *CW* first discussed the overmolding process that Victrex (Cleveleys, Lancashire, U.K.) developed in 2015, it was revolutionary, opening a whole new category of "hybrid composites." In the process, Victrex uses a continuous fiber-reinforced polyaryletherketone (PAEK) composite substrate, and then injection molds onto it a short fiber-reinforced polyetheretherketone (PEEK) compound. In the 2015 article, the result was a high-performance, hybrid composite bracket that was up to 60% lighter than a comparable metal component. The 305°C melt temperature of the Victrex low-melt PAEK (LMPAEK) polymer allows the substrate to melt at the surface when overmolded with the PEEK compound — which melts at 340°C — effectively creating a weld. The overmolding simultaneously functionalizes a composite part — for example, with reinforcing ribs or clips for LED lights — and allows it to be thinner, lighter and use less material than an unreinforced PEEK part.

In 2017, Victrex announced its investment in TxV AeroComposites (see Learn More), a joint venture with customer and hybrid bracket co-developer Tri-Mack Plastics (Bristol, R.I., U.S.). That joint venture, which Victrex subsequently bought out and owns 100%, is now installed in a 5,000-square-meter building in Bristol. "The original idea was to create a sort of center of excellence where you could do all of the design and engineering, get tools built, make prototypes and, ultimately, produce commercial parts," says Jonathan Sourkes, Victrex head of sales for aerospace. "Essentially, we're here to make parts at industrial rates and to inspire other companies to do the same."

De-risking thermoplastic composites production

CW's tour of the Victrex Composites Solutions facility begins in the upstairs conference room, with a discussion about the transition from 2015 until now. When Victrex began production of its

AE250 LMPAEK polymer, says Sourkes, "it saw the need for an entire ecosystem of product formats like fibers, films, powders and UD tapes, and also to perform research on how to process the polymer in composites and predict part performance in order to drive applications development. We have fully characterized the overmold-to-substrate bond, achieving a strength of up to 40 megapascals, which is twice that of an aerospace-grade adhesive bond and 50% better than the typical benchmark for thermoplastic composite welding."

"Hybrid composites are gaining a lot more acceptance," says Rob Mazzella, head of composites for Victrex, "but there's still more to do in raising awareness on the possibilities of the technology to the supply chain. Our driver for this facility has always been capability for high-quality parts at high rates."

"Our goal is to foster industry adoption and to de-risk and accelerate development for our customers," says Sourkes. "That's why we're helping customers to develop hybrid parts, and also selling composite laminates and inserts for others to overmold." This facility was established, says Mazzella, "to support them in a way that requires moving beyond a center of excellence. This is why we've put in place equipment and a production footprint for high-rate PEEK and PAEK composites production. We have invested in automation that delivers industrial cycle times and repeatability."

Hybrid parts, AAM and allowables

Discussion now turns to an array of overmolded thermoplastic composite parts, including a 0.7- x 0.7-meter access door panel for a cargo aerial vehicle. "It's made with 50 plies of UD tape and almost one kilogram of overmolding," says Sourkes. "It also has a double curvature that forms a kind of pocket in the laminate which the overmolding fills." The part was produced for the DARPA-funded RAPM project led by Boeing (Chicago, Ill., U.S.; Learn More). The part weighs 5 kilograms versus the previous aluminum part at almost 10 kilograms. "To get this shape from aluminum, they had to start with a 14- to 23-kilogram billet and CNC machine a lot of material away," says Sourkes. "So, the buy-to-fly ratio was poor. The hybrid composite part has significantly less waste."

Indeed, hybrid parts do really well where the buy-to-fly ratio needs to be improved. "Our materials and process offer sustainability benefits in terms of lightweighting, efficiency and CO_2 reductions," says Sourkes. "The hybrid composite access door has a cycle time under 10 minutes, whereas CNC machining it from aluminum would take all day. So, even though the CNC cost on a per-hour basis is lower than the composites process costs, we're so much lower on process time that we end up with a better part cost." Mazzella points out another part, a monument bracket for a regional aircraft that is still in development. "The buy-to-fly ratio was close to 10[:1], and we came in at 40% of the weight and 40% of the cost of the incumbent part," says Sourkes.

Handing over a key-sized structure with a tear-shaped composite head and threaded metal bolt shank extending from the bottom, Mazzella notes, "This part is much smaller than what we normally work on, but it actually has not only a composite insert but also a metal bearing assembly that is overmolded. It's the type of new application that we're helping to innovate, because even saving a few grams per part adds up when hundreds of parts per aircraft are involved."

The final part to be discussed is for the advanced air mobility (AAM) manufacturer Beta Technologies (South Burlington, Vt., U.S.). "The application is targeting thousands of shipsets per year with multiple parts per shipset," says Sourkes. "This is a glass fiber-reinforced PAEK part that we're prototyping and is most of what is running in our equipment today." Why hybrid composite? "To achieve the shape and not use any metal," says Sourkes. "And the weight reduction is key because every gram matters in these battery-powered vehicles." Even though discussion in the industry has been that AAM primary structures will use thermoset composites, Sourkes notes that "we're hearing from AAM manufacturers that beyond 1,000 shipsets per year, they see the need for thermoplastics." Traction has come quickly with AAM, says Mazzella. "There are certain parts of these aircraft where the requirements lend themselves really nicely to PEEK composites. We're also starting to see the commercial aircraft OEMs and Tier suppliers start to dust off efforts that they were pushing fairly hard pre-COVID."

Another issue for AAM, and an additional key part of the »

Hybrid part prototypes

Top left, clockwise: Monument bracket for regional aircraft, prototype AAM part for Beta Technologies and prototype access door panel for a cargo aerial vehicle.

Source | Ginger Gardiner, *CW*

Flexible, automated production

Robotic spool change-out and creel for automated tape laying (ATL) cell.

Source | Ginger Gardiner, *CW*

ecosystem that Victrex has been working on, is development of allowables databases. "NIAR [Wichita, Kan., U.S.] has published an NCAMP database for Toray Advanced Composites [Morgan Hill, Calif., U.S.] TC1225 carbon fiber/LMPAEK prepreg using static press molding," says Sourkes. "Soon, we'll publish our equivalency to that data using the shuttle press technology we have here. For test parts, we have a molding cycle of less than 15 minutes, but in practice, parts are typically molded in under 10 minutes. This is made possible because our shuttle press has an inherently quicker process time than a static press molding process." While this NCAMP TC1225 database is based on Toray T700 carbon fiber, Victrex is working to get data published through NCAMP using AS4, IM7 and eventually AS7 carbon fibers. This will allow companies to get equivalency with their processes for a relatively small investment. "We've invested significantly to democratize the data to support the industry."

Flexible, industrial production

As we prepare to tour the production floor downstairs, Mazzella explains that Victrex's process is based on automated tape laying (ATL) to create tailored blank preforms, followed by press consolidation, waterjet trimming, stamp-forming, CNC drilling and then overmolding. "Though we'd love to see Victrex materials in large primary structures," he says, "we don't aspire to produce those here." What, then, is the targeted part size? "With ATL and a press, it doesn't make sense to go much beyond 2 meters," says Sourkes. "We could use other processes, but we chose ATL and stamping. By our analysis, if you can make the part in this way, the alternative technologies don't compete economically."

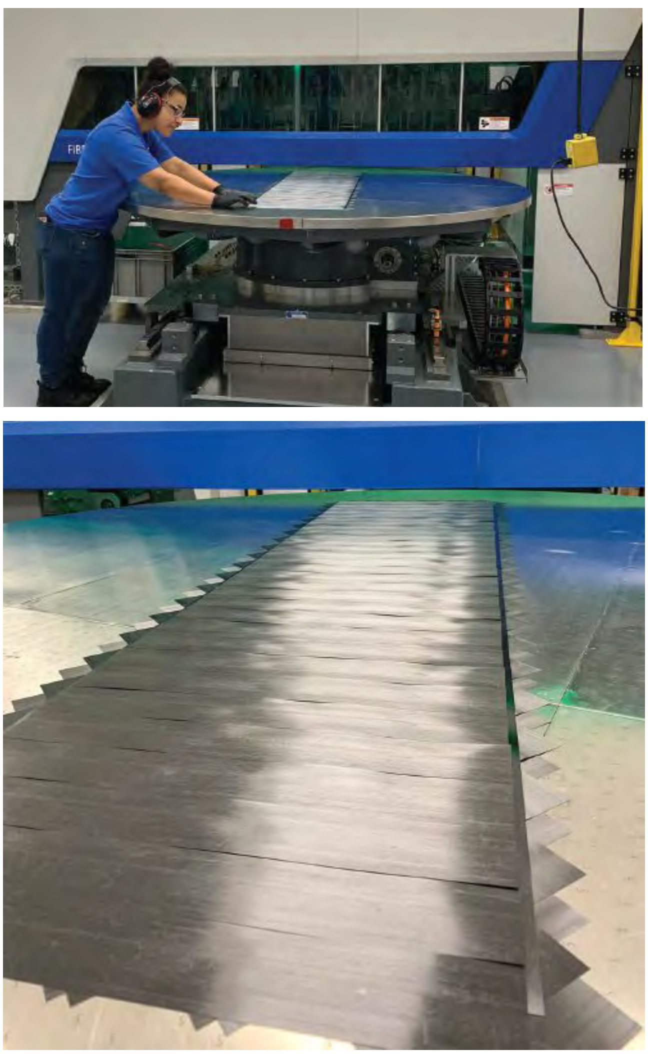
"Our approach," says Mazzella, "has been to put in place the most flexible facility capable of parts you can hold in one hand to parts spanning a meter or two as a hybrid. The programs we have now are feasible at an industrial scale, but if we're going to start running 10,000 or 20,000 units per year of one part, then we'll most likely install a purposely designed cell just for that."

The tour, led by Sourkes and Victrex plant manager Kalon Lasater, began on the first floor beneath the offices, running from the front of the building to the back. The first area contains what are termed "dirty" processes, including CNC machining, a metal shop and an area for prototyping fixtures. A Haas Automation (Oxnard, Calif., U.S.) CNC cell is used to drill stamp-formed parts before overmolding. Just beyond it is an enclosed waterjet cell from Flow International (Kent, Wash., U.S.), used to trim consolidated laminates before stamp-forming.

As we pass through a door into the main production area, there is, notably, a lot of open space. "We installed equipment for what was ready for production today," says Sourkes, "so we have a lot of space for growth." Lasater notes that the floor layout was designed to allow for additional shuttle press stations as well as ATL, stamp-forming and overmolding lines. We walk past the shuttle press consolidation cell on the left and the robotic forming station opposite it on the right toward the enclosed ATL cell ahead on the left.

Automated tape laying (ATL) cell

Inside the ATL cell, a Dieffenbacher (Eppingen, Germany) Fiberforge 4.0 tailored blank line is producing carbon fiber/PAEK



Fast preforms via ATL

Rotary table (top) and multi-layer carbon fiber/PAEK preform (bottom).

Source | Ginger Gardiner, *CW*

Drying and consolidation

ATL preforms are dried in an oven (right photo) and then consolidated in the two-tower press (left photo). A consolidated laminate (lower right) inside a sheet metal transport tool is exiting the roller track and will be extracted using the robot with orange vacuum grippers. Source | Ginger Gardiner, *CW*

preforms for yet another AAM project. Standing in front of the Fiberforge, the operator control station is at left, and beyond that is an area for storing tape spools. Between the spool storage and the Fiberforge machine is a robot that picks up new spools and switches them out with depleted spools in the machine's creel. This creel, which forms the left end of the Fiberforge machine, can feed up to four types of tapes, each with buffered unwind and tension control.

The next station to the right features two parallel rapid tape dispensers. These feed and cut tape with a <1 second cycle time at a maximum tape length of 2,000 millimeters. This includes subsequent ultrasonic spot welding to tack each ply to the one beneath. Alternatively, instead of one long tape, two shorter tapes can be placed simultaneously with the same sub-second speed.

Dieffenbacher claims a maximum deposition rate of 490 kilograms/hour. The ATL system works with all formulations of thermoplastic tapes, including Victrex PEEK and LMPAEK as well as glass and carbon fibers. Tape width can range from 50 to 165 millimeters and thickness from 0.1 to 0.4 millimeter. Cut tape length can range from 30 to 2,000 millimeters.

After cutting, the tapes are placed onto a 2-meter-diameter rotary table, fixed by a vacuum system and immediately tack-welded by a series of ultrasonic welding heads. Once the whole ply is completed, the table rotates and indexes to receive the next ply or translates quickly out from the tape layer toward the control station for inspection by the operator.

The process enables near-net shape layups and minimizes material waste. The ATL system allows layups with a small gap (e.g., 0.4 millimeter) between tapes. "The gaps close up as the tapes spread during consolidation," notes Lasater. "We have placed up to 50 plies for that access panel we showed, but we haven't hit our max yet." Parts with 90 plies have been made by layering two ply stacks on top of each other. "This system is different from continuous compression molding [CCM]," he explains, "in that we don't have to butt-weld tapes together to include off-axis plies. The table simply rotates, so we have a wide range of possible fiber angles, and weld locations are offset so that they aren't in the same location for each ply."

Weld locations are specified as part of production engineering design, as is the pressure for each weld and the shape, number and placement of tapes for each ply. Tailor-Gen is the software Dieffenbacher uses for its operator interface. "Imagine using Solidworks to design a laminate," says Lasater. "You can predict run-time, material consumption and where each cut tape will be placed. It will also detect issues and reject the design, so that you're not allowed to lay a bad course."

Drying and consolidation

From the ATL cell, the tailored blanks are taken to a drying oven that sits adjacent to the shuttle press consolidation area. Even though PEEK and LMPAEK have <1% moisture absorption, finished tailored blanks are dried as a precautionary step to make »

■ Robotic stamp-forming

The rails in the foreground guide laminates fastened into tension frames (above, right) into and out of the stamp-forming cell featuring two robots and a 275-ton press in the background, flanked by upper and lower IR ovens on each side.

Source | Ginger Gardiner, *CW*

■ Precise tensioning for wrinkle-free parts

Consolidated thermoplastic composite laminates are fastened into frames with specifically located and tensioned to allow forming without wrinkles. This laminate will be stamp-formed into the parts shown stacked on p. 25.

Source | Ginger Gardiner, *CW*

sure no moisture exists that could cause porosity in the consolidated laminate. The oven drying cycle is typically 8 hours at 135°C, but depends on the thickness, says Lasater. The blanks are layered into wire racks within a large cart, which, when wheeled into the oven, enables cross-flow to dry each laminate. During our tour, the cart had ATL blanks on the bottom and already-consolidated sheets on top. "We have two drying steps: one before consolidation and one after water jet cutting, before we put the consolidated blanks into the forming cell," says Sourkes.

The consolidation cell measures roughly 6 x 9 meters and features a bespoke press with two towers that contain separately actuated platens, made by a U.S. supplier of traditional industrial equipment. The glass fiber/AE250 LMPAEK laminate used in the AAM part seen in the conference room is being consolidated using three sets of transport tools. Each 10-minute consolidation cycle comprises three simultaneous stages: (1) new blank moves into the first "hot" tower; (2) melted blank from first "hot" tower moves into second "cold" tower (which is still hot); (3) consolidated blank exits the second tower and moves around a deliberately sized track of metal rollers, the length calculated for sufficient cooling to develop the crystallinity needed for full mechanical properties. At the end of the track, the cell operator uses a robot with vacuum grippers to open the transport tool, and then, wearing heat-resistant gloves, removes the still-hot laminate and places it into a storage rack.

"We have invested in automation that delivers industrial cycle times and repeatability."

A single operator can run the whole cell, including loading and unloading of the transport tools. The cell can run with a cycle time as low as three minutes, says Lasater, "in which case, we'd use four to five transport tools. These tools are size-specific but not part-specific and are made from low-cost sheet metal."

"Normally, this type of press would only have two cylinders," he continues, "but all of ours have four, which, when combined with advanced hydraulics and controls, achieves a very high level of parallelism during consolidation and also in our stamp-forming cell." This is important to maintain flatness and precision in the laminates and finished parts.

"We also apply a Victrex LMPAEK film that aids in bonding during hybrid overmolding, which is part of the standard ply schedule for hybrid laminates," Lasater explains, pointing to a box beneath the storage rack. Consolidated blanks are then sent next door to the waterjet cell for edge trimming and adding features prior to stamp-forming. As explained above, they are then dried again before proceeding to the stamp-forming cell.

Stamp-forming and overmolding

This cell features a 275-ton press, made by the same supplier as the two-tower consolidation press. A stack of infrared (IR) ovens (Infrared Heating Technologies, Oak Ridge, Tenn. U.S.) is located on each side of the press for four ovens total. "This allows the cell to match the index pace of the press," says Lasater. "As long as we have three to four fixtures for the consolidated sheets, we can have a laminate into the press each time it opens."

The fixtures are metal frames configured precisely to hold the consolidated laminate and enable forming the desired 3D geometry without wrinkles. Sourkes notes that the forming process is typically optimized during design using forming simulation software like AniForm (AniForm Engineering, Enschede, Netherlands). "Deeper-draw, complex geometries require extensive simulation to arrive at an optimized fixture design," he adds. "That's how we also derive the optimal press-closing speeds and pressure profiles, which are key parameters."

The clamping fixture sits on a set of rails that feeds into the

Injection overmolding

The Engel Victory 130 injection molding cell can overmold composite substrates up to 1 square meter. More cells will be added as programs complete qualification over the next five years. Source | Ginger Gardiner, *CW*

stamp-forming cell, which is also run by one operator. After fastening the laminate into the forming fixture, the operator pushes a button and the fixture moves into the cell where one of two Yaskawa (Miamisburg, Ohio, U.S.) robots picks up the fixture and places it in the top left IR oven. After a brief preheat cycle, the IR oven opens and the robot quickly transfers the fixture into the forming press, which immediately closes and begins the 2-minute press cycle for this part. The time and temperature of the IR oven and press follow a pre-programmed recipe optimized during the part design process. “We control both temperature and pressure and know where the preform is located within the press every time,” says Sourkes. Once the press cycle is complete, the robot removes the fixture from the press and returns it to the rail system where the operator removes it and prepares another laminate.

After stamp-forming and CNC drilling, parts are transferred to the overmolding cell, located directly across from the ATL cell. Situated within a large walled production area is a single Engel (Schwertberg, Austria) Victory 130 injection molding machine that has been tailored for the high temperatures required for PEEK and PAEK. “We also need a machine that can take large substrates up to 2 meters wide or long,” says Lasater, “and overmold these using shots of plastic that are 1 kilogram or less, which is small compared to typical plastics injection molding. And we need significant force to resist the backpressure of overmolding, otherwise the molding compound would flash out. That’s why these machines tend to be high tonnage for the shot size.”

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From the overmolding area, parts are transferred to the rear of the building and prepared for shipping. As we walk back toward the front of the building, we turn left just before the stamp-forming cell and enter a lab set behind it. This analysis lab is where part samples are checked for crystallinity using a differential scanning calorimeter (DSC). “We use this for validating process parameters,” says Lasater, “to confirm our cooling cycle, for example. We then use our process control to make sure every part conforms to the specification.” In the opposite corner is a Hexagon Manufacturing Intelligence coordinate measuring machine (CMM), used to validate geometry precision before finalizing process specs.

Five years forward

As the tour concludes, I ask the team to describe this production floor in five years. “We’ll have purpose-built production cells,” says Sourkes. “We have very flexible equipment on the floor right now, but installation of new cells will be optimized for a family of parts, most likely for AAM. In five years, we’ll also have hybrid processes qualified with commercial aerospace OEMs, which will open further applications for us and other parts manufacturers.”

“Those qualifications are investments and programs that are already ongoing,” adds Mazzella. “Some will come online in closer to two years, but by five years, everything we’ve got active now should be at TRL [technology readiness level] 9.” Sourkes notes that four to five NCAMP databases for thermoplastic composites should also be completed, “which will allow us to help our customers get parts certified with the FAA and EASA. Right now, everything is point design, but in five years, it will be much easier. And that’s really why this dedicated composites solutions facility exists — to take that design and development capability and polyketone expertise, along with the process and production lessons that we’ve learned here, and apply this to convert aluminum, titanium or thermoset composites designs into thermoplastic hybrid composites parts that can be produced at an industrial scale.” CW

ABOUT THE AUTHOR

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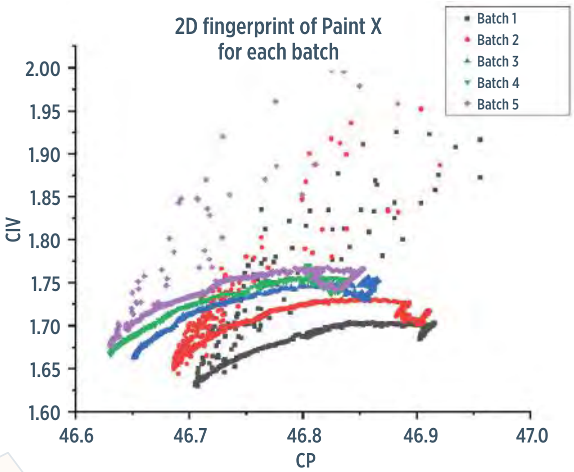
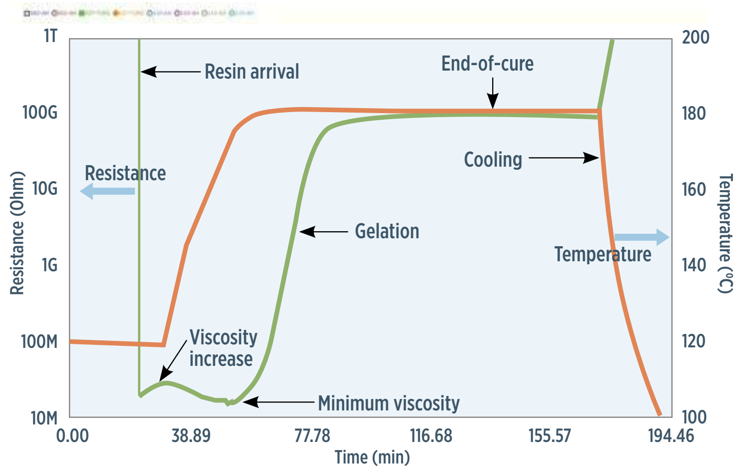




Sensors: Providing the data needed for next-gen composites manufacturing

In the quest for sustainability, sensors are reducing cycle times, energy use and waste, automating closed-loop process control and increasing our knowledge to open new possibilities for intelligent manufacturing and structures.

By Ginger Gardiner / Senior Editor

» As global industry continues to emerge from the COVID-19 pandemic, it has pivoted to prioritize sustainability, which demands reduction of waste and resource consumption (e.g., energy, water and materials). Thus, manufacturing must become more efficient and intelligent. But this requires information. For composites, where does this data come from?

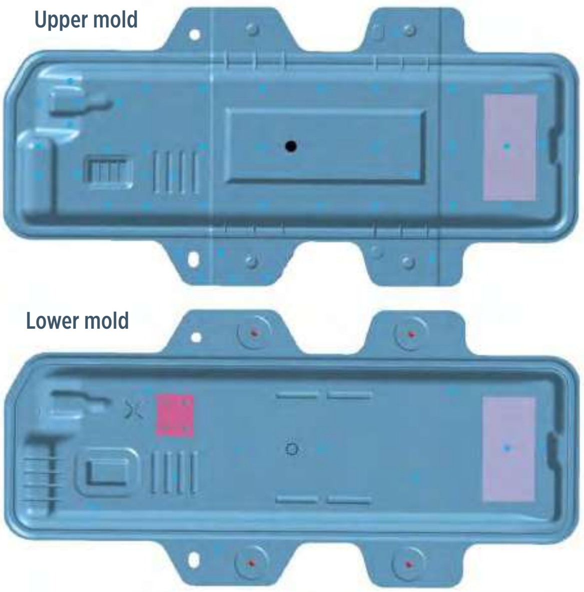
Defining the measurements required to improve part quality and production, and the sensors required to achieve those measurements, is one of the first steps toward intelligent manufacturing, as described in *CW*'s 2020 series of articles on Composites 4.0. Throughout 2020 and 2021, I have written about sensors — dielectric sensors, thermal flux sensors, fiber optic sensors and contactless sensors that use ultrasound and electromagnetic waves — as well as projects that demonstrate their capabilities (see Learn More for *CW*'s Sensors content collection online). This article draws from this coverage to discuss the sensors being used in composites, their promised benefits and challenges and the landscape of technology being developed. Notably, companies that are becoming the future leaders of the composites industry have already begun to explore and navigate this landscape.

Why use sensors?

Goal #1: Save money. In my Dec. 2021 blog, "Customizing ultrasonic sensors for composites process optimization and control," I described the University of Augsburg's (UNA, Augsburg, Germany) work in developing a network of 74 sensors used to manufacture an electric vehicle battery box cover

Visibility into processes

Graphs at top (left to right): Collo permittivity (CP) versus Collo ion viscosity (CIV) using electromagnetic sensor and resin resistance versus time (Synthesites). Sensors at left (top to bottom): Heat flux (TFX), in-mold dielectric (Lambient), ultrasonic (Univ. of Augsburg), disposable dielectric (Synthesites) and microwire (AvPro) in between penny and thermocouple. (Left) digital model of caprolactam injection into preform (CosiMo project, DLR ZLP, University of Augsburg).



Network of sensors in CosiMo

A network of 74 sensors — 57 were ultrasonic sensors developed by the University of Augsburg (shown at right as light blue dots in upper and low mold halves) — were used in the T-RTM molding of a thermoplastic composite battery box cover demonstrator for the CosiMo project. Source | CosiMo project, DLR ZLP Augsburg, University of Augsburg

demonstrator for the CosiMo ("composites in smart mobility") project. The part was made using thermoplastic resin transfer molding (T-RTM) which in-situ polymerizes a caprolactam monomer into a polyamide 6 (PA6) composite. Markus Sause, a UNA professor and director of the Augsburg Artificial Intelligence (AI) Production Network at UNA, explains why sensors are important: "The biggest advantage we are offering is to visualize what's going on inside the black box during processing. Currently, most manufacturers only have limited systems to make that happen. For example, they are using very simple or specific sensors when fabricating large aerospace parts using resin infusion. And if the infusion process goes wrong, you basically have a large piece of scrap. But if you have a solution to understand what goes wrong during production and why, you can then address and correct it, and save a lot of money."

Thermocouples are one example of a "simple or specific sensor" used for decades to monitor temperature in composite laminates during autoclave or oven cure. They have even been used to control the cure temperature in an oven or in a heat blanket to cure a composite repair patch using a hot bonder. Resin manufacturers have used various sensors in the lab to monitor change in resin viscosity with time and temperature to develop their recommended cure cycles. But what we're discussing here is a *network* of sensors that are used to visualize and control the process *in-situ*, based on *multiple* parameters (e.g., temperature and pressure) and the *state of the material* (e.g., viscosity, polymerization, crystallization).

Notably, the ultrasonic sensor developed for the CosiMo project uses the same principle as ultrasonic testing that has become the mainstay for non-destructive inspection (NDI) of *finished* composite parts. "Our aim was to *minimize* the time and labor required for post-production inspection on future components as we move toward digital manufacturing," says Petros Karapapas, principal engineer at Meggitt (Loughborough, U.K.). He worked with the National Composites Center (NCC, Bristol, U.K.) to demonstrate use of linear dielectric sensors developed by Cranfield University (Cranfield, U.K.) to monitor flow and cure of Solvay (Alpharetta, Ga., U.S.) EP 2400 epoxy during RTM of a 1.3-meter-long, 0.8-meter-wide and 0.4-meter-deep composite housing for a commercial aeroengine heat exchanger. "As we look at how to make larger components and at higher production rates, we cannot afford to do all of the conventional post-processing inspection and testing for each part," says Karapapas. "Right now, we make test panels alongside such RTM parts and then we do mechanical tests to validate the cure cycle. But with this sensor, that won't be necessary."

"We are not aiming to be another lab device, but instead are focused on systems for production," says Matti Järveläinen, CEO and founder of ColloidTek Oy (Collo, Tampere, Finland). In my January 2022 blog, "Fingerprinting liquids for composites," I explored Collo's combination of electromagnetic field (EMF) sensors, signal processing and data analytics to measure the "fingerprint" of any liquid, such as a monomer, resin or adhesive. "What we are offering is a new technology to provide direct feedback while the process is ongoing so that you can better understand how the process actually works and reacts if something goes wrong," says Järveläinen. "Our sensors convert real-time data into physical quantities that are understandable and actionable, like rheological viscosity, which allows optimizing the processes. For example, you can shorten mixing time because you can clearly see when mixing is complete. So, you can improve productivity, save energy and reduce scrap versus processing that is less optimized."

Goal #2: Increase process knowledge and visualization. In the case of processes such as polymerization, says Järveläinen, "you cannot see much from a snapshot only. You are just taking a sample and going into the lab and seeing what the state was minutes or hours ago. It's like driving on a motorway and just »

Dielectric

Types: Point, line

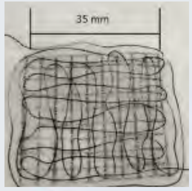
Measures: Resin electrical resistivity, ion viscosity and permittivity, temperature

Installation: Reusable in the mold or resin feed line, disposable on top of/inside part (affects properties)

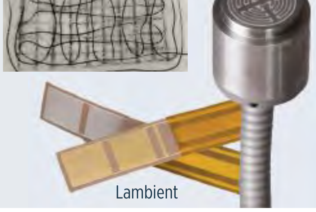
Monitoring: Flow, cure, T_g, viscosity

Contactless: No

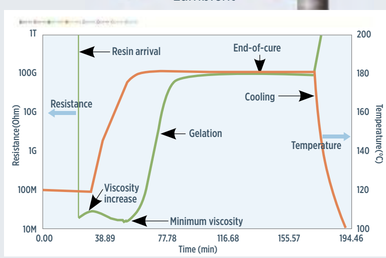
Suppliers: Lambient, NCC/Cranfield Univ., Netzsch, Synthesites



NCC, Cranfield University



Lambient



Synthesites

Electromagnetic

Types: Point

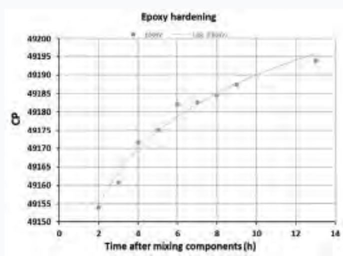
Measures: Resin ion viscosity, permittivity, plus six more variables

Installation: Reusable in liquid (Collo Probe) or in mold, mix vessel or pipe (Collo Plate)

Monitoring: Flow, cure, viscosity, polymerization, homogenization, sedimentation, agglomeration, impurities, fingerprint of liquid

Contactless: Yes, interrogates through non-metal to 2-10 cm depth at >1 MHz

Suppliers: CollodTek



Collo

Fiber Optic/FBG

Types: Line (100-200 µm-diameter, up to 100 m-length) with up to 40 sensing points

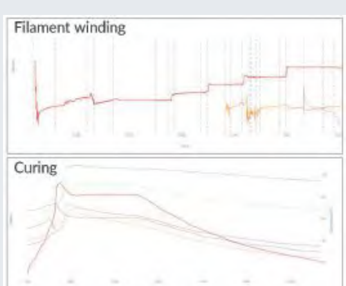
Measures: Temperature, strain/ pressure via reflected light

Installation: In the part without affecting properties

Monitoring: Flow, cure, load, vibration, winding tension, damage, fatigue, SHM, recertification

Contactless: No

Suppliers: Com&Sens, Luna Innovations, PhotonFirst



Com&Sens

opening your eyes for one minute each hour and trying to predict where the road goes from that." Sause agrees, noting the sensor network developed in CosiMo "helped us to have full visibility into the process and material behavior. We could see the local effects in the process in response to variations in part thickness or in the integrated materials, like the foam core. What we're trying to do is provide information about what is actually occurring in the mold. And this allows us to determine various things such as the shape of the flow front, the time for it to reach each part of the preform and the degree of polymerization at each sensor location."

Collo has worked with manufacturers of epoxy adhesive, paint and even beer to create a process profile for each batch produced. Each manufacturer can now see the dynamics of its process and set more optimal parameters with alarms to enable intervention when the batch is out of spec. This helps to stabilize and improve quality.

"I want to know what's going on inside the part manufacturing process while it's happening, as opposed to opening the box and seeing what happened afterwards," says Karapapas at Meggitt. "What we developed using the dielectric sensor from Cranfield gave us eyes on the process in-situ, and we were also able to validate cure of the resin." Monitoring of cure/polymerization and resin flow is possible with all six types of sensors described here on pages 30-31 (not an exhaustive list, but just a small selection, as are the suppliers). Some sensors have additional capabilities and combining sensor types can expand what is possible to track and visualize during composites molding. This was demonstrated during CosiMo, which used ultrasonic, dielectric and piezoresistive in-mold sensors (Kistler, Winterthur, Switzerland) for temperature and pressure.

Goal #3: Reduce cycle time. Collo sensors can measure the homogeneity of two-part, snap-cure epoxy as parts A and B are mixed and injected during RTM and at every location in the mold where such sensors are placed. This could help to qualify faster cure resins for applications such as urban air mobility (UAM), which would offer much faster cure cycles versus current one-component epoxies like RTM6.

Collo sensors can also monitor and visualize an epoxy resin being degassed, infused and then cured as well as when each process is complete. Ending cure and other processes based on the actual state of the material being processed — versus a legacy time and temperature recipe — is called material state management (MSM). Pursued for decades by companies like AvPro (Norman, Okla., U.S.), MSM tracks variations in the part's materials and process as it pursues specific targets for glass transition temperature (T_g), viscosity, polymerization and/or crystallization. The sensor network and digital analysis in CosiMo, for example, was used to determine the minimum amount of time required in the heated RTM press and mold, finding that a maximum polymerization of 96% was achieved in 4.5 minutes.

Suppliers of dielectric sensors such as Lambient Technologies (Cambridge, Mass., U.S.), Netzsch (Selb, Germany) and

Synthesites (Uccle, Belgium) have also demonstrated their ability to shorten cycle times. Synthesites reported from R&D projects with composites manufacturers Hutchinson (Paris, France) and Bombardier Belfast, now Spirit AeroSystems (Belfast, Ireland), that it was able to reduce the cure cycle for RTM6 by 30-50% based on real-time measurements of resin electrical resistance and temperature, which are converted into estimated viscosity and T_g by its Optimold data acquisition unit and Optiview software. "The manufacturer can see the T_g in real time, so they can decide when to stop the cure cycle," explains Synthesites director Nikos Pantelelis. "They don't have to wait to complete a longer-than-necessary legacy cycle. For example, the legacy cycle for RTM6 is 2 hours at 180°C for full cure. We've seen that in certain geometries this can go down to 70 minutes." This has also been demonstrated in the INNOTOOL 4.0 project described in "Speeding RTM with heat flux sensors," where thermal flux sensors were used to reduce the RTM6 cure cycle from 120 to 90 minutes.

Goal #4: Closed-loop control for adaptive processes. For the CosiMo project, the real quest was to enable automated, closed-loop control during composites part production. This was also the goal for the ZAero and iComposite 4.0 projects (as was a 30-50% cost reduction) which I discussed in 2020. Note that these dealt with different processes — automated placement of prepreg tape (ZAero) and fiber spray preforming and RTM with snap-cure epoxy (iComposite 4.0) compared to the high-pressure T-RTM in CosiMo. But all of these projects used sensors with digital models and algorithms to simulate the process and predict outcomes for the finished part.

Sause explains that process control can be envisioned as a series of steps. The first step is to have the sensors and process equipment integrated, he says, "to visualize what's happening inside your black box of processing and what parameters to use. Another few steps, perhaps halfway to closed-loop control, is to have the ability to hit the stop button in order to intervene, adapt the process and prevent reject parts. As a final step, you can develop the digital twin, which enables automation but also requires investment in a machine learning approach." In CosiMo, this investment allowed the sensors to feed data to the digital twin, where edge analytics (calculations performed at the edge of the process line versus from a central data repository) were then used to predict flow front dynamics, the fiber volume content of each textile preform and potential dry spots. "Ideally, you can establish settings to enable closed-loop control and adjustment during the process," says Sause. "These would include parameters like injection pressure, mold pressure and temperature. You can also use this information to optimize your materials."

On the way to that goal, companies are using sensors to automate processes. For example, Synthesites is working with its customers to integrate sensors with equipment so that resin inlets are closed when infusion is completed or a heated press is opened when target cure has been reached. »

Heat Flux

Types: Point

Measures: Heat flow, temperature, (pressure TBD)

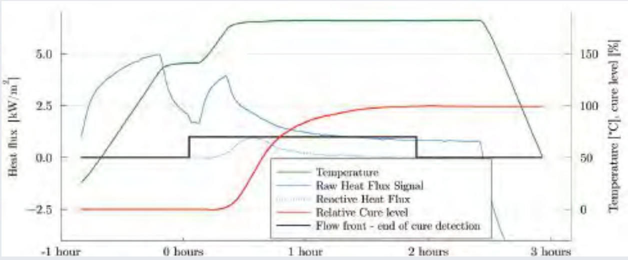
Installation: Reusable in the mold or resin feed line, disposable on top of/inside part (affects properties)

Monitoring: Flow, cure

Contactless: With material, <1 mm from tool surface

Suppliers: TFX

TFX



GKN Fokker Landing Gear, Techni-Modul Engineering, NLR and TFX

Microwire

Types: Line (3-70 μm-diameter, 1-4 cm up to km-length)

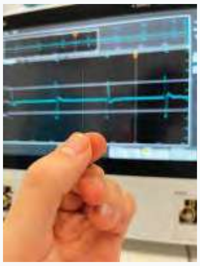
Measures: Temperature, strain/pressure, magnetic field

Installation: In the part without affecting properties

Monitoring: Flow, cure, load, vibration, fatigue, damage, SHM, recertification, position, electric current

Contactless: Interrogator ≤10 cm from part at <10 kHz

Suppliers: AvPro, RVmagnetics



RVmagnetics

Ultrasonic

Types: Point

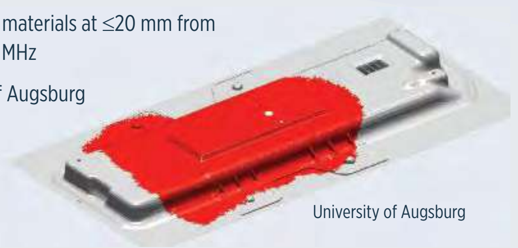
Measures: Acoustic properties (impedance, velocity of sound, attenuation)

Installation: Reusable in the mold

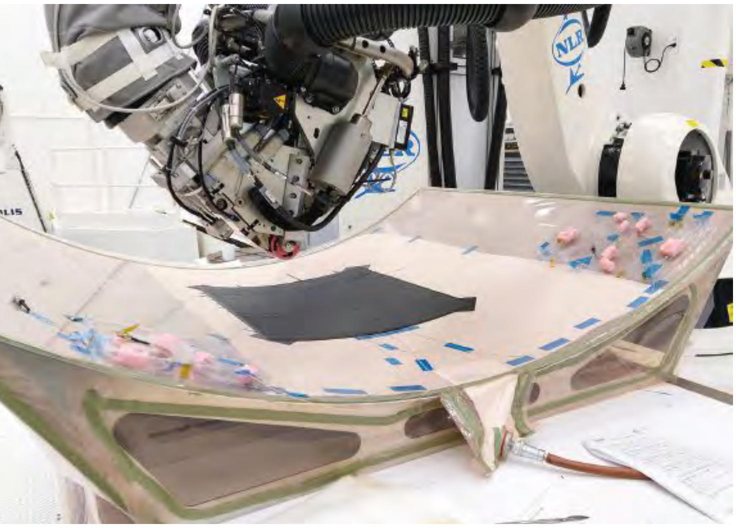
Monitoring: Flow, cure, polymerization

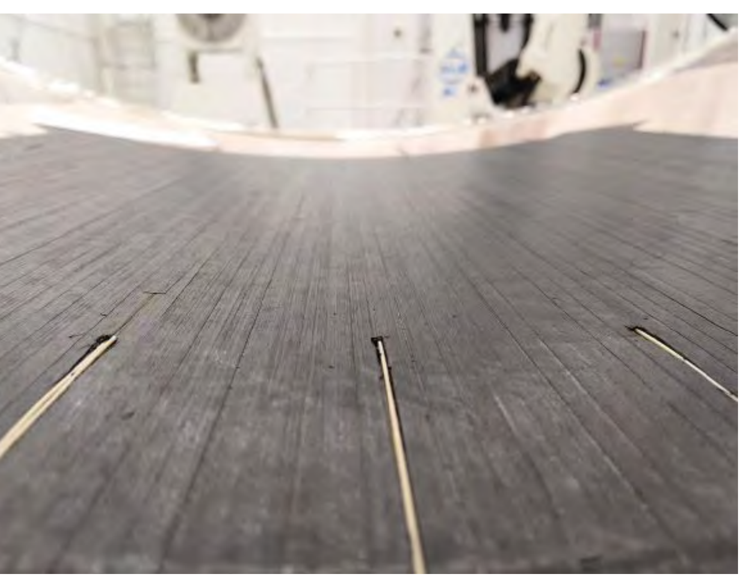
Contactless: With materials at ≤20 mm from tool surface and 2 MHz

Suppliers: Univ. of Augsburg



University of Augsburg





AFP of fiber optic sensors

NLR integrated a special unit into lane eight of a Coriolis AFP head to place four fiber optic sensor arrays into a high-temperature, carbon fiber-reinforced composite test panel. Source | SuCoHS project, NLR

Selecting and integrating sensors

To determine which sensors are best for each use case, notes Järveläinen, "you need to understand what variations in material and process you want to monitor, and then you must have an analyzer." An **analyzer** takes the raw data collected by the interrogator or data acquisition unit and converts it into usable information for the manufacturer. "You actually see many companies that have sensors integrated, but then they don't do anything with the data," says Sause. What is needed, he explains, is "*systematic* data acquisition, and also a data storage architecture, to be able to do something *with the data*."

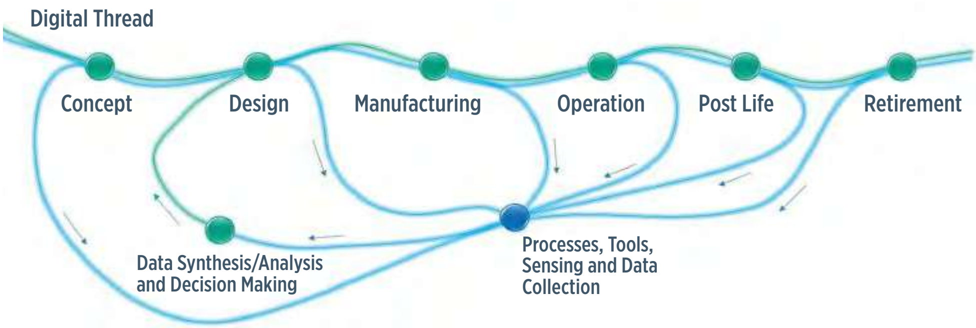
"End users don't just want to look at raw data," says Järveläinen. "They want to know, 'is the process optimized?' and 'when can it proceed to the next step?' For that, you need to do analytics incorporating multiple sensors and then use machine learning, which speeds up the process." This edge analytics and machine learning approach, used by Collo and the team in CosiMo, enables visualization such as graphs of viscosity, digital models of the resin flow front and, ultimately, the ability to control process parameters and machinery.

Optimold is an analyzer that Synthesites has developed for its dielectric sensors. Controlled by Synthesites' Optiview software, an Optimold unit uses temperature and resin resistance measurements to make calculations and show real-time graphs monitoring the resin state, including mix ratio, chemical aging, viscosity, T_g and degree of cure. It can be used with prepreg and liquid molding processes. A separate unit, Optiflow, is used for flow monitoring. Synthesites has also developed a Cure Simulator, which requires no cure sensors in the mold or part, but instead uses temperature sensors and a resin/prepreg sample in this analyzer unit. "We are applying this latest approach for infusion and adhesive curing for wind turbine blade production," says Synthesites director, Nikos Pantelelis.

Thus, most sensor suppliers have developed their own analyzers, and some use machine learning while others do not. But it is also possible for composites manufacturers to develop their own customized systems or buy off-the-shelf instruments and modify them to meet specific needs. However, analyzer capability is just one factor to consider. There are many others.

Contact is also an important consideration when selecting which sensors to use. Sensors may require contact with the material, the interrogator or both. For example, heat flux and ultrasonic sensors can be inserted into an RTM mold at 1-20 millimeters from the surface — contact with the composites in the mold is not necessary for accurate monitoring. Ultrasonic sensors can also interrogate *into* the part at different depths based on the frequency used. Collo electromagnetic sensors can read into the depths of a liquid or part as well — 2-10 centimeters depending on the interrogation frequency — *and* through a non-metallic container or tool in contact with the resin.

However, magnetic microwire is currently the only sensor able to interrogate up to 10 centimeters away from the composite. This is because it uses electromagnetic induction to elicit a response from the sensor, which is embedded in the composite. AvPro's ThermoPulse microwire sensor, embedded in an adhesive



Enabling digital twin and thread

Com&Sens is working with composite manufacturers to use its fiber optic sensors to enable a flow of digital data through design, production and service (above) to support a digital ID card (right) that supports the digital twin for each part manufactured. Source | Com&Sens and Fig. 1 in "Engineering Design with Digital Thread" by V. Singh, K. Wilcox.

bondline, has been interrogated through a 25-millimeter-thick carbon fiber laminate to measure temperature during bonding. Due to microwire's hair-like diameter of 3-70 micrometers, it does not affect composite or bondline properties. At a slightly larger diameter of 100-200 micrometers, fiber optic sensors can also be embedded without reducing structural properties. However, because they measure using light, fiber optic sensors must have a wired connection to the interrogator. Similarly, because dielectric sensors use electric voltage to measure a resin's properties, they too must be wired to the interrogator, and most also must contact the resin they are monitoring.

Temperature capability of sensors is another key consideration. For example, most off-the-shelf ultrasonic sensors typically operate at temperatures up to 150°C, but the part in CosiMo required molding at more than 200°C. Thus, UNA had to design an ultrasonic sensor with that capability. Lambient's disposable dielectric sensors can be used on a part's surface up to 350°C and their reusable, in-mold sensors can be used up to 250°C. RVmagnetics (Koice, Slovakia) has developed its microwire sensor for composites to withstand a 500°C cure. Although the Collo sensor technology itself has no theoretical temperature limitation, says Järveläinen, the tempered glass shielding for Collo Plate and a new polyetheretherketone (PEEK) housing for Collo Probe are both being tested for continuous service at 150°C. Meanwhile, PhotonFirst (Alkmaar, Netherlands) used a polyimide coating to provide a 350°C service temperature for its fiber optic sensors used in the SuCoHS project for sustainable and cost-effective, high-temperature composites.

Whether a sensor measures at a **single point or is a linear sensor** with multiple sensing points is another key factor, especially for installation. For example, Com&Sens (Eke, Belgium) fiber optic sensors can be up to 100 meters long with as many as 40 fiber bragg grating (FBG) sensing points at a minimum 1-centimeter spacing. These sensors have been used for structural health monitoring (SHM) in 66-meter-long composite bridges as well as for monitoring resin flow during infusion of large bridge decks. Installing separate point sensors for such projects would require myriad sensors plus significant installation time. The NCC and Cranfield University claim a similar benefit for their linear dielectric sensor. Compared to the single-point dielectric sensors supplied by Lambient, Netzsch and Synthesites, says Jack Alcock, Technology Pull-Through (TPT) program manager at the NCC, "for our linear sensors, we can monitor resin flow continuously along a length, which significantly reduces the number of sensors you need in your part or tool."

Linear sensors are also facilitating automated installation. In the SuCoHS project, Royal NLR (Netherlands Aerospace Centre, Marknesse) developed a special unit, integrated into lane eight of a Coriolis Composites (Queven, France) automated fiber placement (AFP) head to embed four arrays (separate fiber optic lines), each with five to six FBG sensors (23 sensors total supplied by PhotonFirst), in a carbon fiber test panel. RVmagnetics has placed its microwire sensor into pultruded glass fiber-reinforced polymer (GFRP) rebar. "The wires are discontinuous [most microwires for composites are 1-4 centimeters long] but are placed automatically on a continuous basis as the rebar is produced," says RVmagnetics cofounder, Ratislav Varga. "You have a coil with 1 kilometer of microwire and feed it into the rebar production equipment, without changing how the rebar is made." Meanwhile, Com&Sens is working on automated techniques for embedding fiber optic sensors during filament winding of pressure vessels.

Carbon fiber can cause an issue with dielectric sensors due to its ability to conduct electricity. Dielectric sensors use two electrodes placed in close proximity to each other. "If the fibers bridge the electrodes they will short circuit the sensors," explains Lambient founder, Huan Lee. In this case, a filter is used. "The filter lets resin through the sensors but insulates them from the carbon fiber," he says. The linear dielectric sensor developed by Cranfield University and the NCC uses a different approach, comprising two twisted copper wires. When voltage is applied, an electromagnetic field is created between the wires, which is used to measure resin impedance. The wires are coated with an insulating polymer which does not affect generating the electric field, yet prevents short circuits from carbon fiber. »

Cost, of course, is also a concern. Com&Sens cites an average cost of €50-125 per FBG sensing point, which could come down to roughly €25–35 if applied in volume — e.g., to 100,000 pressure vessels. (This is a fraction of the current and projected production capacity for composite pressure vessels.) Karapapas at Meggitt says quotes he received for fiber optic lines with FBG sensors averaged £250/sensor (≈€300/sensor) and interrogators were roughly £10,000 (€12,000). "The linear dielectric sensor we've tested is more a coated wire you can buy off the shelf," he adds. "The interrogator that we use," adds Alex Skordos, reader (senior researcher) in Composites Process Science at Cranfield University, "is an impedance analyzer, which is very accurate and costs at least £30,000 [≈€36,000], but the NCC uses a far simpler interrogator that comprises essentially off-the-shelf modules from the commercial company Advise Deta [Bedford, U.K.]." Synthesites quotes €1,190 for in-mold sensors, €20 for disposable/on-part sensors, €3,900 for Optiflow and €7,200 for Optimold, with an escalating discount for multiple analyzer units. These prices include the Optiview software and any support necessary, says Pantelelis, adding that wind blade manufacturers are saving 1.5 hours per cycle, enabling an additional blade per month per line and 20% reduced energy usage for an ROI of just four months.

> "We can provide a digital twin data-pool for every composite pressure vessel produced."

New possibilities, path forward

Companies that use sensors will gain an advantage as Composites 4.0 digital manufacturing moves forward. For example, as pressure vessel manufacturers try to decrease weight, material use and cost, says Grégoire Beauduin, Com&Sens business development director, "they can use our sensors to prove their designs and for monitoring production as they ramp to meet required volumes by 2030. The same sensors used to assess strain levels within the plies during filament winding and cure can also monitor the tank's integrity during thousands of refueling cycles, predict needed maintenance and enable recertification at the end of design life. We can provide a digital twin data-pool for every composite pressure vessel produced, and this solution is also being developed for satellites."

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Thus, sensor data enables digital twins but also the digital thread spanning design, production, in-service operation and end-of-life. When analyzed using AI and machine learning, these data feed back into design and processing, enabling improved performance and sustainability. This also changes how supply chains can cooperate. For example, adhesive producer Kiilto (Tampere, Finland) uses Collo sensors to help its customers control the proportions of components A, B, etc. in their multi-component adhesive mixing equipment. "Kiilto can now tune the composition of its adhesives for individual customers," says Järveläinen, "but it also allows Kiilto to see how the resin is interacting in its customer's process and how its customer is interacting with its products, and this is changing how the supply chain can work together."

Sensors are also enabling innovative new material and process combinations. Described in *CW*'s 2019 article on the OPTO-Light project, "Thermoplastic overmolded thermosets, 2-minute cycle, one cell," AZL Aachen (Aachen, Germany) used a two-step process to horizontally compression mold unidirectional (UD) carbon fiber/epoxy prepreg and then overmold with 30% short glass fiber-reinforced PA6. The key was to only partially cure the prepreg so that remaining reactivity in the epoxy could achieve attachment with the thermoplastic. AZL used Optimold and Netzsch DEA288 Epsilon analyzers with Synthesites and Netzsch dielectric sensors as well as Kistler in-mold sensors and DataFlow software to optimize molding. "You must look inside the prepreg compression molding process because knowledge about the state of cure must be sure in order to achieve a good join with the thermoplastic overmolding," explains AZL research engineer, Richard Schares. "In the future, the process may be adaptive and intelligent, with process pivoting triggered by the sensor signals."

However, there is a fundamental problem, says Järveläinen, "which is the customer's lack of knowledge regarding how to integrate these various sensors into their processes. Most don't have sensor experts in their companies." For now, the path forward requires a back-and-forth exchange of information between the sensor manufacturer and the customer. And there are organizations like AZL, DLR (Augsburg, Germany) and the NCC that are developing multi-sensor expertise. Sause says there are groups within UNA and also spin-off companies that can provide sensor integration and digital twin services. The Augsburg AI Production Network has rented a 7,000-square-meter facility for that very purpose, he adds, "extending the development blueprint from CosiMo to a very broad scale, including automated cells linked together where partners from industry can place machines, run projects and see how to integrate new AI solutions."

Meggitt's dielectric sensor demonstration with the NCC was just such a first step, says Karapapas. "Eventually, I want to monitor my processes and workflow and feed that into our ERP system so that I can know in advance what components to make, what people I need and what materials to order. We have now started that evolution toward digitized automation." CW

ABOUT THE AUTHOR

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New Products

» TESTING SYSTEMS

Universal testing systems series deliver increased force capacities


Source | Instron

Instron (Norwood, Mass., U.S.) announces the capacity expansion of the 3400 and 6800 Series high-force universal testing systems, successors to Instron's 3300 and 5900 Series systems. Now available in force capacities ranging up to 300 kN, the 3400 and 6800 Series host new features focused on durability, ergonomics and simplifying mechanical testing of composites.

The universal testing systems provide a new dimension of performance and durability, Instron contends. Reduction in debris ingress has been achieved through gasketing and a patent-pending airflow design. The frames have been fortified against shock and vibration, ensuring continuous testing at the maximum rated frame capacity. Additional design steps were also taken to locate internal electrical and mechanical hardware safely away from the test area, while an abrasion-resistant coating is applied to the 12-mm metal work surface for durability.

Both series are equipped with maintenance-free, brushless AC servomotors supporting continuous cyclic, creep and relaxation testing for up to 10 days. The 3400 Series provides a data acquisition rate up to 1,000 Hz and the 6800 Series increases the data acquisition rate up to 5,000 Hz. According to the company, these enhancements are meant to secure long-lasting service life.

To reduce the rate of accident recurrence during test setup, Instron has built in its patent-pending Operator Protect system architecture along with Safety Coaching, which are designed to limit the machine's movement during test setup while providing visual machine status reminders to the operator and bystanders. Additional features are also present in setup mode to aid this goal: Crosshead movement speed is restricted, the Smart-Close Air Kit restricts gripping pressure on low force grips to a pre-defined safe level and Safety Coaching uses system lighting and a color-coded border around the software to visually indicate that the machine is in safe setup mode. Once the operator is ready to begin testing, a virtual interlock button allows the enablement of the system's full crosshead speed, full grip pressure capabilities and triggers visual cues that signify that the safety limits have been removed for testing. System movement on the 3400 Series is controlled from a redesigned Operator Panel, while the 6800 Series introduces a novel, ergonomic handset so the system may be operated from a distance.

To improve operator comfort, the 3400 and 6800 Series systems are available with a tall base option. The tall base is said to move the testing platform to an ergonomically comfortable height and adds a shelf for storage. The testing systems also have a new, contoured base design for improved access to the test space for fixture assembly and a comfortable reach to the control panel on the 3400 Series or the handset on the 6800 Series.

All 6800 Series systems are equipped with an Auto Positioning feature that remembers a pre-assigned fixture separation and the starting location for the assigned test method. When using a test method configured with Auto Positioning, an operator is shown a picture of the assigned fixtures, reminded to set travel limits and is notified when and where the crosshead will move for test commencement. The goal of Auto Positioning is to improve data repeatability and reduce testing errors.

The 3400 and 6800 Series systems are also equipped with a Collision Mitigation feature to help reduce accidental equipment and specimen damage. Collision Mitigation enables the systems to continually monitor force during jog and return, and will automatically stop the crosshead movement if an unexpected force is detected. Mishaps happen, Instron says, and the goal of Collision Mitigation is to reduce the negative financial and downtime impacts associated with such occurrences.
instron.com

» CAE TOPOLOGY OPTIMIZATION SOFTWARE

Full-scale topology optimization software for composites

Anisoprint (Esch-sur-Alzette, Luxembourg), a composite 3D printing startup, and **Additive Flow** (London, U.K), a British additive manufacturing (AM) software developer, now offer a full-scale computer-aided engineering (CAE) tool compatible with Anisoprint's slicing software, Aura, for composite 3D printing. The software will reportedly enable users to optimize geometry smoothly through all phases of the design process. The beta version was released in October 2021.

Continuous composite 3D printing requires extensive expertise to design anisotropic structures, specifically for fiber paths, load simulation patterns, thermal exposure calculations, weight and other tasks. According to the companies, such tasks can only be performed by professionals with structural performance or materials expertise.

Additive Flow's software, Formflow, is a CAE tool for performance analysis and structural anisotropic design. Additive Flow says Formflow will boost the advantages of Anisoprinting. Developing designs with anisotropic structures is now automated and precise, and prototyping will be faster with assistance from AI-driven computation and optimization. The trial-and-error method will now be replaced by physics-based simulation algorithms that define optimally performing parts. Material use will also be optimized.

Source | Anisoprint

According to Additive Flow, FormFlow takes care of topology, decreasing the manual input involved in printing and enabling specialists to focus on other work. In addition, the software leads to improved flexibility due to clear quantitative analysis of loads.

Formflow is now designed to export files compatible with the Aura proprietary slicer. Users are not required to know the geometry of the model, only the target parameters. Thermal resistance, strength, stiffness, weight, sustainability, time and cost of production can be mapped in Formflow to calculate the optimal shapes and properties. Once the model is optimized, it is fed to Aura to prepare for printing. **anisoprint.com**

Pultruded fiberglass rods enhance athletic training device

Jump Sticks, developed by Flexi-StiX LLC, combine pultruded fiberglass rods within a PVC tube to produce a semi-flexible but resistant training device for enhanced dynamic athletic training.

Source (all images) | Flexi-StiX

For sports that require jumping or running, athletic training will likely involve dynamic movements that not only strengthen certain leg muscles but activate the fast-twitch muscle fibers to enable more power and higher performance. One composites-based training solution, called a Jump Stick, promises athletes of all levels a safe, effective and more dynamic solution.

Gordon Brown, president of Flexi-StiX LLC (Anderson, S.C., U.S.), began his career in textiles and composites in 1968, including work with pultrusion company Morrison Molded Fiber Glass Co. (now Strongwell, Bristol, Va., U.S.). There, Brown became interested in the use of pultruded fiberglass rods in gym equipment, for their ability to add "bendable resistance," he says. Brown developed and patented a bendable bar comprising rectangular rods of pultruded fiberglass/epoxy contained within a flexible PVC tube.

Brown explains that in his patented process, he inserts long, thin fiberglass/epoxy-pultruded bars of rectangular cross-section into a round tube, where they fit securely but loosely. When the device is bent or shaken during a training exercise, the flexible tube oscillates around the fiberglass rod. "Having the fiberglass shapes float inside the extruded tube allows for the shapes to automatically orient themselves so that they will bend around the major axis of the fiberglass-pultruded shape when the product is bent," he says. The rectangular cross-section is key to the rods staying in place, he adds. "When you deal with products that flex or oscillate, you have to be concerned with flex fatigue, and one way to get sufficient bending stiffness with good flex fatigue life is to use a rectangular shape."

In 2003, Brown started Flexi-StiX LLC to market and sell his inventions. The first commercial iteration of Brown's design was licensed to Body Bar Inc. (Louisville, Colo., U.S.). In 2012, Brown developed and commercialized the Tsunami Bar, which is marketed as a flexible barbell that can be weighted using traditional disc weights and used in the same manner as traditional steel barbells. In 2020, Brown developed the Jump Stick, which is a version of his flexible composite bar specifically used to activate the fast-twitch muscle fibers in the legs so that athletes can train to jump higher or move with greater agility. The athlete holds a Jump Stick in each hand while jumping, using the weight and resistance from the bar to train the leg muscles to fire faster.

Each Jump Stick, weighing less than 5 pounds, is said to produce about 40 pounds of bending resistance when bent into a U shape. Brown says that if an athlete jumps five times up and down as fast as they can, putting as much force into the ground as they can using the Jump Sticks, they will jump between 1 and 5 inches higher on their next standing vertical jump. For the Jump Sticks, one to three fiberglass pultruded shapes, all of which are 0.187-inch thick and 0.5-inch wide, and about a half-inch shorter than the tube itself, fit into the tubing depending on the weight and stiffness needed. Flexi-StiX uses Glasforms pultruded rods supplied by Avient (formerly PolyOne, Avon Lake, Ohio, U.S.). "When in use, all of the shapes will move to bend around their major axis as the device is bent when the athlete jumps rapidly. If you are familiar with leaf springs on an automobile, my use of multiple fiberglass-pultruded shapes is similar," Brown says.

To test and validate the Jump Sticks, Brown has been working with coaches and athletes at local high schools and Furman University (Greenville, S.C., U.S.). Currently, the product is available in two sizes: 35 inches and weighing 2 pounds with the addition of rubber weights, intended for young athletes; and 49 inches with 4 pounds of weight for college or pro athletes. CW

Composites Events

Editor's note: **Events listed here are current as of Feb. 14, 2022. Visit short.compositesworld.com/events for up-to-date information.**

March 6-10, 2022 —San Antonio, Texas, U.S.
AMPP Annual Conference Expo
ace.ampp.org/home

March 10-12, 2022 — Barcelona, Spain
BIT's 6th Annual World Congress of Smart Materials
bitcongress.com/topwcsm2022

March 11-12, 2022 — Miami, Fla., U.S.
International Conference on Composites Aerospace and Aviation (ICCAA)
waset.org/composites-aerospace-and-aviation-conference-in-march-2022-in-miami

March 22-24, 2022 — San Diego, Calif., U.S.
ACMA Thermoplastic Composite Conference
web.cvent.com/event/725f7da1-204b-4e1d-8153-7393c676ce81/summary

March 22-23, 2022 — ONLINE
Clean Sky Spring Event
duurzaam-vliegen.nl/event/save-the-date-20-21-april-for-clean-skys-spring-event-2021

March 29-31, 2022 — Moscow, Russia
Composite-Expo
composite-expo.com

March 29-31, 2022 —Rosemont, Ill., U.S.
Plastics Technology Expo 2022 (PTXPO)
plasticstechnologyexpo.com

April 4-7, 2022 — Colorado Springs, Colo., U.S.
37th Space Symposium
spacesymposium.org

April 5-7, 2022 — Detroit, Mich., U.S.
WCX World Congress Experience 2022
sae.org/attend/wcx

April 5-7, 2022 — Bilbao, Spain
WindEurope Electric City 2022
windeurope.org/annual2022/
medicalamcon.com

April 6-7, 2022 — Bristol, U.K.
ACM5: The Fifth International Symposium on Automated Composites Manufacturing
acm5.org

April 6-7, 2022 — POSTPONED
SMCCreate 2022
mcbmc-europe.org

April 12, 14, 19 and 21, 2022 — ONLINE
Advanced Air Mobility Composites Technology Days
web.cvent.com/event/54b7e2d9-4083-408e-9aba-6ab87286b380/summary

April 12-13, 2022 — Birmingham, U.K.
MedicalAM
medicalamcon.com

April 22-24, 2022 — Wuhan, China
8th International Conference on Mechanics of Composites (MECHCOMP8)
bagevent.com/event/MECHCOMP8/p/429324

April 26-27, 2022 — Manchester, U.K.
ConstructionAM
constructionam.com

April 26-28, 2022 — TBA
Advances in Rotor Blades for Wind Turbines
iqpc.com/events-wind-rotor-blades

April 26-28, 2022 — Atlantic City, N.J., U.S.
International Offshore Wind Partnering Forum
2022ipf.com

April 27-28, 2022 — Seattle, Wash., U.S.
ASTM April 2022 Committee Week
astm.org/COMMITTEE/D30

April 27-29, 2022 —Nicosia, Cyprus
5th International Conference on Structure Nanocomposites
nanostruc.info

May 2-5, 2022 — Houston, Texas, U.S.
OTC – Offshore Technology Conference
otcnet.org

May 2, 2022 — Paris, France
SE Summit 22
sampe-europe.org/conferences/se-summit-paris-2022/

May 3-5, 2022 — Paris, France
JEC World 2022
jeccomposites.com/events/jec-world-2022/

May 5-6, 2022 — Paris, France and ONLINE
World Pultrusion Conference (WPC)
pultruders.com/wpc2022

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Why aren't composites synonymous with infrastructure?

Multi-composite thrust chamber aims to boost rockets, reduce cost for New Space economy

Source | DLR Institute of Structures and Design

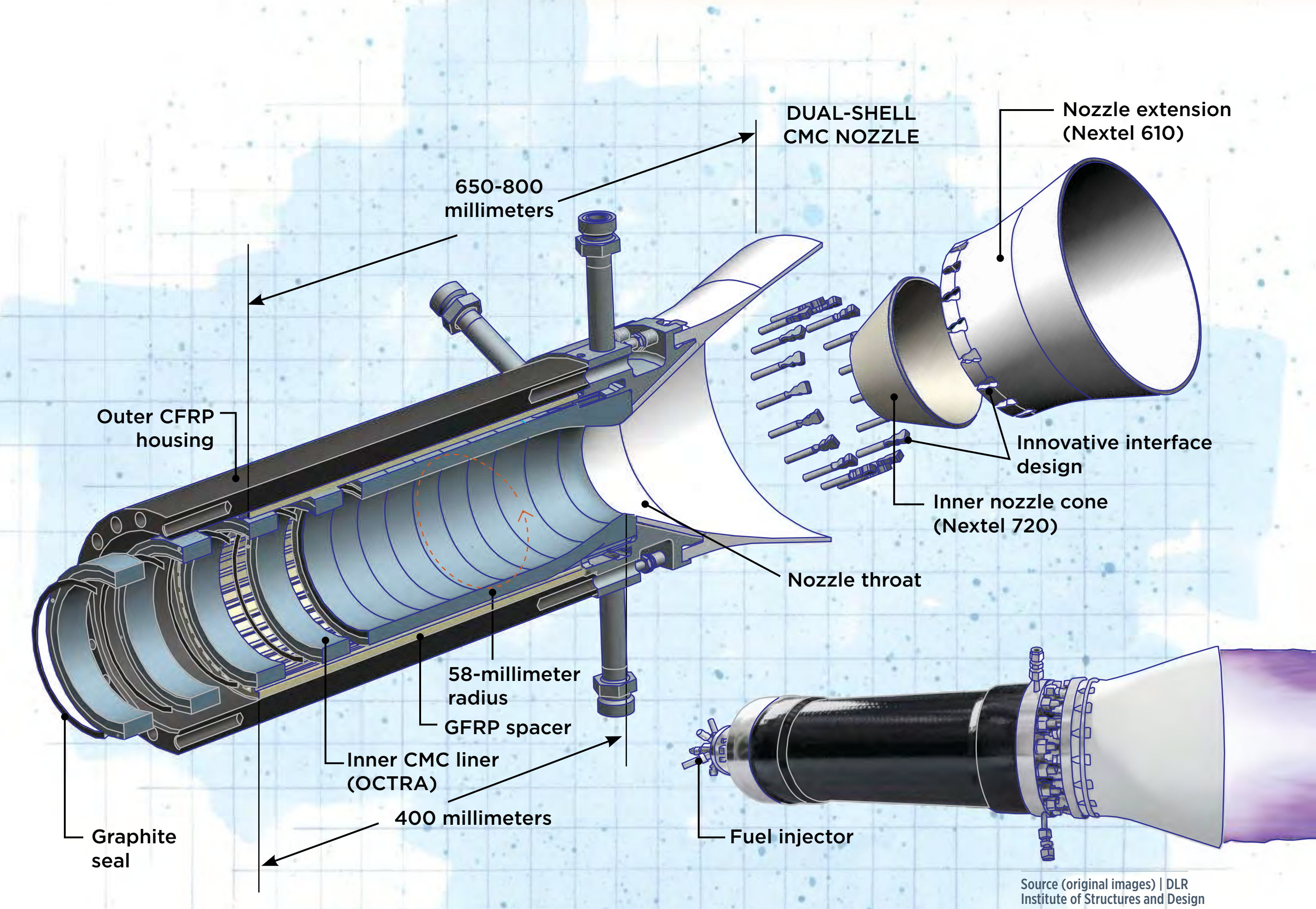
Black Engine uses new, microporous CMC liner for transpiration cooling and multiple lightweight composites in modular design that offers increased lifetime and lower maintenance versus current launch vehicle engines.

By Ginger Gardiner / Senior Editor

»New Space is the economy and ecosystem that is commercializing travel and operations in space. As explained in a workshop by Gary Martin, director of partnerships at NASA Ames (Mountain View, Calif., U.S.), "We are at the cusp of a revolution — new industries are being born that use space in nontraditional ways, with increased competition and new capabilities that will change the marketplace forever." This fast-forward reinvention of the space industry and its supply chains spans a wide range of activities, such as low and high Earth orbit (LEO, HEO) operations involving satellites and space stations, as well as asteroid mining and zero-gravity manufacturing in deep space. One common thread is the need for more efficient and lower cost reusable launch vehicles.

The power to launch a vehicle into space forms in the thrust chamber, comprising a fuel injection system, a combustion chamber for burning the propellants and an expansion nozzle for expelling the resulting gases at high velocity to produce thrust. Most international producers of launcher propulsion systems typically use metal thrust chambers. The German Aerospace Center (DLR) Institute of Structures and Design in Stuttgart, however, has developed a novel design that uses carbon and glass fiber-reinforced polymer (CFRP, GFRP) composites as well as a new type of ceramic matrix composite (CMC). This thrust chamber has a total length of 650-800 millimeters, depending on launch vehicle configuration, and comprises a metallic fuel injector head bolted to a CFRP outer housing. Within this housing, the CMC combustion chamber stretches roughly 400 millimeters with an inner radius of 58 millimeters. A GFRP spacer provides the interface to the outer housing, while a dual-shell CMC nozzle forms the opposite end from the injector.

This multi-material design enables transpiration cooling, which in turn provides a significant reduction in the combustion chamber pressure loss that is typical with legacy metal designs using regenerative cooling. Additionally, the novel use of composites offers the potential to reduce structural weight, perhaps as much as 25%, and increase engine efficiency, with a target of >5%. These materials also enable a modular design that decouples thermal and structural loads and offers the potential for increased reliability, reduced cost and a path forward for further novel optimizations. DLR is in the process of demonstrating this "world-first" technology to a technology readiness level (TRL) of 5 via ground tests of a 60-kilonewton thrust chamber fueled by liquid methane (LCH_4) and liquid oxygen (LOX).



Source (original images) | DLR Institute of Structures and Design

DESIGN RESULTS | **Black Engine multi-composite thrust chamber**

- Extremely high load capacity with up to 25% lower structural weight versus metal designs.
- Decouples pressure loads from thermal loads for increased reliability and service life.
- More efficient transpiration cooling uses minimal fuel due to microporous, high-temp CMC liner.
- Modular, scalable design lowers cost versus legacy and 3D-printed metal designs.

Susan Kraus / Illustration

Black Engine for New Space

"There are actually three separate entities that are called Black Engine," explains DLR researcher Markus Selzer. "First, there is the technology, which is for a transpiration-cooled CMC engine thrust chamber. Second, is the Black Engine project, ongoing at DLR since March 2019, to demonstrate this technology in a methane-burning, 60-kilonewton format. And third, we are working together with a spin-off company founded by one of our team members that is also called Black Engine Aerospace [BEA, Heilbronn, Germany]. This new company will bring the Black Engine technology to market. As part of this commercialization, the company is also developing a new mobile test bench [Fig. 1, p. 44] that can be rapidly transported to test these new rocket engines at customer sites around the world."

The history of the Black Engine technology reaches back to 2000, says Selzer, with DLR's first research into transpiration cooling — a rarely used but very efficient cooling method (see below) — and CMC materials in combustion chambers.[1] Note, though modern rocket engines don't normally use transpiration cooling, they all use fuel that also functions as a coolant. In 2010, DLR successfully tested a CMC thrust chamber system fueled by cryogenic liquid hydrogen (LH_2) and oxygen at the European Research and Technology Test Facility P8 (DLR Lampoldshausen).[2] "We are now further developing that proven technology to use methane and also scale it up to 60 kilonewtons," he adds.

Why LCH_4 as fuel and 60 kilonewtons of thrust? The two researchers first explain the latter. "So, that's 6 tons of thrust," says Selzer's teammate, Helge Seiler, "which is in the range of what is used to power the second stage for a launch vehicle." In addition to using the engine in a second or third stage, says Selzer, "you would also cluster nine of them in the first stage, for example, to bring 400 kilograms of payload to the ISS [International Space Station]. This aims at the New Space market, where »

FIG. 1 Mobile test rig

The thrust chamber being developed in the Black Engine project will be ground tested in the mobile test bench being developed by Black Engine Aerospace (BEA).

Source | DLR, BEA

all of these companies are developing small rockets to send satellites and other payloads into various orbits."

This clustering of small engines sounds very similar to the SpaceX approach with its Merlin engines. "Yes, but the Merlin motors are 15 times more powerful than ours," notes Seiler. "However," says Selzer, "there are hundreds of companies in the world that are developing small rockets, and they will eventually need smaller engines like what we are developing. And a lot of these small engines are using methane as fuel. This is because, when looking at the performance of the whole launcher system, methane kind of hits a 'sweet spot' of performance, reliability and storability."

For example, the cryogenic temperature required for LCH_4 is 110 K/-162°C, which is the same as for LOX, Seiler explains. "So, the tanks can share the same bottom in the launch vehicle. Even though LH_2 is a better cooling fluid, it requires 20 K/-253°C, so that the LOX and LH_2 tanks cannot share the same bottom. Also, if you want to fly to the moon or Mars, it's easier to both store and produce methane."

Modular, lightweight, *decoupled* design

As shown on p. 43, the Black Engine thrust chamber comprises an outer CFRP housing and inner CMC liner, with a GFRP spacer in between; the left and right ends of the chamber are, respectively, the fuel injector and CMC rocket nozzle. The CFRP housing is made using standard materials, says Selzer. "In the past, we made it ourselves using a vacuum infusion process, but we have now transitioned to a commercial producer of CFRP tubes, Carbon Express [Schwarzach, Germany], using Hexion [Columbus, Ohio, U.S.] 828 epoxy resin and Toray [Tokyo, Japan] 12K fibers."

"The GFRP spacer is a filament-wound tube with longitudinal stringers or longerons," says Seiler, "which also provide channels for the fuel coolant. The spacer helps to evenly distribute the methane fuel around the CMC liner and keeps the liner from moving within the CFRP housing." It also provides guidance for the CMC segments during assembly. "It's an important part," adds Selzer, "but it's not something that takes a lot of load." To date, the spacers are made in-house by DLR technicians using Hexion RIM 935 epoxy and a mix of P185-EC14-2400 glass fiber roving from Saint-Gobain Vetrotex (Chambéry, France) and Interglas 92125 twill fabric from Porcher Interglas Technologies (Erbach, Germany). That, too, will be transferred to a commercial producer in the future.

The CMC inner liner is made from stacked rings cut from flat CMC plates. "We put that stack into the outer CFRP tube equipped with the GFRP spacer and then compress the rings and hold everything together using the bolts in the CFRP housing," says Selzer. "From a manufacturing standpoint, it's a very easy process. The plates aren't attached to each other, just compressed using small dowel pins for alignment."

"It's like the CMC rings are swimming inside the CFRP housing," notes Seiler. "One advantage of this design is that it decouples the thermal loads, which are carried by the CMC rings, from the pressure loads, which are carried by the CFRP housing. The pressure loads are coming from the nozzle, and also from the combustion and expansion of the hot gas in the combustion chamber."

He explains that if the chamber was a monocoque, or monolithic shell, then it would have to carry pressure and temperature loads. "Uncoupling these makes the combustion chamber design more reliable," he points out. "We project that the chamber will last much longer than conventional metal chambers, which typically fail due to thermal loads. These thermal loads are caused by the large temperature differences in the system, ranging from cryogenic temperatures with oxidizer and fuel to the high temperature during combustion. The thermal expansion during a run leads to damage. You can use such engines five to 10 times, but then you have to check for cracks. We expect to avoid this in our chamber."

"This is one advantage to using a CMC inner liner," says Selzer, "which has a very low CTE [coefficient of thermal expansion]. So, even if the thrust chamber is cycled from low to high temperatures many times as it is reused, it shouldn't matter. And the structural loads are decoupled anyway." Another benefit of this approach is if damage occurs during production and reuse, "we just replace that one ring," says Seiler. "This isn't possible with one-shot, 3D-printed engines or cylinders."

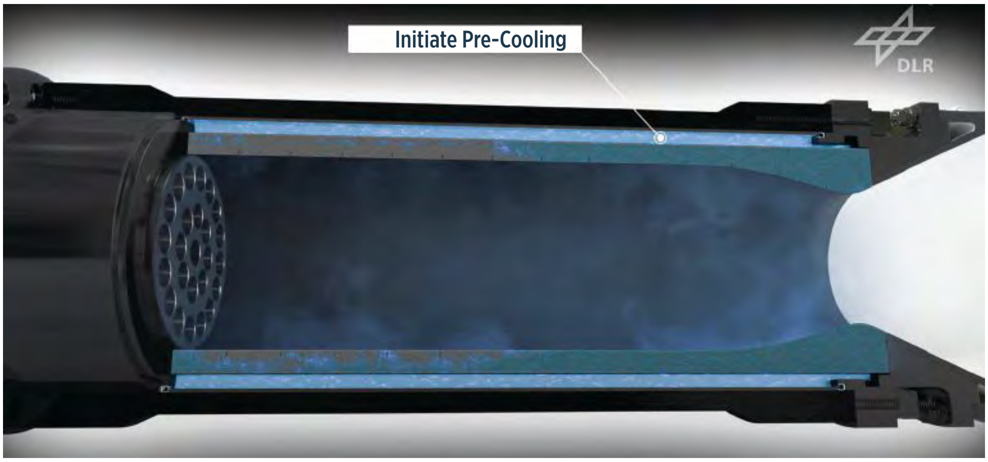


FIG. 2 Transpiration cooling

Microporous OCTRA ceramic matrix composite (CMC) enables cryogenic fuel to transpire through the combustion chamber inner liner to also function as efficient coolant. Source | DLR

New CMC for transpiration cooling

Until late last century, regenerative cooling was standard for almost all rocket thrust chambers. This method relies on convection between the cryogenic fuel, used as coolant, and the hot structure of the thrust chamber, but requires thin walls, which are prone to cracking, and small cooling channels that result in a high pressure loss (roughly 20% of the combustion pressure) in the cryo-fuel coolant flow. These drawbacks degrade the chamber's ability to withstand the higher temperatures required for increased performance. Film cooling, favored in most rockets today, can reduce thermal and structural loads, but requires large blowing ratios of coolant to overall fuel flow, significantly reducing rocket motor efficiency. Transpiration cooling offers a higher cooling efficiency versus regenerative and film cooling by passing the cryo-fuel coolant through the chamber structure, which is porous. Though its efficiency has been known since the 1950s, suitable porous structural materials have, until now, not been readily available.

"We are using a new type of CMC," says Selzer. Developed by DLR and called OCTRA, the CMC uses carbon fiber reinforcement in a carbon-silicon carbide matrix (C/C-SiC).[3] "The technology is based on materials that have been used by our department for decades," he explains. "When used in reentry and heat shields, the materials are usually dense and not porous. With OCTRA, we are replacing some of the carbon fibers with aramid fibers, which get destroyed during pyrolysis, so that we end up with a CMC that is porous and thus permeable, so that we can use it for our transpiration cooled engine." (See sidebar "OCTRA: Porous CMC for transpiration cooling," p. 46.)

From a thermal point of view, "transpiration cooling is the most efficient cooling method you can use," says Seiler, "providing, due to the microporous nature of the material, a continuous coolant film where needed. With film cooling, you would have to maintain additional film layers along the chamber wall, almost like the waterfalls you see inside buildings."

But like any other cooling method, transpiration cooling also has drawbacks. "In regenerative cooling, for example, the heated coolant gets fed to the injector head after cooling the combustion chamber, hence the energy in the coolant is not lost," says Selzer. "The coolant used for transpiration cooling — just like with film cooling — eventually leaves the nozzle unburned, hence you will lose some efficiency. The overall goal while using transpiration cooling is therefore to reduce the required mass flow to optimize the whole system."

He explains that the materials in Black Engine help reduce that coolant flow, "because you don't have to have as much cooling thanks to the higher temperature capability of the CMC materials versus metals. Our aim is to get the amount of cooling to levels with only a small impact on the efficiency. And then you have other advantages from the CMC, such as very low CTE, which gives us an advantage with longer lifetime and higher reliability."

"Also, the pressure loss for engines using regenerative cooling can be very high," he continues. "Your turbo pumps have to provide a very high pressure, while the transpiration cooling doesn't need that. Basically, you can use the transpiration cooling at a pressure that's the same as for the injection head. And because you don't have to have as much pressure, you can downsize to smaller turbo pumps. That's another inherent advantage of this cooling technique."

Seiler gives an example: "For our 70-bar combustion chamber, we only need 5-7 bar of pressure for the coolant flow, and that's what you would need for the injector anyway, so basically we need no additional pressure for cooling. With regeneratively cooled systems, the pressure needed just for cooling is usually 10-20% of the chamber pressure. With transpiration cooling, you can use that to downsize the turbo pumps or increase the chamber pressure which results in higher engine performance."

Dual-shell CMC nozzle and interface design

The CMC rocket nozzle is not made from OCTRA. For higher temperature resistance, it uses instead Nextel aluminum-oxide (Al_2O_3) ceramic fiber from 3M (Minneapolis, Minn., U.S.) and a hybrid matrix of Al_2O_3 and yttria stabilized zirconia (3YSZ) manufactured by Inovaceram (Sachsenheim, Germany). The nozzle comprises the inner nozzle cone and exterior nozzle extension, » SIDEBAR

OCTRA: Porous CMC for transpiration cooling

The German Aerospace Center (DLR) Institute of Structures and Design has decades of experience manufacturing carbon fiber-reinforced carbon matrix (C/C) CMC. Although C/C offers a porous microstructure beneficial for transpiration cooling, it also has lower oxidation resistance and mechanical properties compared to CMC using a silicon carbide matrix. Thus, DLR sought to create a new material with the porosity and permeability of C/C but with improved oxidation resistance.

The new CMC is called OCTRA, and represents a family of products with a range of porosities. Manufacturing begins by creating a green body (composite before carbonization) that uses aramid fiber in addition to carbon fiber as reinforcement. In the subsequent pyrolysis step, the aramid fiber disintegrates, allowing selective insertion of cavities into the CMC. The resulting porosity in OCTRA is tailored by changing the ratio of carbon and hybrid carbon/aramid plies or by changing the content of aramid in the hybrid plies.

The composite green body may be produced using resin transfer molding (RTM), autoclave cure, hot pressing or filament winding. In one example, the OCTRA green body was produced using a hybrid carbon fiber (61%) and aramid fiber (39%) woven twill fabric (ECC Fabrics, Heek, Germany), laid up to form an orthotropic, symmetric laminate, and impregnated with phenolic resin for a 57% fiber content, followed by cure. Phenolic was used because it provides sufficient carbon content in the matrix to produce the necessary C/C material during carbonization.

In the second step, the OCTRA green body was carbonized in an inert nitrogen atmosphere at roughly 1,600°C to convert the phenolic matrix to amorphous carbon. This pyrolysis eliminates the aramid fiber and results in a ≈10% shrinkage mainly in laminate thickness, creating a microscopic network of cracks in the resulting C/C composite with the carbon fibers intact.

In the third step, the C/C component was siliconized via melt infiltration/liquid silicon infiltration (LSI). The component was placed into a coated graphite crucible and granulated silicon was added and heated to >1,420°C to melt the silicon, which then infiltrated the porous C/C component. In an exothermic reaction between the molten silicon and the amorphic carbon matrix, silicon carbide was formed along the microcracks encapsulating the carbon fibers. Siliconization was completed under vacuum at 1,650°C to produce the final C/C-SiC composite.

Porosity can be up to 45% by volume in the C/C intermediate state and 10-25% by volume in the final C/C-SiC composite. Although OCTRA cannot achieve the mechanical properties of dense C/C or C/C-SiC materials, due to its high porosity, tensile strength of 25-50 megapascals and flexural strength of 75-100 megapascals are possible. Mechanical properties can be increased by reducing the amount and diameter of microcrack pores, which in turn can be influenced by the resin and process used in the green body.

In addition to transpiration cooling, OCTRA can be used for ultrasonically absorptive thermal protection system (TPS) materials that provide damping and boundary layer stabilization for improved performance in hypersonic vehicles. For example, OCTRA CMC materials are being considered for use in a passively cooled combustor design for the HIFiRE 8 joint Australia/AFRL (Air Force Research Lab, Wright-Patterson Air Force Base, Ohio, U.S.) hypersonic flight program, expected to fly at Mach 7 for roughly 30 seconds. Compared to using actively cooled metal structures, OCTRA CMC may provide significant weight savings in such scramjet structures.[4]

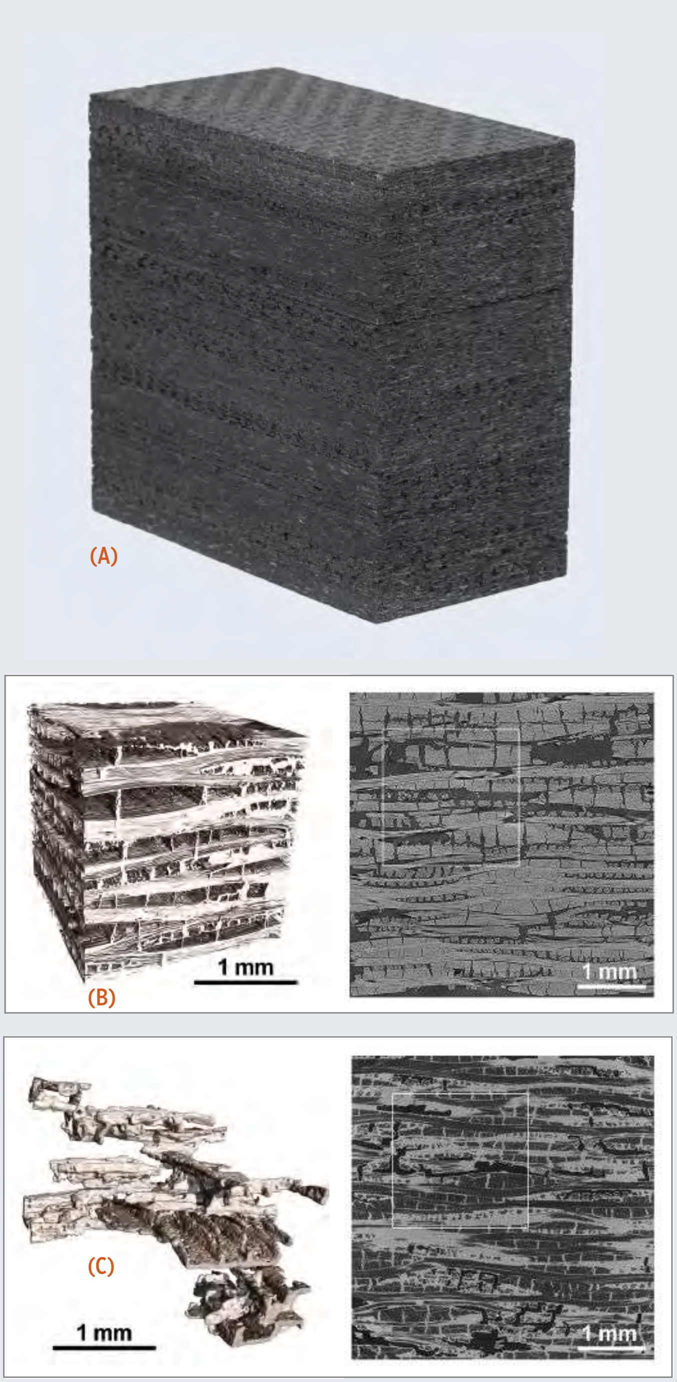


FIG. 3 OCTRA panel, pore structure

OCTRA panel for ultrasonic absorption properties testing (A). Micro computed tomography (CT) scans of OCTRA 40 are shown below (B, C) with negative 3D images of the pore structure at left. The 30%vol porosity in the C/C state (B) is reduced to 10%vol in the C/C-SiC state (C). Pore channels are entirely covered by SiC and become smoother during LSI. Source | DLR each made from a different Nextel fiber. The inner nozzle cone begins 15 millimeters after the nozzle throat (see p. 43), is made using Nextel 720 fabric and is designed to resist temperatures of more than 1,150°C during the minutes-long rocket launches. The nozzle extension is made from Nextel 610 fabric, bolted to the combustion chamber cylinder and designed for strength. This dual-shell construction, similar to the use of multiple composites in the combustion chamber, enables decoupling of thermal and structural loads in the nozzle. "And in the nozzle, we also don't have much need for cooling," says Selzer, "because of the transpiration cooling film and the temperature resistance of the CMC."

Another key aspect of the design is the nozzle attachment interface. "The nozzle is designed with pockets that allow us to affix it to the combustion chamber using bolts shaped like dovetail joints," says Selzer. "These fit into the pockets and connect from the combustion chamber through the nozzle flange in a way that allows thermal expansion." In other words, explains Seiler, "You install it at the size it was manufactured, but when the engine is fired, the nozzle expands. Our interface design allows the nozzle and bolts to expand without interrupting the joint. It handles the CTE and also lowers weight."

New models, tests and future developments

The work DLR has completed to get this far is nontrivial. For example, the team had to develop a computational fluid dynamics (CFD) model to predict the thermal and pressure loads. These loads are then used in a FEM analysis of the thrust chamber.[5] For CFD, the team used the industry-standard CFX v17.2 software from Ansys (Canonsburg, Pa., U.S.). The FEM analysis uses Ansys Workbench 2019 R3. To determine the contour of the rocket thrust chamber, DLR used Rocket Propulsion Analysis (RPA, Rocket Propulsion Software+Engineering UG, Neunkirchen-Seelscheid, Germany). The results from RPA were used to validate the mainstream domain solved in Ansys CFX.[6]

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Though ground testing of a full-scale Black Engine was slated to begin early in Q1 2022, the program has been slowed by the COVID-19 pandemic and the development of the new mobile test bench. The latter is key for commercialization by DLR's project partners at BEA, says Selzer, "because it can be carried all over the world, so that if someone wants to buy this type of engine and to see a live test before finalizing a commitment, it will now be possible to give them that live demonstration within a few weeks, for example." The test bench alone is a complex project, he adds, "but so is our development of this new design along with a new combination of materials. We are planning to have the test bench experiments start soon and completed in 2022."

And yet, even while pushing Black Engine forward in TRL, the team is already anticipating further optimization and performance enhancement enabled by this novel design. "So, the next thing would be to optimize the whole system," says Selzer, "to lower the required coolant amount by tailoring the CMC to the thermal profile during engine burn. Right now, we use the same CMC throughout the combustion liner. But by using our stacked rings design, we could use different CMC materials in different locations. For example, the heat loads are highest in the nozzle throat but lower elsewhere. So, we could tailor the CMC permeability to the liner thermal loads in each area, which would then tailor the coolant flow, and better optimize the chamber as a whole."

The team has also developed a second iteration of the combustion chamber, which uses a revolutionary hyperboloid geometry instead of the industry-standard cylinder tapering into a Laval throat at the nozzle.[5] A Laval nozzle has an asymmetric hourglass shape, where the narrowed and elongated aft section is used to accelerate the hot, pressurized gas exiting the combustion chamber to increase thrust. "The hyperboloid design makes the hot gas flow much more turbulence-free in the nozzle throat area," says Seiler, "and thus leads to lower heat load peaks in this critical flow section. In addition, cooling and fuel injection can be combined in the annular combustion zone adjacent to the injector head, which can increase engine efficiency."

For now, says Selzer, "our focus in the current project is on qualifying the cylindrical combustion chamber and classical nozzle contour. The hyperboloid combustion chamber might be developed and built by BEA." He emphasizes that advancing the current iteration of Black Engine technology to TRL 5 offers significant benefits. "The improvements we are targeting in efficiency, reliability, weight, cost and reusability have the potential to enable rocket engines with higher lifetime and lower maintenance standards compared to current rocket engines. And that has the potential to further decrease the cost for access to space." CW

REFERENCES

1 Hermann Hald, Markus Ortelt, Ingo Fischer, Dirk Greuel and O. Haidn. "Effusion Cooled CMC Rocket Combustion Chamber," AIAA 2005-3229. AIAA/CIRA 13th International Space Planes and Hypersonics Systems and Technologies Conference. May 2005.

2 Markus Ortelt, H. Elsaesser, Armin Herbertz, I. Mueller and Hermann Hald. "Structural Investigations on Cryogenically Operated and Transpiration Cooled Fiber Reinforced Rocket Thrust Chambers," AIAA 2012-4010. 48th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit. July 2012.

3 Christian Dittert and Marius Küttemeyer, "Octra - Optimized Ceramic for Hypersonic Application with Transpiration Cooling," published in the book: Advances in High Temperature Ceramic Matrix Composites and Materials for Sustainable Development; Ceramic Transactions, Volume CCLXIII. July 2017. 10.1002/9781119407270.ch37

4 Glass, D. Capriotti, T. Reimer, et. al., "Testing of DLR C/C-SiC and C/C for HIFiRE 8 scramjet combustor," 7th European Workshop on Thermal Protection Systems and Hot Structures, April 2013. 10.2514/6.2014-3089

5 D. Munk, M. Selzer, H. Seiler, et. al., "Analysis of a transpiration cooled LOX/CH4 rocket thrust chamber," International Journal of Heat and Mass Transfer, vol 182, published Sep 2021. 10.1016/j.ijheatmasstransfer.2021.121986

6 M. Ortelt, H. Seiler, M. Boehle, D. Munk, "Black Engine Ceramic Rocket Propulsion," 70th International Astronautical Congress (IAC), Washington, D.C., U.S., Oct 21-25, 2019.

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Post Cure

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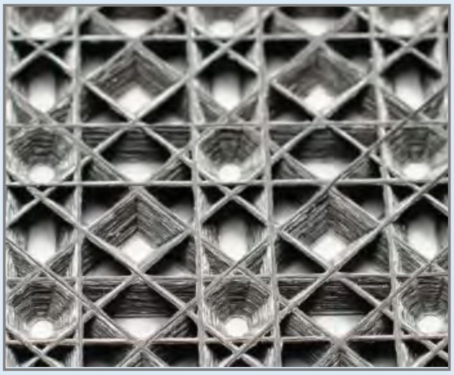
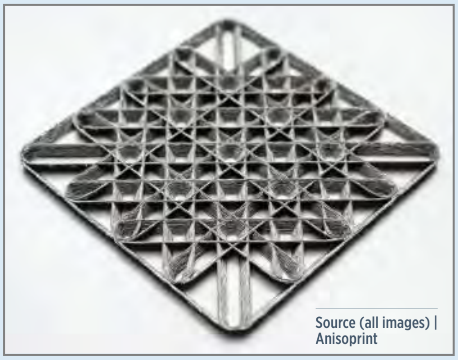
Octogrid structures in continuously reinforced composites





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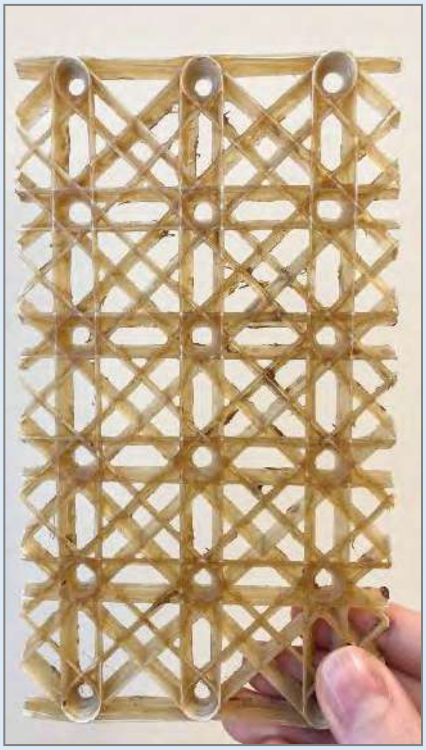

The development of octogrid-shaped composite panels extends back to the 1970s when, at the time, their stiffness-to-weight ratio made them ideal for use as floor panels on space vehicles. However, the various techniques that evolved to create them — the first was to hand-wind the material on pyramidal pins (shown in far right image) — were manual and complex.

Now, according to Anisoprint (Esch-sur-Alzette, Luxembourg), 3D printing enables a more systematic approach toward these multiplex designs — as exemplified by the 3D-printed octogrid fragment on the left — which is useful for replacing honeycomb core and sandwich in structures subjected to bending/membrane loads. This 200 x 200-millimeter panel comprising continuous carbon fiber and a PETG matrix was 3D printed via Anisoprint's Composer A4 3D printer, achieving approximately 40 layers (a height of 12 millimeters). Print properties depend on parameters such as density, angles between the ribs, rib slope, etc., which can be optimized and calculated to achieve targeted specific strength and stiffness properties using Anisoprint's AURA software.

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