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S-shaped CFRP hydrofoils: ROBOTIC AFP DEVELOPS RELIABLE 4D STRUCTURES

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COLUMNS

FEATURES

» DEPARTMENTS

» ON THE COVER

Avel Robotics has pioneered the use of AFP for increased reliability in complex-shaped and -loaded CFRP hydrofoils used in offshore racing sailboats. AFP is used to create a foil's central load-carrying stock — the primary structure for the foil — shown in the series of curved carbon fiber/epoxy laminates here. Construction also entails a 4D process, used to optimize the structures over time. See p. 30.

Source | Avel Robotics © Antoine Louce

FOCUS ON DESIGN

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» Boeing CEO David Calhoun announced at the company's Investor Day conference in early November that Boeing has no plans to announce a new aircraft program until almost 2030 and that the market should not expect a new aircraft from the company to enter into service (EIS) until 2035 at the soonest.

"I don't want to fill a gap in a product line," Calhoun said. "I want to build a product that's going to differentiate in a way that absolutely substitutes the airplanes that came before it. That number has to be at least 20%, 25%, maybe 30% better than the airplanes it replaces. And there are technologies and concepts that go with that, and underlying ways of building it that can get you to that answer, and they all take time, and they all have to be proven."

Boeing needs a healthy supply chain as much as it needs Boeing.

He added, later: "...If it [a new aircraft] doesn't have a sustainability wrapper all around it, if it can't meet the emissions tests, if it can't deliver significant performance advantages, then there won't be an airplane. It just won't [happen]. We may not even be allowed to introduce an airplane that doesn't do something like that."

To provide some context: Boeing has spent much of the last three years righting the ship following two 737 MAX crashes, COVID-19 and a delay in 787 deliveries caused by anomalies in some composite fuselage sections. The 737 MAX is flying again, 787s are being delivered and air travel has steadily increased post-COVID, but Boeing is in a competitive struggle with Airbus.

The European planemaker maintains a comprehensive product portfolio, and the company's long-range narrowbody, the A321XLR, introduced in 2019, is in great demand among customers, having racked up more than 500 orders. Boeing, by contrast, lacks a model to compete with the A321XLR, and is feeling pressure from customers to develop one.

So, a common question asked of Calhoun at any investor event is if and when Boeing will announce a new aircraft to compete with the A321XLR. Calhoun's statement in November is the clearest he's made on this topic.

Many aerospace industry observers and analysts have spent the last year trying to determine what Boeing's timeline might be. Airbus certainly has a head start with the A321XLR, but if Boeing announced a new long-range narrowbody in 2024, it could have an EIS of 2032 — albeit at a cost of about$20 billion.

Calhoun's rationale for not moving sooner on a new program boils down to his desire that Boeing's next aircraft be a differentiator — substantially more fuel efficient, with fewer emissions and a smaller carbon footprint. Anything less, apparently, is a non-starter. These are admirable goals, but refusing to even consider a new aircraft coming to market for another 13 years sends some bad signals.

The first bad signal is being sent to customers. They almost certainly want a more efficient and cleaner aircraft as much as Calhoun does, but they also want the option to buy a long-range narrowbody from a company other than Airbus. Further, airlines benefit from and prefer a competitive marketplace when making buying decisions, and Boeing's abandonment of the middle of the market minimizes their options and leaves Airbus at a distinct advantage when it comes to aircraft pricing.

The second bad signal is being sent to the supply chain. Suppliers in the commercial aerospace industry — including composite material suppliers and composites fabricators — serve their customers most effectively if Boeing and Airbus have vibrant and active programs that drive innovation and help build product and technology diversity. What is an aerocomposites fabricator that has a history in the Boeing supply chain supposed to think of Calhoun's statement? Boeing needs a healthy supply chain as much as the supply chain needs Boeing. If suppliers see limited benefit in remaining in the Boeing supply chain, they will naturally seek business elsewhere, with Airbus, Northrop Grumman, Lockheed Martin, Spirit AeroSystems and others. And they might not return.

With so much at stake and so much to lose, it is a genuine puzzle why Calhoun has staked this position. My hope is that it's one Boeing will, eventually, reconsider. And, frankly, Boeing probably must reconsider this position if it wants to maintain its place as one of the preeminent aerospace OEMs.

JEFF SLOAN — Editor-In-Chief

The importance of resin mixing procedures in the composites shop

FIG. 1 Opening resin containers

The technician opens fresh cans of resin and hardener, taking control of the materials from this point forward. Source | Abaris Training Resources

» In recent months, the topic of storage, handling, weighing, mixing and deployment of epoxy resins and adhesives has once again come to the forefront in conversations with clients.

Primary complaints centered around inconsistencies among operators on the shop floor and within the controlled contamination area (CCA) at two aerospace suppliers. After further examination, it was determined that operators were not referencing documented protocols but instead had been following methods passed down through on-the-job (OTJ) training. Even though there were links to written specifications and procedures in the operational planning, they were rarely accessed by the operators who claimed they "already know what to do." Our conclusion was that many of the details in the written procedures had been lost in verbal communications and thus were being overlooked by shop personnel.

Conversations we had and suggestions we made to tighten up controls and implement best practices are described below.

Storage and handling

Open resin containers in the shop were the first clue that written or verbal procedures were either inadequate or not being used by the operator(s). In one case, the handling method was addressed in a document on how to manage hazardous materials but was not directly conveyed in the procedure referenced in the planning document.

Manufacturers warrant resin shelf life for a limited time, ranging from a few months to years — *as long as you do not open the packaging!* This means that the moment the container is opened, the burden shifts to the user to further control the materials (Fig. 1).

This is how resins (especially amine hardeners) were compromised by untrained operators that left the cans open for long periods of time on the shop floor. An always-open container is more convenient for the operator, but it subjects the resins to carbon dioxide (CO_2), water (H_2O) or other airborne contaminants — which can affect the cured resin properties. Containers should always be sealed when not in immediate use. Better yet, purge each container with nitrogen prior to sealing to best preserve the contents.

Weighing and mixing

With epoxy resins, it is very important to have a precise stoichiometric ratio of the part A (resin) to part B (hardener) to achieve the desired number of reaction sites (cross-links) and hence, full structural properties in the cured resin.

There are two ways to measure resins — using either a parts-by-volume (PBV) or parts-by-weight (PBW) ratio as provided by the manufacturer. Most aerospace manufacturers use PBW methods to ensure accuracy (Fig. 2).

The criticality of this requirement cannot be understated. Operators sometimes get careless and "bounce the scale," adding too much hardener to the resin by accident. Worse yet, they intentionally add more hardener than specified to accelerate the reaction in the name of "saving time," resulting in compromised properties — a problem that largely goes unnoticed until it is.

Proper procedures, along with recurrent training, can go a long way toward reducing the chances of this happening. If the operator knows *why* the mix ratio is so important to the performance of the resin/adhesive, they are likely to be more cautious.

It turned out that the operators in this example also needed instruction on how to properly mix resins and for how long. To better assess the problem, we asked these questions: How long do your operators spend mixing? Do they all follow the same procedure? Are these details getting lost in OTJ? Are the operators taking shortcuts? The answers varied, signaling insufficient familiarity with written procedures.

Manufacturers recommend mixing for three to four minutes for small quantities of low-viscosity (less than 60 Poise) materials — more time may be needed for larger quantities or »

FIG. 2 Weighing, mixing a two-part resin system

This resin has a 100:14 PBW mix ratio with a total amount of 130 grams required. This works out to 114 grams of part A resin and 16 grams of part B hardener. The technician tares the container on the scale and adds the required amount of part A (top left), part B (top right), combines parts A+B (bottom left) and mixes the two components for three to four minutes for a complete blend (bottom right). Source | Abaris Training Resources

FIG. 3 Semkit assembly

The Semkit is made up of a dispensing tube filled with resin, a dasher rod filled with hardener and a ramrod for pushing the hardener into the tube. Source | PPG, Sylmar, California

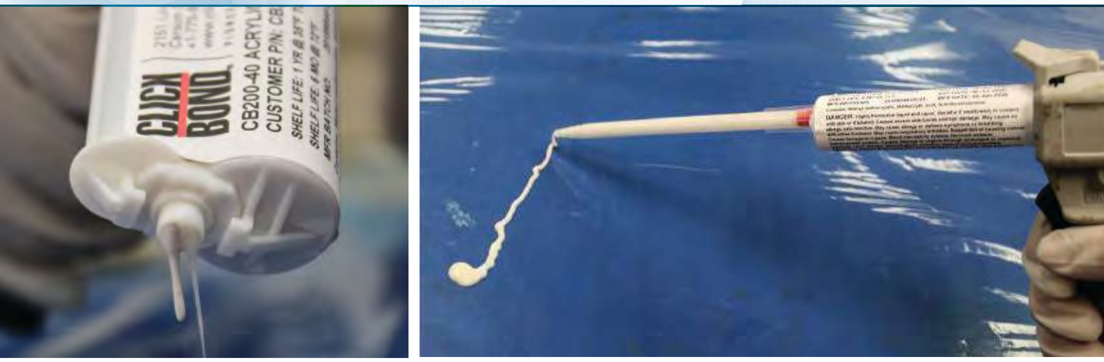

FIG. 4 Cartridges

The technician checks to be sure that both parts A and B are dispensing prior to installing the mixing tip (left). Extruding a small ribbon of resin through the mixing tip prior to using the material (right). Source | Abaris Training Resources

high-viscosity (thixotropic) resins. We found that most operators were mixing small quantities (<300 grams) of resin for less than a minute before deploying it, and only a few took time to scrape the walls and corners of the cup unless there were contrasting colors of resin and hardener. Other topics emerged in these discussions such as awareness of pot life, work time and exotherm hazards, where there seemed to be more common knowledge.

Additional mixing concerns came up about pre-weighed or volumetric packaging. This includes the use of a Semkit, two-part cartridge or a resin bi-pack.

- **Semkits**[1] come with part A in a tube and part B in a dasher rod (plunger). Short of an automated Semkit mixer, mixing these by hand requires some skill. The proper technique: Once the dasher rod is screwed into the top of the tube, push the part A resin up the tube to make room for the part B. Next, retract the dasher rod, and then, using the ramrod, slowly fill the cavity with the part B hardener (Fig. 3, p. 7). Afterwards, holding the red-capped side of the tube upward, push the impeller piston all the way up and down a few times with the ramrod still in place, rotating the impeller at least 180° per stroke. Remove the ramrod and continue mixing for a specified time or number of strokes as indicated on the Semkit card or label. The dasher rod is then removed and the appropriate nozzle is screwed into the end. Place the tube in the dispensing gun and extrude a four- to five-inch ribbon of resin prior to its use in the prescribed application.

FIG. 5 Resin bi-pack procedure

Resin bi-pack as provided (top left). The divider is removed and the resin is mixed with the hardener (top right), mixing is complete after 4 minutes of mixing (bottom left) and the corner is cut and the mixed resin is ready for use (bottom right).

Source | Abaris Training Resources

- **Cartridges** require that the operator check to be sure that both the part A and B are coming out of the end of the cartridge before attaching the tip. First, position all cartridges to be used vertically to enable resins to settle and air to come to the top. Install the cartridge in the gun and hold it vertically with the tip pointing up. Push the plunger until both A and B parts are present. Apply the mixing tip and extrude a four- to five-inch ribbon before use (Fig. 4).
- **Bi-packs** contain the two parts, separated in two sides of a plastic pouch — usually separated with a removable divider strip or burst seal. The seal is removed, and the resin is moved toward the hardener in the pouch and mixed for at least four minutes (Fig. 5).

Pharmacy cage

For high-volume resin and adhesive users, it is recommended that a centralized "pharmacy" system, made up of trained personnel, certified in all aspects of storage, handling, weighing, mixing and distribution, be assigned to prepare sealed kits of precisely measured resins and hardeners needed to meet the demands of each operator's work order(s). This system can be automated and linked to production control so that the pharmacy can work ahead of operator demand.

Uncommon knowledge

It may seem that all of this is common knowledge. However, based on our discoveries, what was thought to be well understood was not. This brings to light one of the issues that I often see in composites production facilities, which is that the simplest stuff gets overlooked because it's not really watched for. The smallest, most important details of the written procedures can get filtered out over time, like a bad game of technical telephone. The good news is that we can audit our operations, provide recurring training to the operators and refocus attention on the little details. We will all feel better about the quality of the product! CW

REFERENCES

[1] Injection-style PPG Semkit package, manual use instructions found at https://www.ppgaerospace.com/getmedia/cc4486e8-4925-45c4-b3ff-8c8488ec318e/Semkit-Mixing-Guide.pdf.aspx

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Louis Dorworth is the direct services manager at Abaris Training Resources Inc. (Reno, Nev., U.S.). Lou has been involved in the composites industry since 1978 and has experience in material and process (M&P) engineering, research and development (R&D), tooling, manufacturing engineering, teaching and troubleshooting. Lou is a coauthor of the textbook titled "Essentials of Advanced Composite Fabrication and Damage Repair," second edition.

Composites GBI is headed toward contraction

October — 50.0

The Gardner Business Index (GBI): Composites Fabricating activity continues to teeter on the edge between contracting and expanding, closing October at 50.0. This follows a similar reading of 50.7 in September. While the composites industry is faring better than most manufacturing sectors, contraction still appears to be a common — and ongoing — theme.

The three components that started to contract in September, new orders, backlog and production, stayed about the same in October. Supplier deliveries lengthened at a slowing rate, suggesting supply chain pain may have eased a bit. Employment *expansion* stayed about the same in October, as did exports *contraction*. CW

ABOUT THE AUTHOR

Jan Schafer, MBA, is the director of market research for Gardner Intelligence, a division of Gardner Business Media (Cincinnati, Ohio, U.S.). She has been an essential part of Gardner Intelligence for over five years, and has led research and analysis in various industries for over 30 years.
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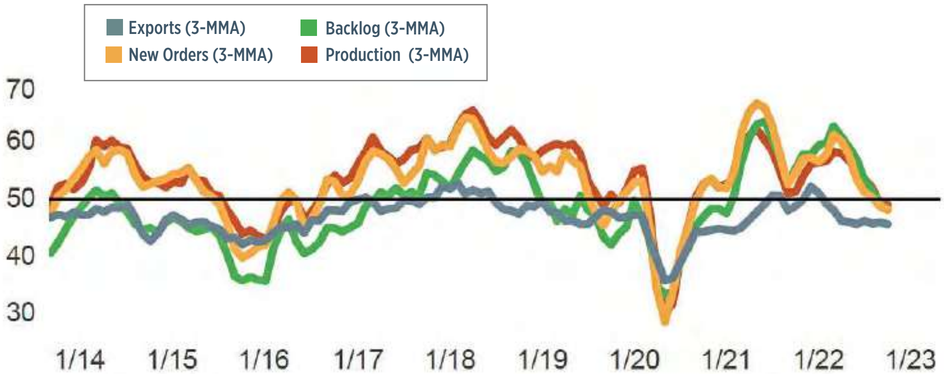
GBI: Composites Fabricating

On the brink

There was no dodging "flat," or little to no growth, in October. The reading reflects a 0.7-point decrease from September, remaining at the point at which fabricators who say business is looking up is about the same as those who say it is slowing down.

Source (all images) | Gardner Intelligence

GBI: Composites Fabricating — Exports, New Orders, Backlog and Production (three-month moving average)



October trends

New orders, production and backlog contracted again in October, but held their own, as did exports.

Faurecia drives a range of composites innovations for safe, sustainable, advanced and customized mobility; Solico introduces Lunaris, its first medical prosthetic design; Collins Aerospace is to build a thermoplastic composite fin for the F-16; and more.

AUTOMOTIVE

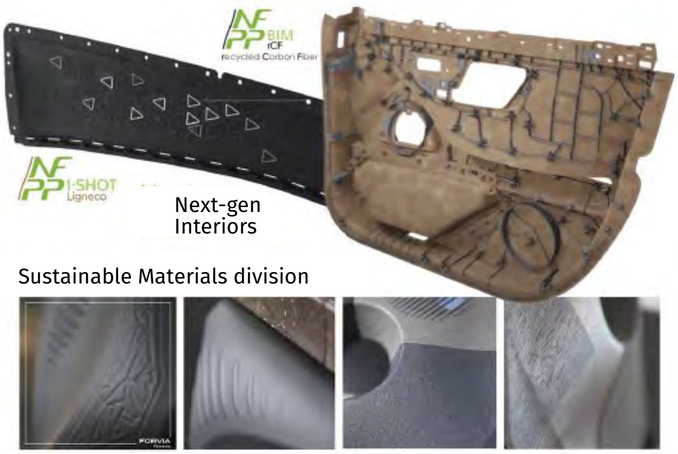
Faurecia advances biocomposites, recyclability, reduced CO_2 and sustainability in automotive

Faurecia (Nanterre, France), part of the Forvia Group, is a global automotive supplier with a mission to develop technologies for safe, sustainable, advanced and customized mobility. While *CW* has more recently reported on the company's carbon fiber-reinforced polymer (CFRP) hydrogen storage tank developments for light commercial vehicles (supplying companies like Group Renault, Stellantis, Hyundai Motor Co. and others), Faurecia's work also extends into advancing biocomposites and smart materials for sustainable vehicle interiors, an area in which it cites decades of experience.

Faurecia is advancing sustainability within its four business groups: Seating, Interiors, Clean Mobility and Electronics. Across these divisions, the company aims to reduce the CO_2 footprint of the materials it uses by 87% by 2030, developing them based on three pillars: use less, incorporate recyclable and recycled materials and create alternatives to petrol solutions, with no impact on cost.

In July 2021, the company created a new cross-functional division, Sustainable Materials, to further develop and manufacture cutting-edge sustainable and smart materials and fulfill these sustainability objectives. Leveraging ultra-low, negative CO_2 emission materials, as well as materials integrating thermal, acoustic and biomedical technologies found under the Interiors and Seating Groups portfolios, the Sustainable Materials division seeks to work across Forvia Faurecia's business groups to propose a low-CO_2 cockpit and CO_2-negative materials to OEMs.

Following these advancements, Faurecia has announced plans to build a dedicated Sustainable Materials R&D Center and a pilot plant, both to be operational by 2023, with a sales target of €2 billion in 2030.



Source | Faurecia, collage edited by *CW*

NFPP and NAFILean natural fiber composite innovations

Since 2003, Faurecia says its high natural fiber-reinforced polypropylene (NFPP) composite materials have been a key solution toward enabling the next generation of vehicle interiors. Compression molded with up to 50% natural fibers, NFPPs are said to reduce weight and CO_2 emissions by 50% compared to similar all-plastic products and are designed to achieve the greatest weight reduction without sacrificing performance or mechanical properties; in the past three years alone, NFPPs have helped the company eliminate almost two million kilograms of plastic.

NFPPs are also optimal for creating interior parts in a variety of finishes, according to Faurecia, including making the natural fibers visible. The NFPP range can be integrated with all of Faurecia's latest solutions for vehicle interiors, including radiant panels, smart surfaces and decorative lighting.

NAFILean, launched in 2011, is a recyclable, lightweight natural fiber material that uses hemp fibers. This biocomposite "meets OEMs' performance and safety requirements," says Laurence Dufrancatel, innovation materials manager and Sustainable and Smart Product Line core team member in a February 2021 interview on the subject. She also notes that a number of biofibers are suitable (like linen and bamboo). The NAFILean family of products has evolved over the years and continues to do so.

Faurecia is now working on CO_2-negative NFPP products which use up to 100% recycled plastic polymers and bring added functionality. It details three such products — NAFILean Stiff, NAFILite, NAFILean R — in the February 2021 report, "Innovation for sustainable interiors":

- NAFILean Stiff makes for a tougher part that can be used in different settings while still saving 52% of CO_2 emissions.

- NAFILite has a microcell structure, with 29% reduction in weight and 43% reduction in CO_2 emissions before its use phase.
- NAFILean R, using a 100% recycled plastic (polypropylene) matrix, saves 108% of associated CO_2 emissions and is, in effect, a CO_2-negative product. Its PP matrix also consists of around 20% organic content, achieving a 25% weight reduction.

NFPP using recycled carbon fiber

Another innovation, rCF NFPP consists of 40% natural fibers, 50% PP and a nonwoven layer comprising 10% recycled carbon fibers (rCF). Faurecia's rCF NFPP is 50% lighter than injected solutions and 25% lighter than standard compression-molded parts. It was a JEC Innovation Award 2021 finalist in the "Automotive and Road Transportation – Exterior" category.

Together, rCF NFPP and NAFILean-R earned Faurecia the German Innovation Award 2022 in the "Excellence in Business-to-Business" competition category. It also won the "Automotive Technologies" category award, "setting standards in recycling and contributing to weight reduction in vehicle interiors and thus to a reduced carbon footprint in automotive construction."

Pursuing even further weight, emission reductions

Other novel NAFILean products are under development, such as NAFILean Perf, which will reportedly offer the highest reductions in weight and CO_2 emissions yet — 41% and 58% respectively.

NaFILean biocomposites currently equip 17 vehicles — including the Renault *Clio*, the Alfa Romeo *Giulia*, the Peugeot 508 and the Land Rover *Velar* — and can be found in around 13 million cars.

How will innovations for sustainable materials at Faurecia evolve? "In order to reach our objective to reduce the CO_2 emissions associated with materials by 87%, we have identified a number of innovation tracks, some of which will bear fruit sooner, and others which will be developed over the coming years," says Dufrancatel.

"Currently, NAFILean products are manufactured through injection processes. We are developing the NFPP family for a new range of interiors components for compression technology, the first generation of which is already in serial production. While compression has its own challenges, it also presents opportunities to develop natural fiber composites using other plants (such as flax and kenaf), and expand the uses of our solutions (in visible parts, for example). The NFPP family offers up to 50% weight reduction and, with up to 45% bio-based content, can halve the CO_2 emissions associated with these products. A new generation with 50% recycled content is in development."

Between now and 2023, she says, Faurecia is aiming to incorporate more recycled content and more biofibers into NAFILean and NFPP, as well as lightweighting materials and design. In the mid-term, by 2025, the company hopes to tackle visible parts and include more recycled content, improve production processes and recyclability, and work on lean architecture.

Read the full article at
short.compositesworld.com/faurecia

Solico composite engineers bring comfort, flexibility to new Axile Bionics ankle prosthetic


Source | Solico

Solico NL (Oosterhout, The Netherlands), a composites engineering specialist for the industrial, marine and defense sectors, announced its recent collaboration with prosthetics specialist Axiles Bionics (Bruxelles, Belgium). The Axiles Bionics' Lunaris is an ankle-foot prosthesis that features bespoke composite components engineered and optimized by Solico.

The new Lunaris prosthesis uses advanced composite components to reduce the overall weight and outer dimensions of the unit, enhancing the performance and aesthetics when compared to earlier all-metallic designs. The innovation enables Axiles Bionics to contain the Lunaris' AI sensor package in a compact size 36 foot, as well as deliver the specific non-linear stiffness required for a more natural gait.

Solico engineers worked closely with the Axiles Bionics design and engineering teams throughout the two-year project, carrying out laminate optimization, finite element (FE) simulations and strength verifications for the composite components.

"The Lunaris was a unique and challenging design project, being our first composite medical prosthesis design, and also a much smaller structure than we typically analyze," Katleen Mattheus, composite lead engineer, Solico, says. "Our FE analysis allowed us to predict the stiffness of various setups and model how the foot would behave, speeding up the optimization process and reducing the real-life test time required. The final design was load tested in our lab to verify the strength and real-life characteristics of the composite parts."

"We decided to bring Solico in since the start of our development process," Pierre Cherelle, CEO, Axiles Bionics, adds. "Doing so very early on, and designing collaboratively, has given us the opportunity to not only integrate high-level expertise in composite materials and their behaviors, but also to bring very practical know-how in the daily and long-term use of those components. This resulted in a fantastic product, as well as a significant increase in intellectual property [IP]."

AEROSPACE

Collins Aerospace selected by AFRL to produce thermoplastic composite fin for F-16

Source | Collins Aerospace

Collins Aerospace (Riverside, Calif., U.S.) was selected by Air Force Research Laboratory (AFRL, Wright-Patterson Air Force Base, Ohio, U.S.) to receive a contract award to build an advanced, high-impact-resistant F-16 ventral fin using Collins' thermoplastic welding technology, which will significantly reduce weight and cost of the current design.

Collins is investing approximately $100 million over the next five years toward the advancement of its thermoplastic technology and plans to qualify and process thermoplastic materials for both military and commercial use. Under the three-year contract, the proposed work includes application of a specialized welding process, component design and prototype fabrication for the F-16 ventral fin. The effort will leverage best practices from similar programs including the recent composite-based F-16 horizontal stabilator.

"We are seeing an increased demand and opportunity to replace legacy aircraft components with thermoplastics," Stan Kottke, vice president and general manager of Aerostructures for Collins Aerospace, says. "The trend is using advanced thermoplastic materials to lower the cost and weight while reducing our overall environmental footprint, and those benefits are directly passed on to our customer."

Through automation processes on the manufacturing floor, the cost savings are expected to be upward of 30% where Collins can use thermoplastic composite materials. Thermoplastic resin is inherently tougher than thermoset resins typically used in production, the company notes. Tougher materials reduce the overall weight, enabling thinner design and increased range of the payload. Thermoplastic materials have an indefinite shelf life, can be stored at room temperature and can be reused or recycled. This eliminates the need for energy-intensive cold storage required for thermoset raw materials.

According to Collins, the next step is to advance and mature the designs and manufacturing technologies specific to forming and thermally joining thermoplastics to create component assemblies. This work will be accomplished within the Riverside composites center.

CARBON FIBER

Carbon Fiber Recycling now accepts carbon fiber bobbin waste

Source | Carbon Fiber Recycling

Carbon Fiber Recycling (CFR, Tazewell, Tenn., U.S.) has announced it is now accepting carbon fiber bobbin waste from manufacturers looking to recycle 100% of their waste stream. CFR has developed a capability to efficiently recycle "depleted" carbon fiber bobbin waste consisting of bobbins that have carbon fiber yarn left wound on the cores. The cardboard, the fiber, the pallet and the shipping boxes are all recycled, and nothing goes to a landfill, CFR reports.

"Some manufacturing processes end up with a small amount of windings left on the cores of the bobbins," Tim Spahn, director of licensing and sales at Carbon Fiber Recycling, notes. "Until now, they haven't been worth doing anything with, and much of this waste ends up in landfills. We've set out to change the course of this material and keep it out of the landfill altogether. We've now developed ways to recycle everything, potentially allowing a manufacturer to claim they are a zero-waste landfill company."

CFR says it is currently processing about 60 tons of this material per month and are looking to increase this volume to 200 tons or more per month. According to Spahn, the company has processing space to handle multiple tractor-trailer loads per week. Moreover, the processing system is scalable, and CFR is looking to create new relationships with manufacturers that are striving toward becoming zero-landfill companies.

If your company is interested in setting up a conversation to discuss your waste stream materials with CFR, reach out to Tim Spahn at 203-313-0558 or tspahn@carbonfiberrecycling.com.

Tri-Mack introduces thin, lightweight thermoplastic composite enclosures

Tri-Mack Plastics Manufacturing Corp. (Bristol, R.I., U.S.) announces its latest product development achievement, a lightweight, high-strength enclosure made from just eight plies of unidirectional (UD) carbon fiber-reinforced thermoplastic (CFRTP) tape and only forty thousandths of an inch (0.40-inch) thick.

The new enclosures demonstrate Tri-Mack's expertise in the production of large, thin covers with deep draws using UD tape. At CAMX, the company displayed a range of cover sizes and materials made using Tri-Mack's production process: automated tape laying (ATL), consolidation and stamp forming. Tri-Mack's thermoplastic composite process produces parts in minutes, rather than the hours typically required for thermosets, the company contends.

"We see these new TPC [thermoplastic composite] covers meeting rising demand for strong, lightweight enclosures that can shield functional components in aircraft, drones and a variety of other industrial uses," Tom Kneath, vice president for sales and marketing, Tri-Mack Plastics Manufacturing, says. "Where strength and durability are priorities in addition to the lightest weight, continuous fiber TPCs are the material of choice. It is less brittle than thermosets, delivers 10 times the strength of injection-molded parts and, with our enclosure, provides a 30% weight reduction versus 6061 aluminum."

The new enclosures are not limited to carbon fiber. They can be produced using glass fiber, and with different base resins as well, including polyaryletherketone (PAEK), polyetheretherketone (PEEK) and polyetherimide (PEI), providing a variety of customizable properties and solutions.

The enclosure's manufacturing process also enables added functionality, creating "smart composites" by embedding EMI shielding, or adding localized reinforcement through tailored layups. "We can add electrically conductive layers into our process to enable EMI shielding performance at a fraction of the weight of metal," Max McCabe, sales engineer, adds. "This also eliminates the plating and painting process steps of typical EMI solutions used on composite parts." Electrical conductivity and shielding effectiveness can be tailored to end use with a wide variety of durable composite materials, further broadening potential applications across aerospace, unmanned air vehicles (UAVs), undersea applications and electric vehicles (EVs).

Tri-Mack's process engineering manager Ben Lamm, leader of the new enclosure project, says that it was a technical challenge to form the large, deep covers out of TPC. "With UD materials, you're stacking plies that are oriented in different directions throughout the part," he says. "Making complex shapes this way requires individual plies to slip against each other as you are forming. Getting them to move the way you want requires strategic layup and tool design, as well as subtleties in material handling during processing."

Toray Composite Materials America to double Torayca T1100 production capacity


Source | Toray Composite Materials America Inc.

Toray Composite Materials America Inc. (TCMA, Tacoma, Wash., U.S.), a global carbon fiber and advanced composite materials producer, announces a significant upgrade to its carbon fiber facility located in Decatur, Ala., U.S. The $15 million investment will double the production capacity of the high-performance Torayca T1100 carbon fiber and add critical redundancy. The upgrade is set to begin in April 2023 and be completed by September of the same year.

The upgrade is in response to the rising demand for defense applications in the U.S., significantly increasing the availability and shortening lead time of Torayca T1100 next-generation intermediate modulus plus (IM+) carbon fiber. According to TCMA, this material is a critical component in several U.S. Department of Defense (DOD) weapon systems, as well as structural applications in future vertical lift (FVL) platforms.

"We're excited about adding capacity and flexibility at our Decatur plant for our defense customers," Dennis Frett, president of TCMA, says. "Not only are we doing our part to reinforce the country's industrial base and the [current] administration's "Made in America" priorities, but we're also strengthening our country's domestic capacity for advanced materials technology."

Toray is one of the largest producers of carbon fiber in the U.S. and has a fully integrated supply chain. The Decatur plant has operation lines from precursor to carbon fiber and is one of three Toray manufacturing facilities. The company has other locations in Tacoma, Wash., and Spartanburg, S.C., producing precursor, carbon fiber and prepreg.

ENERGY

Siemens Gamesa, Airborne collaborate to automate wind turbine blade manufacture


Source | Siemens Gamesa Renewable Energy

Siemens Gamesa Renewable Energy (SGRE, Zamudio, Spain) has contracted Airborne (The Hague, Netherlands) to engineer and supply an automated system for the manufacture of composite offshore wind turbine blades.

By working together, both companies bring years of expertise in the manufacture of wind turbine blades, composite processing and automation to make this project a success. Airborne is a 100% composites-focused digital automation company with more than 25 years of experience in developing composite solutions for high-tech industries such as aerospace, automotive and renewable energy. Siemens Gamesa supplies wind turbines globally with what it says is a unique process for manufacturing large offshore blades.

"We are excited to support Siemens Gamesa in this challenging project," Marcus Kremers, CTO of Airborne, notes. "The scale of the operation is impressive and the requirements on layup rate are higher than we have ever seen. We are proud to bring our technologies and expertise to the table and jointly develop the right technology."

Morten Westeraa, robotics expert of Siemens Gamesa agrees, finding potential and demand in the global wind turbine market. "It is essential that our production is kept at the highest level of efficiency, throughput and quality," Westeraa adds. "We are confident that Airborne is a very skilled partner on this journey."

BIZ BRIEF

University engineering researchers have developed a new self-healing composite material that enables structures to repair themselves in place, without having to be removed from service.

"Previous strategies for self-healing composites have faced two practical challenges," according to Jason Patrick, corresponding author of the research paper and an assistant professor of civil, construction and environmental engineering at North Carolina State University. "We've come up with an approach that addresses both of those challenges in a meaningful way, while retaining the strength and other performance characteristics of structural fiber composites."

Read the full article at **short.compositesworld.com/selfhealing**

AEROSPACE

Firefly Aerospace *Alpha* rocket successfully reaches orbit, deploys customer payloads

In October 2022, Firefly Aerospace (Austin, Texas, U.S.) successfully launched its all-composite *Alpha* FLTA002 rocket, reaching orbit and deploying customer payloads. Liftoff took place on Oct. 1 at 12:01 a.m. PST from Vandenberg Space Force Base in California. With mission success, Firefly says it is the first company to launch and reach orbit from U.S. soil in only its second attempt. It is also reported to be the first and only U.S. commercial space company with a rocket ready to take customers to space in the highly desired 1,300-kilogram payload lift class.

Source | Firefly Aerospace

"With the success of this flight, Firefly has announced to the world there is a new orbital launch vehicle, available today, with a capacity that is pivotal to our commercial and government customers," Bill Weber, Firefly CEO says. "Proving our flight and deployment capabilities on only our second attempt is a testament to the maturity of our technology and the expertise of our team. This is an exciting day at Firefly and we have many, many more ahead."

Alpha is an all-composite rocket that uses patented tap-off engine cycle technology, which reduces cost and improves efficiency while maintaining the strength and reliability of the rocket. After liftoff, the rocket completed all major technical milestones — including insertion into an elliptical transfer orbit, coasting to apogee and performing a two-burn maneuver, relighting the second stage during its first orbital flight.

FLTA002 deployed a total of three payloads, including demonstration satellites from NASA TechEdSat-15 in conjunction with San Jose State University (SJSU, Calif., U.S.), Teachers in Space and Libre Space Foundation. These payloads will perform several in-space experiments, including an "exo-brake" to help in the deorbiting of satellites and test a fully free and open-source telecommunications constellation.

Building on its success, Firefly is completing the Acceptance Testing Protocol (ATP) for its *Alpha 3* vehicle in preparation for its upcoming NASA VCLS Demo 2-FB ELaNa 43 launch. In addition, Firefly continues the production of multiple rockets at its Texas manufacturing facilities using all the lessons learned from existing flights and testing. Firefly is scheduled for six *Alpha* launches to take customer payloads to space in 2023, and 12 more in 2024.

Firefly sends special thanks to SLD-30 for its continued support and partnership and the customers on FLTA002 for their dedication and unwavering confidence in Firefly's technology.

New polymer expands composites options in demanding environments

Aromatic thermosetting copolyester offers unique properties, availability in multiple form factors.

By **Peggy Malnati** / Contributing Writer

Novel polymers

One of the first applications where ATSP polymer is being considered is for a NASA-funded project involving rollable or foldable composites for deployable structures. In order to participate, late last year ATSP Innovations sent polymer in film form to a prepregger who successfully impregnated a thin-ply, plain-weave carbon fiber fabric.

Source (all images) | ATSP Innovations Inc.

»One hundred and sixty years after Alexander Parkes introduced the first human-made plastic at the London International Exhibition, and 115 years after Leo Bakeland created the first fully synthetic and commercially successful polymer, development of new resin systems — as opposed to novel blends and alloys of existing polymer families — are no longer a common occurrence. Hence, when an organization introduces a new polymer — especially one with a unique combination of properties enabling the material to be used in a variety of applications and supplied in many form factors — it's worth paying attention. Such is the case with a new-to-industry resin system that was invented 12 years ago by Dr. James Economy, a long-time professor and former head of the Department of Materials Science and Engineering at the University of Illinois at Urbana-Champaign. Economy passed away at the age of 92 in the fall of 2021, leaving a body of work consisting of 250 research papers, 47 book chapters, 100+ U.S. patents including invention of at least 20 polymer technologies and countless contributions to materials science and engineering.

Called aromatic thermosetting copolyester (ATSP), the novel resin technology is owned by ATSP Innovations Inc. (Houston, Texas, U.S.). The material was introduced in a technical presentation at the 2021 Society of Plastics Engineers (SPE, Danbury, Conn., U.S.) Automotive Composites Conference & Exhibition (ACCE) last November. We sat down with presenter Dr. Jacob Meyer, ATSP Innovations' co-founder and vice president technology, and Economy's former student, to discuss the polymer's unique properties and some potential applications being investigated.

Thermoset and thermoplastic properties

ATSP is a non-catalyzed, condensation-cure polymer system that combines continuous amorphous and liquid crystal segments. As such, it offers an interesting hybrid of properties commonly found among thermosets *and* thermoplastics. For example, like thermosets, once polymerized and cross-linked, it offers high thermal and broad chemical resistance and tight control of dimensional stability. Its glass transition temperature (T_g) is more than 250°C and it doesn't thermally degrade at temperatures below 500°C, meaning it's ideal for use in truly demanding environments where most polymers have long since melted or fallen apart.

However, like thermoplastics, it offers good processability, post-mold "weldability" and melt reprocessabilty, enabling scrap and end-of-life (EOL) parts to be recycled. It softens between 170-180°C, is an uncured liquid between 230-240°C, begins curing at 270°C and is fully cured at 340°C. Depending on form factor and how fast one wishes to heat and cure the polymer, heat sources such as infrared, microwave and induction may be used. Even its mechanical properties blend the best of thermosets (tensile modulus of 4.2 GPa) and thermoplastics (8-10% strain to failure).

Since it's aromatic — meaning it starts as a ring structure — and an oligomer, heat application of 270-340°C prior to polymerization leads to a rapid drop in viscosity (this varies by formulation, but is on the order of 4,000-10,000 centipoise), enabling ATSP to wet out a wide variety of fibers, including carbon, glass, basalt and natural fibers. In fact, Meyers says ATSP has produced carbon fiber-reinforced composites with up to 70% fiber volume fraction (FVF). He says the material also offers excellent bonding to a variety of nanoparticles, including graphene.

In neat form, ATSP has a specific gravity of 1.32. It's said to have low outgassing, be free of volatile organic compounds (VOCs) and be without environmental, health or safety concerns. Equally interesting, it possesses a long shelf life with no need to refrigerate or freeze. In fact, Meyer recalls finding a batch of ATSP powder that had been sitting on a shelf for three years and successfully producing a cast film with it.

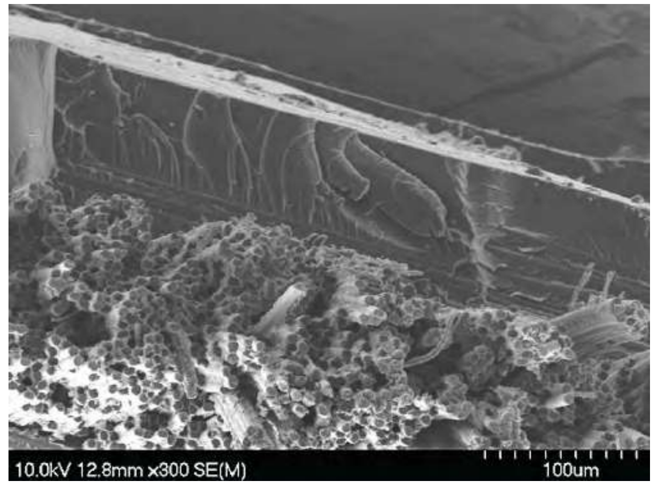
A good electrical insulator, neat ATSP has a dielectric constant of 5.0 at 25°C and 10 kilohertz, and a dielectric breakdown strength of 384.4 volts/micrometer. The material also offers high oxidative stability, easy machinability with low dust (helpful when machining shapes) and a very low moisture absorption rate of 0.2-0.3%.

ATSP also has excellent and inherent non-halogenated flame retardancy with a limiting oxygen index (LOI) of 40% and UL 94 V-0 listing at 1.5 millimeters. When exposed to an open flame, Meyer says the polymer forms a stable char, which insulates unburnt material below. Additionally, it offers high lubricity and low wear, making it interesting for tribological applications.

Perhaps its most notable feature is something called solid-state interchangeable/exchangeable bonds, a function of interchain transesterification reactions (ITR), which enable previously cross-linked parts to be "welded" together like a thermoplastic after applying heat (in the range of 270-340°C) and pressure (average 1-4 MPa). Want to separate those cohesively bonded pieces? Just bump the heat up again and pull them apart.

Many form factors, potential applications

Meyer says that the polymer can easily be tailored to produce specific properties, which also enables ATSP Innovations to offer the material in multiple form factors and to explore its use in a broad range of potential applications.

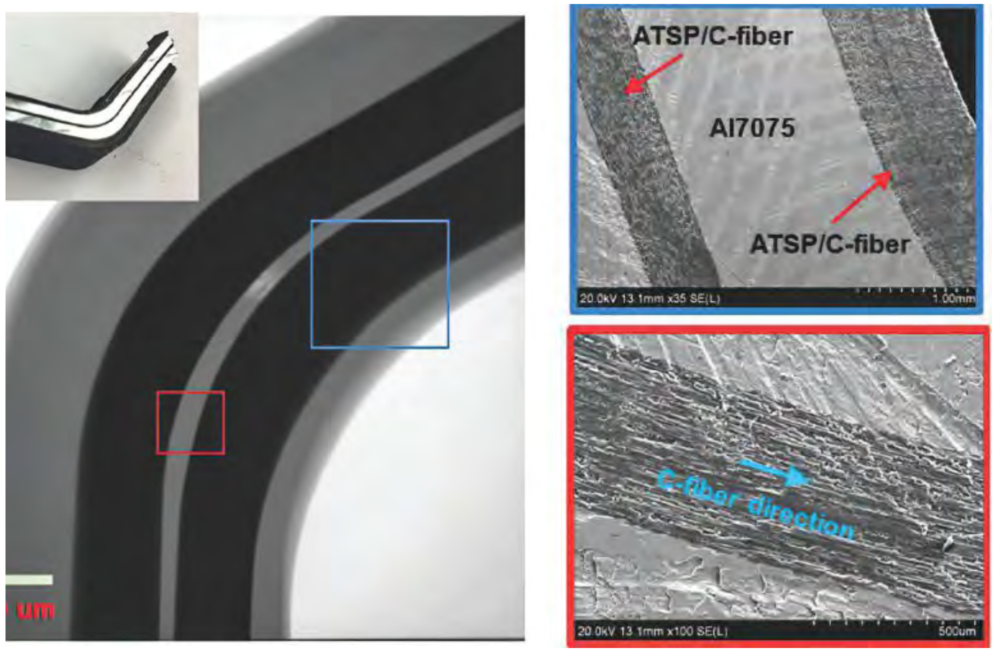


Taking a closer look

The scanning electron micrograph (SEM) image at top, shows that a fracture has occurred entirely in the matrix at 90° to the carbon fiber tow, as no broken fibers are observable. This indicates that failure was matrix-dominated and the material demonstrated high fiber/matrix interfacial shear strength. The SEM image on the bottom shows resin still intimately bonded to fibers at the fracture surface.

For example, it can be supplied as prepolymers (which can be solvated), pre-cured bulk sheets or shapes (blocks of solid neat or reinforced polymer used to machine rather than mold parts), or as a structural composite in the form of B-staged molding compounds with discontinuous fiber or composite laminates with continuous fiber architectures. Additionally, it's also available as a powder or film for coating or impregnating other materials.

Besides its use as a structural composite, which is of interest in aerospace and automotive markets, ATSP is currently being evaluated as a high-performance melt- or solvent-spun fiber. It's also being studied as an open-cell foam (with foaming produced as a natural byproduct of the condensation-cure reaction). While researchers have only achieved a density reduction of 0.2 gram/cubic centimeter to date, the fact that ATSP foam provides sound damping plus excellent thermal insulation (0.10 watt/meter-Kelvin) and flame retardancy makes it interesting as a high-temperature »



Interchangeable/ exchangeable bonds

On the far left image is an X-ray computed tomography (CT) image of an interchain transesterification reaction (ITR)-bonded carbon fiber-reinforced ATSP composite/Al7075 multi-material laminate with a curved geometry. On the far right are two SEM images taken of the cross-section area of the sandwich construction.

barrier material or the core for a sandwich panel composite for applications in building/construction, infrastructure, aerospace and automotive where it could potentially compete with polyimide foams.

Furthermore, ITR can be put to use by creating a structural adhesive with high shear strength (20 MPa at 80 microns thickness) over a broad temperature range. As an adhesive, the material (in powder coating form) is transparent, fast bonding, offers excellent adhesion to a broad range of industrial materials, including polymer composites, aluminum, steel and glass, and comes with the thermoplastic-like advantage of being able to be bonded, unbonded and rebonded multiple times without losing properties. In fact, the non-tacky bonding process can be done in the field without use of gloves or other personal protective equipment (PPE). Reportedly, the adhesive technology was developed in collaboration with NASA (Washington, D.C., U.S.) for potential use in space assembly operations.

LEARN MORE

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

Still another application area the company is exploring is production of high-performance polymer bearings with an ATSP film/coating that has been formulated for extreme working conditions of high loads, high speeds and high temperatures. ATSP can even be formulated for 3D printing.

Aerospace and oil/gas customers are said to be interested in ATSP as a replacement for polyetheretherketone (PEEK), polyetherketoneketone (PEKK) and polyethersulfone (PES). Transportation OEMs are reportedly interested in it as a replacement for para-aramid-reinforced ballistic panels. Neat polymer is said to behave similarly to phenolic, although it is easier to mold.

ASTP Innovations sells its powdered resin (for compression molding or spray coating), machinable bulk sheets and compression moldable composite laminates and molding compounds under the name Estherm. It calls its tribological coatings NOWE and its adhesive products Self-Bond.

Next steps

"ATSP has such a unique combination of properties that our biggest challenge isn't finding an interesting application or two, but rather to focus on just a few areas — like composites and adhesives — that are likely to be easier to implement and can help us commercialize this polymer at last," Meyer explains. ATSP Innovations is working with Allied Composite Technologies LLC (Rochester Hills, Mich., U.S.) on business and application development and licensing. The polymer is also being strategically sampled in the aerospace, automotive, building/construction, infrastructure and oil/gas industries. The first commercial applications could be seen as early as next year. In the meantime, Meyer says ATSP Innovations is actively seeking and engaged with prospective partners, collaborators and customers to bring this technology to market.

Asked where he anticipated pricing would be for ATSP once commercialized, Meyer adds, "This is in large part a matter of scale, but our long-term goal is to be competitive with nylon (polyamide) and our nearer-term, more conservative price points should still be viable for pilot-level production." CW

ABOUT THE AUTHOR

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Metal AM advances in composite tooling

Multiple metal additive technologies are gaining market acceptance and interest for composite tooling used in processes ranging from short-fiber injection to autoclave-cure prepreg.

By Peggy Malnati / Contributing Writer

» Tooling is a vital element of any successful manufacturing program for composite parts, but it is often one of the last aspects considered during the development process. This is unfortunate since tool production — especially hard/metal tools — can have long lead times and add considerable cost to the bottom line. In fact, on many programs, tool production is the rate-limiting step, slowing commercialization and adding a high cost burden.

Luckily, metal additive manufacturing (AM) — which was initially used to produce prototype and low-volume metal parts — is starting to gain converts as a method to fabricate tooling components and entire molds. Like other 3D printing technologies, AM offers higher design freedom than machining or forming metals, plastics or composites themselves, easily printing geometries that are impossible or extremely costly to achieve with conventional manufacturing technologies. And most 3D printing processes can produce these structures with significantly shorter lead times, helping OEMs bring products to market faster, at lower cost and with a smaller carbon footprint.

The GA-ASI *SeaGuardian*

A recent development project evaluated the feasibility of using wire-arc additive manufacturing (WAAM) to produce layup tooling for complex contoured winglets mounted at the tips of the wings of MQ-9B *SkyGuardian* and *SeaGuardian* (shown above) remotely piloted aircraft from General Atomics Aeronautical Systems Inc. The additive tooling matched identical carbon fiber-reinforced composite tooling in terms of dimensional control, vacuum integrity and true position hole location, while providing improved durability. It also reduced maintenance costs, tool costs (30-40%) and tooling lead times (20-30%).

Source | General Atomics Aeronautical Systems Inc.

In this article, we'll cover several metal additive technologies and describe the types of tools or tool components they're being used to produce and why. Here, we're distinguishing between technologies that are already proven and are gaining wider acceptance on production programs — often for high-volume manufacturing — and technologies that are close to or just beginning use on commercial programs. In future articles, we'll continue this discussion with additional technologies and describe novel ways that metal AM is helping toolmakers and molders produce better parts.

Production proven: Direct metal laser sintering/solidification

There are several metal AM technologies that are already production proven. That is, their processes have been vetted, their benefits catalogued and they currently are used to manufacture numerous components for injection molds producing parts for medium- and high-volume commercial programs in the automotive, rail, large appliance and personal care/medical industries.

Our focus is on one of these processes, generically called powder bed fusion (PBF), although variations include selective laser melting (SLM), selective laser sintering (SLS), electron beam melting (EBM) and direct metal laser sintering/solidification (DMLS).

In powder bed processes, a build plate sits in the bottom of a preheated chamber that is blanketed with inert gas at near-vacuum conditions. A very fine layer of metal powder is applied to the build plate via roller or blade, after which a thermal energy source (typically laser or electron beam) is directed at specific locations on the build plate where it melts and fuses powder into solid metal, forming the first layer of a part. The process continues until sufficient layers are deposited and fused to complete part geometry, after which it is removed from the chamber, depowdered and CNC machined to achieve required dimensions and finishes.

Benefits of powder bed processes include access to a broad range of metals and production of fully dense parts (without the need to sinter) with excellent mechanical properties (often as good as/or better than forged metal parts). It's typical of AM/3D printing processes to offer greater design freedom than can be achieved — especially cost effectively — with conventional methods like machining, stamping, forging, casting or even molding because parts are built a single layer at a time in three dimensions. Proponents of the technology like to say that "complexity is essentially free in AM."

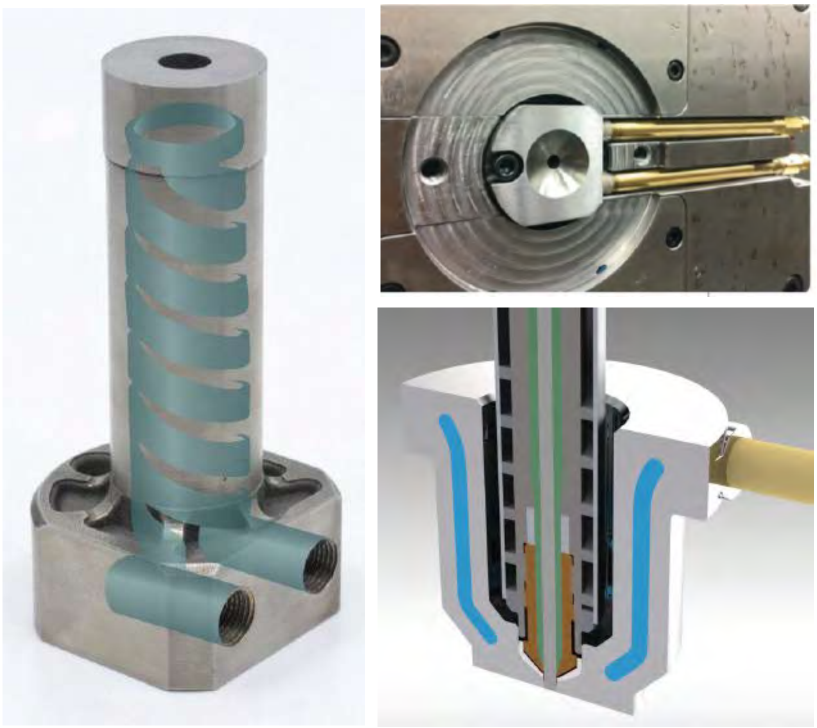
Since powdered metal is laid down one layer at a time in the PBF process, sparse, solid or hollow lattice-type structures can be printed to reduce mass and material use in the same volume. It also can create complex internal geometry that is difficult or impossible to produce any other way. Because of this, very complex, hollow conformal cooling (or heating) channels that follow the contour of a part can be printed in geometries that would be impossible to gundrill.

For thermoplastics, this means cooling lines can be placed closer to critical geometry, allowing molders to shorten cycle times while reducing warpage, scrap and energy use. Similarly, for thermosets, heating lines can be created to speed curing times. PBF also permits creation of contiguous micro-scale holes/channels, producing selectively porous internal geometry that can be used very effectively for venting. This eliminates nearly all of the problems associated with porous metal matrix composites (MMCs) that have long been used to create vented inserts for injection molds.

Limits of PBF include slow deposition rates, especially when intricate geometries are involved, high energy use and safety issues regarding the handling of fine powders, which require printers to be housed in specialized rooms (often temperature- and humidity-controlled cleanrooms with antistatic flooring staffed by operators wearing protective clothing). Some processes also induce high internal stresses in the workpiece that have to be post-print stress relieved.

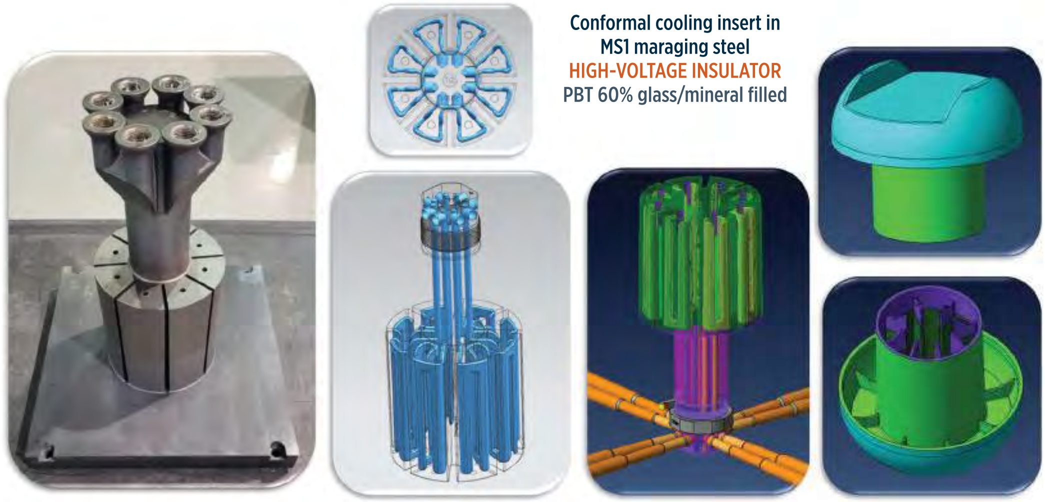
Although build envelopes have been steadily increasing, they still are measured in millimeters or centimeters, not meters, so printable part sizes are necessarily small relative to other additive processes we'll cover. Therefore, while PBF can produce extremely complex parts, the process is typically used to produce lifters, slides or inserts installed inside injection or compression molds rather than the molds themselves.

One mold component supplier that uses metal AM is PCS Co. (Fraser, Mich., U.S.), which rolled out its first H13 steel sprue bushings with conformal cooling channels for molds with cold runners at NPE 2018 and, two years later, added 420 stainless steel conformally cooled gate inserts for molds with hot runners. These PBF-printed, conformally cooled components are ideal »



Printing complex, hollow conformal cooling channels

For injection molds, PCS Co. offers sprue bushings (left standalone and top right seated in tool) printed in H13 steel and gate inserts (bottom right) printed in 420 stainless steel that feature integral conformal cooling channels. Molders and moldmakers who have used the drop-in replacement report significant cycle time reductions. Source | PCS Co.



Embracing metal AM

Intricate conformal cooling lines (three middle images) were printed in the tool insert (left-most image) used to mold the highly reinforced thermoplastic polyester railway insulator (two images on far right). The DMLS-printed insert (produced in MS1 maraging steel) is shown on its build plate (left-most image), from which it was wire EDM'd prior to final machining and installation in the mold.

Source | Linear AMS, a Shapeways company

for situations where large sprues feed small or thin parts. Since cooling represents 70-80% of the total injection cycle, moldmakers and molders using these drop-in replacements versus comparable components without conformal cooling have reported dramatic improvements in productivity — 15-80% cycle time reductions, depending on application. Given that molders are under constant pressure to reduce costs, PCS reports components can pay for themselves within days to weeks.

In one case, an automotive processor was injection molding spoiler seals in a two-cavity tool with a single cold runner that was 4-times thicker than the parts being produced, limiting the molder's ability to reduce cycle times without risking stringing of still-hot material as the tool opened. After the original cold sprue bushing was replaced with a conformally cooled sprue bushing, cycle times were lowered, reducing cost pressures on the molder.

In another case, an automotive molder struggling to achieve a high-quality finish on a fastener in a four-cavity tool was maxing out injection pressures (155 MPa), risking over-shearing the material (with commensurate risk of property degradation) and damaging the press. After switching to a conformally cooled gate insert, cycle times were reduced from 20.3 to 17.8 seconds, injection pressures were reduced to 21 MPa and the processor saved $35,000-$40,000/month.

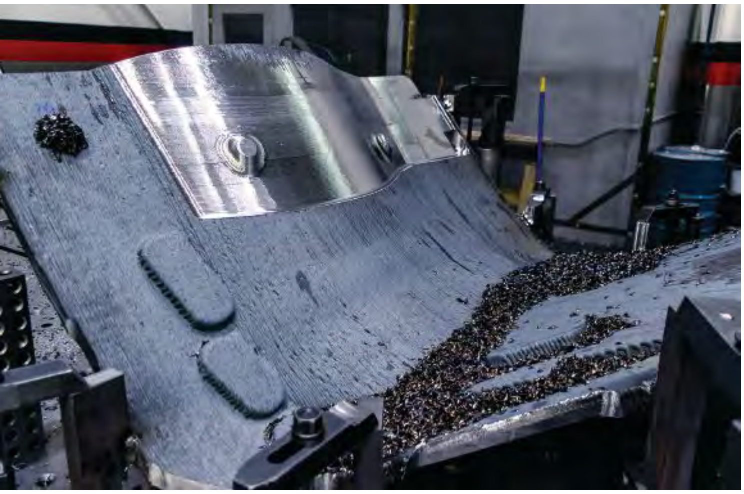
"Thanks to the versatility of 3D printing, we can manufacture complex parts with geometries that are practically impossible to make through conventional methods," explains Paul Graceffa, PCS Midwest sales manager. "Customers ask us for 3D-printed technology for their molds because they know it gives them an edge over their competition. Most select these components because of the savings potential they offer during production of plastic [neat, reinforced and filled polymer] parts."

Toolmakers, particularly those that also mold, are embracing the benefits of metal AM as well. Linear AMS, a Shapeways company (Livonia, Mich., U.S.), has used multiple metal AM technologies to produce conformally cooled inserts for its injection molds since 2005. Early on, Linear found itself owning one of only two DMLS printers in North America, so it quickly had aerospace and defense companies asking to visit and watch the printer work, since the only other DMLS printer was owned by an aerospace competitor. Soon, the Linear team became so skilled at designing and producing conformally cooled inserts that it effectively offshored its conventional moldmaking and focused on designing and producing conformally cooled inserts for its own molds and those of other toolmakers.

A good example of the type of complexity that Linear regularly produces with its conformally cooled inserts is the mold for a high-voltage electrical insulator used by the New York Transit Authority on railways for switching tracks. Reminiscent of a giant mushroom, the 123-millimeter-diameter x 270-millimeter-tall part is injection molded using 60 grams of 60% fiberglass/mineral-reinforced polybutylene terephthalate (PBT). The conformally cooled insert takes up nearly the entire core geometry of the single-cavity, oil-cooled tool, which was designed to produce three different insulators in three different lengths, which are selected by changing inserts. Given the size and length of the part, and the critical need to control dimensionality in the semi-crystalline polymer, the team wanted to better manage the temperature delta predicted by moldfilling analyses between the top and bottom/thick and thin sections of the part to achieve acceptable cycle times and extend the life of the mold. The insert nearly exceeded the height (Z-axis print envelope) of the DMLS printer. Linear is also molding the parts at its Charlotte, Mich., U.S. facility.

"Our industry would benefit from strengthening its DED tool manufacturing supply chain."

"Over the years, we've heard so many positive comments from customers about the savings they've achieved by incorporating conformal cooling in their molds," recalls David Myers, Linear AMS business development manager. "Among my favorites are: 'We've never been able to process that detail prior to having the thermal control conformal cooling provides us,' 'The reduced cycle is so significant that we've relaxed our CAPEX [capital expenditure]



Wire-arc additive manufactured tooling

Since WAAM, like other LFAM processes, produces parts with bumpy/striated surfaces, post-print CNC machining is needed to achieve final part dimensions and an acceptable finish. In the image above, the as-printed mild steel surface is dark gray, while the post-print machined surface is silver. Source | Lincoln Electric Co.

Targeting aerostructure programs

The severe curvature of this winglet's facesheet is difficult and costly to achieve in conventional metal forming or machining, as well as in carbon fiber-reinforced composite tooling, adding cost and lead time to aerostructure programs, which is why GA-ASI has been evaluating LFAM options. While the backing structure for the WAAM tool could have been printed, GA-ASI determined it was faster and cheaper to produce and assemble it via conventional means.

Source | General Atomics Aeronautical Systems Inc.

request to buy another injection molding machine,' and 'We normally would have commissioned two tools [for this program] owing to capacity concerns, but we're staying so far ahead with conformal cooling, that one tool is all we need.'"

Production ready: Wire-arc AM

Just as with polymer AM, the metal AM segment has responded to industry demand to be able to print much larger pieces much faster — albeit with less detail and using different technical approaches — by developing large-format AM (LFAM) printers. Metal LFAM is gaining converts — especially in the aerospace/defense industry — for single-sided prototype and production tooling. One such technology is wire-arc additive manufacturing (WAAM), a subset of the broader directed energy deposition (DED) category of 3D metal printing. Several companies sell WAAM systems; one that offers 3D metal printing services is Lincoln Electric Co. (Cleveland, Ohio, U.S.), which also offers post-print machining, fabrication and inspection.

WAAM combines a gas/metal arc welding source mounted to an industrial robot arm, a multiaxial positioner on which the build takes place and metal in wire form, which is more economical than powder forms for the same alloys. The technology offers rapid deposition rates of 2.3-4.5 kilograms/hour and printing is done in open air without the need for protective enclosures or nitrogen blanketing. This greatly extends the build envelope — currently 1.2 x 1.5 x 2.0 meters in Lincoln's metal 3D printing factory. The company says the technology can be readily scaled to even bigger systems, although Lincoln also has successfully printed multiple shorter tool segments and welded them together to produce a 3.1-meter-long x 3.8-meter-wide x 1.1-meter-tall tool. Printing and joining segments not only extends the effective "reach" of the technology but shortens build times too.

As with other polymer and metal LFAM technologies, post-print machining is usually required because as-printed surfaces are too rough. Therefore, prints are slightly oversized to enable light CNC machining to achieve final dimensions and acceptable finishes.

WAAM produces fully dense parts without the need for post-print sintering or hot isostatic pressing (HIP). However, like other welding-type metal 3D-printing technologies, WAAM induces internal stresses that often, although not always, need to be addressed through thermal stress relief. Lincoln says geometry dictates whether this is done between printing and rough machining or between rough and finish machining. Still, compared to conventional metalworking techniques, WAAM can reduce tool lead times from months to weeks, helping manufacturers bring products to market faster.

And like other AM technologies, it increases design freedom and offers parts consolidation opportunities. For example, in the same build, WAAM permits conformal cooling/heating channels to be printed and/or integral backing structures that support thin-shell facesheets. Reduced tool mass makes shipping, handling and storage easier, plus, with less mass to heat/cool, autoclave cycles can be shortened.

For aerospace tooling, mild steels are favored when molding fiberglass-reinforced prepreg, while Invar is favored for carbon fiber-reinforced prepreg, owing to the desire to match tool and part coefficients of thermal expansion (CTE) to avoid breaking parts during demolding, or creating die-lock/trap conditions in overhang areas. WAAM is best suited for low-volume production of large structures measured in meters and hundreds of kilograms with complex geometries that would be challenging to achieve conventionally.

A good example is a tool designed, printed and tested during »

	Target GD&T	Actual Measurement
Profile Tolerance	0.51 mm	-0.10/+0.15 mm
True Position Hole Location	0.51 mm	0.02 mm/0.09 mm
Vacuum Integrity (pressure loss)	0.5 inHg/10 min	0.2 inHg

CHART 1 Winglet tool results

The first winglet tool produced in the study passed GA-ASI's initial assessments. It was vacuum tight, had a uniform thermal survey and met/exceeded all target GD&T requirements. Data provided by General Atomics Aeronautical Systems Inc.

a development project between General Atomics Aeronautical Systems Inc. (GA-ASI, Poway, Calif., U.S.), a global company in unmanned aircraft systems (UAS), and Lincoln Electric.

"We've developed an additive manufacturing ecosystem around DED technologies over the last few years after looking at several available large-scale metal deposition modalities for lamination tooling applications," explains Steve Fournier, GA-ASI senior manager – Additive Design & Manufacturing Center of Excellence. "We sought a technology that allowed us to deposit metal as fast as possible while producing dimensionally precise features repeatedly in a vacuum-tight option capable of withstanding repeated autoclave cycles up to 350°F [177°C]. Among its potential uses, we're especially interested in exploring steel and Invar lamination tools because of the cost and lead time challenges we routinely face with traditionally produced similar tools."

The part selected for the study was an L-shaped, 2.7- x 1.4-meter fiberglass-reinforced epoxy prepreg winglet, which is mounted at the tip of each 12-meter wing on the MQ-9B *SkyGuardian*/*SeaGuardian* remotely piloted aircraft (RPA), which is used for activities like search and rescue, law and border enforcement and aerial surveillance, yet is compliant with civil airspace requirements. The winglets greatly reduce vortex-induced turbulence and drag generated at wing tips, helping the RPA fly for up to 40 hours while carrying a payload of up to 2,155 kilograms.

The winglet tool was a good test case owing to its size and severe curvature in several axes, which made it challenging to produce conventionally either in metal or carbon fiber-reinforced composites. The tool also features a return flange with compound curves that is mechanically fastened to the tool body to control joint dimensions during layup and cure, but is removed prior to demolding to facilitate part removal.

Once printed, machined to tolerance, assembled and inspected by Lincoln, GA-ASI put the tool through its paces. In addition to visual inspection and geometric dimensioning and tolerancing (GD&T) inspection via laser scanning, the team looked at moisture pickup on the material, CTE characteristics, tool release, porosity and vacuum integrity, and thermal

■ Large-scale metal deposition

An interesting feature on the WAAM winglet tool is a removable return flange with compound curves that is mechanically attached to the tool body during layup and autoclave cure to control joint dimensions but is removed prior to demolding to assist with part removal. Produced as a separate print without the need for a support structure, the flange, like the tool body itself, featured 9.5 millimeters of overbuild material for machine stock. The main body and flange were match drilled to control dimensional accuracy.

Source | Lincoln Electric Co.

behavior. Next, GA-ASI subjected it to durability/thermal cycle testing. This involved a large number of iterative cycles running the tool through the autoclave alone, laying up and curing a winglet composite part, then inspecting both tool and part.

Although the tool is still completing qualification, it has so far demonstrated preliminary success in reaching production-level use for GA-ASI's manufacturing operations. Furthermore, the company reports cost savings on the order of 30-40% and lead time savings of 20-30% versus conventional manufacturing.

"We're expanding our use of DED tooling for production-level applications across multiple UAS platforms and we feel that DED is absolutely part of our tooling solution portfolio," adds Fournier. "However, it's important to understand that not all DED tools present the same cost benefits, so you have to find the right tool — those with challenging facesheet geometries with features like large curvatures that are difficult to form or weld conventionally — to build a good business case. Our industry would really benefit from strengthening its DED tool manufacturing supply chain."

"It's important to stress that our two companies did a lot of upfront work to determine the best design and manufacturing approaches for the winglet tool to minimize manufacturing costs," adds Mike Wangelin, Lincoln Electric Additive Solutions business development manager. "As Steve notes, not every tool brings the same cost benefit. You definitely have to balance size and complexity against the difficulty of machining that shape out of a billet or forming it out of plate stock — especially these days with all the supply chain issues and cost increases on just about everything."

Production ready: Additive friction stir deposition

Another large-format metal AM process that is being evaluated in several industries was developed by Aeroprobe Corp. and spun off as a wholly owned subsidiary in 2018 as Meld Manufacturing Corp. (Christiansburg, Va., U.S.). »

■ Coating, joining, repairing

The AFSD process can apply coatings on metals or repair high-value metal parts that otherwise can't be welded conventionally. Here, it's being used to repair corrosion/pitting on a nickel/aluminum/bronze (NAB) propellor blade.

Source | Meld Manufacturing Corp.

The multi-patented technology is generically described as additive friction stir deposition (AFSD), although Meld says it isn't based on friction stir welding as the name seems to suggest. Still, both are solid-state joining processes and both rely on heat, pressure and shear generated by friction between a rotating tool and a workpiece to soften and bond two metals.

AFSD plastically deforms 1-2 millimeters (a value that is adjustable) of both the workpiece and the material being added and "stirs" them together, creating an isotropic, monolithic structure with select properties better than and grain structures finer than the parent materials. Unlike welding- or melt-based printing processes, it doesn't induce high internal stresses in the workpiece. As a result, the process can do many interesting things.

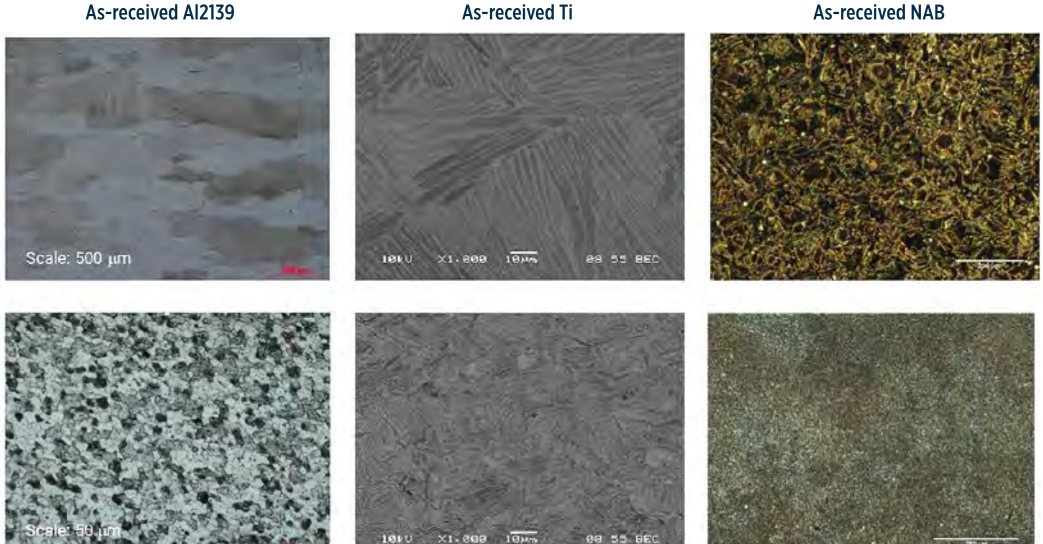
Not only can it be used to additively manufacture parts and tools, but it also can coat, join and repair nearly any metal or MMC — even alloys like 7075 aluminum, which can't be melt processed, 6061 aluminum, which can't be printed with any other process and AZ91 magnesium, which can't be fusion welded. It can repair valuable parts that can't otherwise be fixed because welding would distort them. AFSD is essentially metal agnostic. It also can be used to create novel alloys that would be difficult to combine in conventional alloying processes. The main constraint is that both materials must have relatively similar melt temperatures and CTEs. The input material for Meld's printers is bar stock, although powder feeders can be added. However, unlike PBF-type processes, it doesn't require micron-scale powders or protective enclosures.

Another interesting feature is AFSD's rapid deposition rates. To date, rates as high as 13.6 kilograms/hour for aluminum; 4.9 kilograms/hour for steel; 7 kilograms/hour for titanium; and 0.7 kilograms/hour for nickel have been demonstrated. Aeroprobe and Meld CEO Nanci Hardwick says the deposition rate differences are more a function of which materials the company has spent the most time working with, rather than something inherent to the metals themselves. These high deposition rates are of interest to many aerospace, naval and defense companies that have been hard hit by supply chain disruptions, which have delayed critical forgings and castings. With AFSD, it may be faster to print a part than wait for it to be cast or forged and shipped.

Still another feature that makes AFSD interesting is that the process requires less energy and operates at lower temperatures than other metal AM printing processes and it does so in an open atmosphere — no vacuum, no nitrogen blanketing, no protective enclosure — which means its build envelope is only limited by the height of the pedestal or the size of the gantry on which the machine head is mounted. While Meld offers four standard printer sizes, it builds custom-size units as well. In fact, the company recently won a U.S. Army competition to build the world's largest metal additive printer capable of producing a part that is 6.1 x 9.1 x 3.7 meters — large enough to print a mold or sections of a mold.

"If anyone is interested in bringing tool production in-house,

As-received Al2139 | As-received Ti | As-received NAB

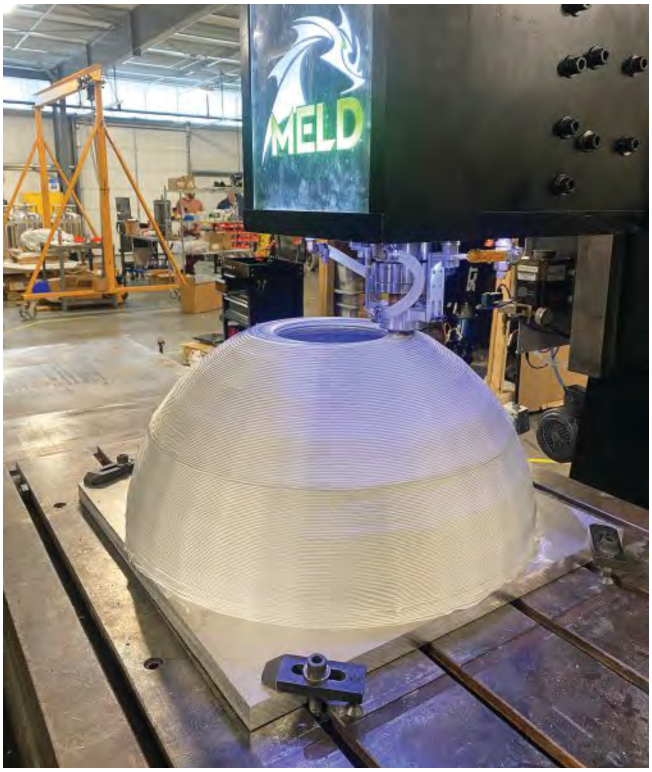


As-deposited Melded Al2139 | As-deposited Melded Ti | As-deposited Melded NAB

■ AFSD material properties

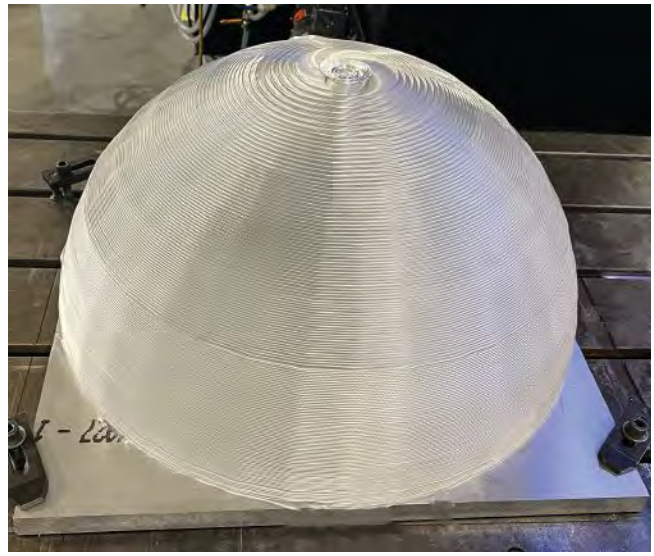
Metal parts from Meld's AFSD process typically demonstrate grain sizes 1-2 orders of magnitude smaller and more isotropic than the parent material, which leads to parts with higher strength, and better corrosion and wear resistance than the starting material.

Source | Meld Manufacturing Corp.



■ **Surpassing conventional additive manufacturing processes**

On the left is a 61-centimeter-tall hemisphere with a 61-centimeter-diameter base and wall thickness of 3.8 centimeters being printed in 6061 aluminum alloy — a material that cannot be printed in any other metal additive process. Below is the completed part prior to CNC machining. Source | Meld Manufacturing Corp.



it's extremely easy to do with our machine and process," adds Hardwick. "Our printer basically functions like a CNC machine except it puts metal back on a part rather than removing it. The printer runs on G-code and looks a lot like a mill. It's a very approachable process that doesn't require hazmat suits, special labs and a tech with a Ph.D. to run the equipment."

AFSD produces near-net-shape parts that are fully dense and, unlike welding-based processes, it doesn't induce high stresses in the workpiece that need to be post-print stress relieved. The company says it can go straight from printing to machining. Like other LFAM processes, it produces a bumpy/striated surface that needs to be cleaned up with CNC machining to create desirable finishes. Machine shops report that AFSD-printed parts machine the same as the parent material. Interestingly, not only does it not induce high stresses, but AFSD also changes the starting material's grain structure.

Meld already has machines in the field at universities and research centers in several countries as well as in companies in the aerospace, defense and marine markets. Most groups are using them for repair work or to print metallic parts, although interest in tooling is starting to grow. In fact, Hardwick reports that Meld has received inquiries about using AFSD to print tooling and then add a harder surface coating for applications with very high production rates, like automotive.

"It's important to note that the Meld process is best suited for quickly producing big parts with fairly basic geometries," adds Hardwick. "Fine detail is best achieved during finish machining rather than printing."

One interesting tooling study that Meld has participated in with researchers at University of Dayton Research Institute (UDRI, Dayton, Ohio, U.S.) involved a large, printed 6061 aluminum mold used to autoclave cure a fiberglass-reinforced laminate part.

"The Meld process was selected because the size and depth of the tooling cavity would have required an unacceptable amount of machining time if done conventionally," recalls Scott Huelskamp, P.E., UDRI senior composites engineer, team lead – advanced manufacturing process development, Structural Materials Division. "The Meld tool required only a final CNC machining pass after printing and gave us a tool that — aside from its initial bumpy surfaces — was otherwise nearly indistinguishable from one that had been machined from a billet of aluminum. To date, we've molded two parts on that tool and haven't seen any porosity issues or undue movement in the tool."

CW's coverage of metal AM tooling opportunities will continue in the February 2023 issue. CW

LEARN MORE

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Plant tour: Avel Robotics, Lorient, France

From AFP hydrofoils to more efficient aircraft parts, Avel uses digital design, multiprocess production and a rule-breaking approach for complex 4D composites.

By Ginger Gardiner / Senior Technical Editor

» Avel Robotics is located in Lorient, the epicenter of France's "Bretagne Sailing Valley." It is home to an ecosystem of at least 50 companies that support the all-composite vessels that compete in offshore racing, including a unique concentration of composites-savvy naval designers and fabricators. Lorient has become "home base" for skippers, teams and their high-performance yachts for competitions such as the Route du Rhum, Transat Jaques Vabre, Americas Cup, Vendée Globe and Jules Verne trophy as well as the myriad races for classes such as Ultim, Figaro, Mini 6.50 and Class40.

Perhaps the most well-known class is IMOCA (International Monohull Open Class Association), comprising 18.28-meter-long monohulls. This class, says vendeeglobe.org, "sees the 60-foot yachts as innovation-oriented laboratories that can help find new solutions for the nautical industry."

Indeed, this is how Avel was born. Luc Talbourdet, president of Avel Robotics, previously managed an IMOCA team that had decided to invest in carbon fiber-reinforced polymer

Breaking rules, not foils

Avel Robotics has pioneered the use of AFP for increased reliability in complex-shaped and -loaded CFRP hydrofoils, used in offshore racing sailboats such as the new IMOCA-class racer for Boris Herrmann and Team Malizia, *Seaexplorer*, designed for The Ocean Race 2023 and the Vendée Globe 2024.

Source | Avel Robotics © Antoine Louce and © Yann Riou for Team Malizia

(CFRP) hydrofoils in 2016. These appendages can lift boats out of the water to "fly" above the surface — that's 8-10 metric tonnes moving at up to 30 knots/56 kilometers per hour. Daggerboard foils also provide significant sideforce underwater and righting moment to counteract the heeling moment of an IMOCA yacht's massive sails.

"There was a problem, because some of the hand-layup prepreg foils were breaking," notes Talbourdet. Issues included variability in quality and delamination. Adrien Marchandise, co-founder and now Avel's CTO, had been hired by Talbourdet to complete his PhD research on making foils using automated fiber

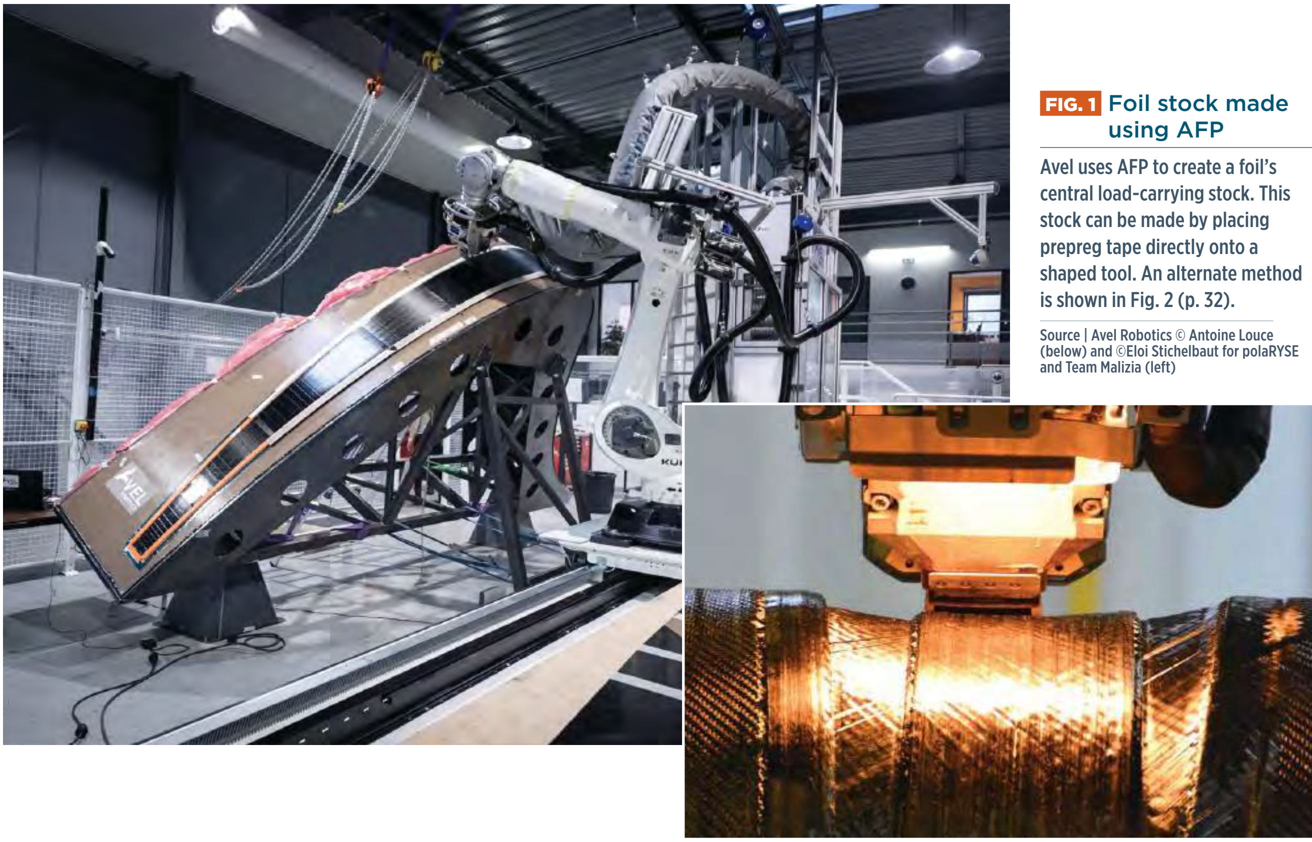


FIG. 1 Foil stock made using AFP

Avel uses AFP to create a foil's central load-carrying stock. This stock can be made by placing prepreg tape directly onto a shaped tool. An alternate method is shown in Fig. 2 (p. 32).

Source | Avel Robotics © Antoine Louce (below) and ©Eloi Stichelbaut for polaRYSE and Team Malizia (left)

placement (AFP). After significant investigation, the two saw a path for more reliable, high-performance foils and Avel Robotics was formed in 2017.

"We were the first to manufacture nautical foils using AFP," says Talbourdet. "It is imperative that foils are reliable, and using robot-based AFP brings both quality and repeatability of the layup. It also reduces layup time and dramatically reduces carbon waste."

Avel Robotics owns two Coriolis Composites (Quéven, France) C1 AFP machines, each applying up to eight tapes with a layup precision of ±0.2 millimeters. The company has progressed from 15-kilogram foils for the first 26-foot catamaran for the Easy To Fly class (ETF26) to its current 300-kilogram foils for top IMOCA skippers such as Boris Herrmann and Samantha Davies. Avel will equip half of the latest generation "foilers" engaged on the next Vendée Globe race — an impressive achievement, the company points out.

Avel has grown to 28 employees and has doubled its turnover to reach €2.7 million in 2022. In five years of production, it has delivered CFRP parts for 57 projects in offshore racing, naval and defense applications, and is now pursuing opportunities in the aircraft industry. ISO 9001 certified since 2018, Avel has completed a test program for one aircraft OEM and is in discussions with a variety of other small to medium aircraft companies. "We already make wings for boats," says Talbourdet. "We have the AFP capacity to help companies who can't or don't want to buy their own machines, but more importantly, we have the digital design and complex composites fabrication expertise to truly add value."

> "We've got the skill and tools to make aeronautical parts, and we also have a unique AFP capacity."

Complex 3D design

IMOCA boats can have five appendages total — typically twin rudders, twin daggerboards or hydrofoils on the sides and one keel at the hull bottom. Avel has produced rudders, daggerboards and hydrofoils. The latter are typically larger and have more shape. For IMOCA boats, they can be described as C-shaped and, while sailing, can look a bit like upturned whale fins, albeit very long and thin. They actually have a somewhat S-shape, thanks to a "shaft" section that attaches into the hull and allows the foils to be extended and retracted. The 300-kilogram hydrofoil mentioned above measures 6-8 meters long with a 0.5-meter radius in the curved elbow.

"One pair of hydrofoils takes one month for design and five months to produce," says Marchandise, who leads the tour »

FIG. 2 Stock manufacturing using pre-cured plates

A foil in progress (left) shows a stock with Corecell foam sections being bonded on. Note the foil tip at the right of the photo. This stock is made from curved plates — using AFP layup onto a flat table (above) — which are then autoclave cured, sandwiched with epoxy adhesive in between the plates and autoclaved again to form an integrated stock structure. Source | *CW* (left), Avel Robotics © Antoine Louce (above)

through an initial layup area as we enter Avel's main production hall. "We receive a 3D shape from the designer and then create a structural design using 3D Experience [Dassault Systèmes, Vélizy-Villacoublay, France]." This software platform includes Catia and SolidWorks plus other CAD and CAE tools. "Our design includes many different parts that will be assembled." These include the main load-carrying spine, or stock, foam sections and a trailing edge and leading edge. "We produce all of these different parts using a variety of techniques," says Marchandise. "We then assemble these 3D puzzle pieces." The result is a very complex, highly loaded and weight-optimized hydrodynamic structure.

AFP stocks

"AFP is used mainly for the stock," says Marchandise, "which is the primary structure for the foil." There are two ways these stocks can be made. One is to place the unidirectional (UD) prepreg tapes onto a curved mold (Fig. 1, p. 31) and then cure them in an autoclave.

Alternatively, the stock can be built as a series of precured curved plates that are then bonded with epoxy adhesive and cured again in Avel's 2.3- x 5.4-meter Daxen (Malissard, France) autoclave to form a bonded assembly (Fig. 2). One advantage of this method, notes Marchandise, is that the plates are made on a layup table, which avoids the time and cost of building a tool.

As Marchandise explains this second technique, we walk past just such a series of curved, AFP laminates on a table, prepared for autoclave cure with thermocouple cables extending from the layups. "We AFP onto a flat mold table using tow steering to 'draw' the curved stock plies. The stock width is also not constant but narrows toward the foil tip. We use a variety of fiber orientations, designed to handle the loads in each region." These include 0° plies that follow the longitudinal axis of the foils and 90° cross-plies.

"We also use 45° plies in the curve of the foil to increase delamination resistance from shear forces," says Marchandise. "This is an added value of our design and AFP approach because we have a higher granularity in our ability to tailor the number and orientation of plies at each section. We design each ply, working in cooperation with the naval architect for the foil and the sailing team to achieve the performance desired."

These flat but sinuous stock layups use toughened epoxy prepreg from Hexcel (Stamford, Conn., U.S.) or Toray (Tokyo, Japan) reinforced with intermediate modulus (IM) or high modulus (HM) carbon fiber. Completed layups receive a metal caul plate and are vacuum bagged, followed by autoclave cure at a pressure of 7 bar for 24-72 hours. Cure temperature ranges from 80-180°C depending on prepreg supplier and type. "Laminate thickness drives cycle time due to exotherm," notes Marchandise, adding that five such parts are typically cured in the same autoclave cycle.

Battens, foam and resin-infused skins

The tour has now moved into a tented enclosure inside an adjoining production hall, where a foil is in the process of being constructed (Fig. 2). A completed multi-plate stock can be seen with foam sections adhesively bonded on top and bottom — the foil is on its side, its leading edge facing the floor.

This stock will form the center of the foil's architecture, which is comparable to that of a wind turbine blade. Corecell foam core from Gurit (Wattwil, Switzerland) has been bonded on either side of the stock to help withstand impact from unseen floating objects in the water.

Leading edge and trailing edge inserts will be bonded outside of the foil sections to complete the airfoil-shaped chord. These inserts follow the same curve as the foil and narrow at its tip. They are also made from multiple plates called battens, produced via AFP and autoclave cure (Fig. 3).

"We then stack the battens on top of each other and dry fit them to see if the metrology quality is good enough," says Marchandise. After metrology requirements are met, adhesive is applied to each batten, and the stacks are autoclave cured per the same process as for the multi-plate stock, becoming integrated leading and trailing edge inserts. These triangular prisms taper from the widest battens that mate with the foam sections to the narrowest battens that form the acute outer edges of the leading and trailing edges (Fig. 4). "We then bond these to the foil using epoxy adhesive," says Marchandise.

The result is shown in Fig. 4, the foil on its side and seen from the end that attaches into the hull. A cured batten stack forms the trailing edge insert bonded on top of the light-colored stripe of foam (the foil tip is off to the left, not shown). Beneath the foam is the foil's stock structure, with the leading edge insert bonded at bottom.

The next step is to apply the skin. "We hand layup dry quasi-isotropic plies around the bonded structure and infuse it with epoxy resin from Sicomin [Châteauneuf les Martigues, France]," continues Marchandise. "We can't use prepreg because the foil's chord length will gain two to three millimeters when it cures »

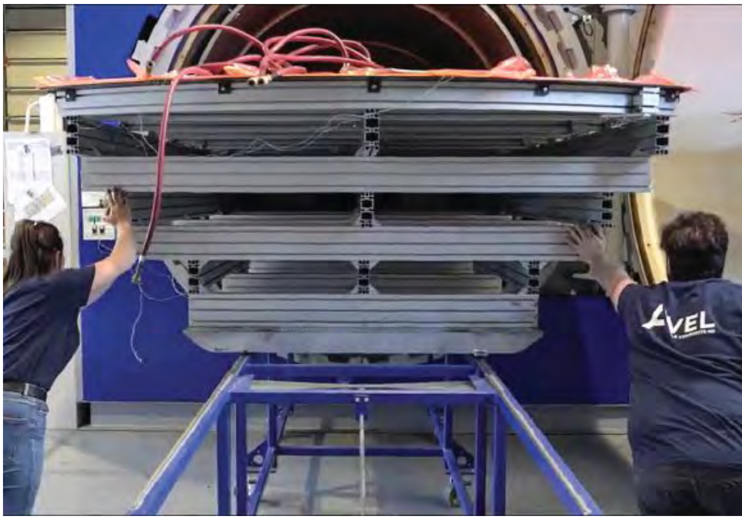


FIG. 3 Autoclaving battens

Spar plates and battens made using AFP on flat tables are shown here being loaded into Avel's autoclave for cure. Source | Avel Robotics © Antoine Louce

FIG. 4 3D CFRP foil

A foil is being finished, shown from the end that will attach into the sailboat hull. Bonded foam and CFRP batten sections that comprise the foil's trailing edge can be seen at top. Source | Avel Robotics © Yann Lhuisset due to thermal expansion. This dilatation of the composite primary structure, which is positive through the thickness, causes spring-back issues in the skins [i.e., deviation in the molded shape due to thermal effects]. To avoid this, all skins are made using wet layup or infusion. To use prepreg, we would need one that cured at 40°C."

Cost vs. performance

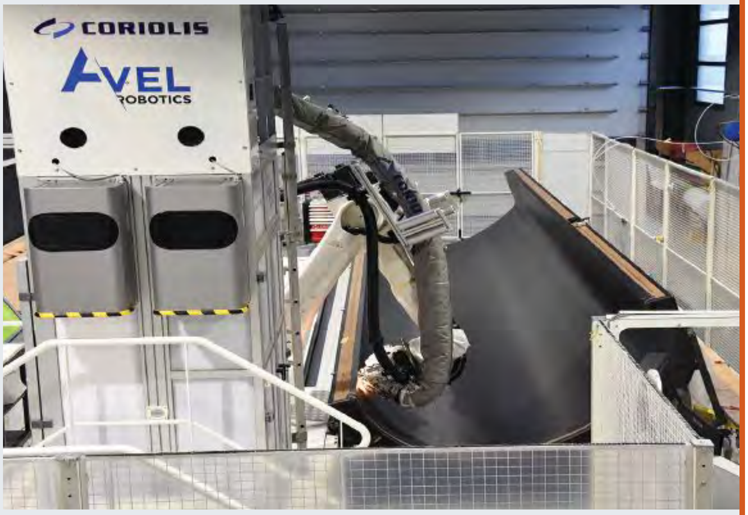
This multipiece, multistep foil construction seems incredibly complex. How is it possible to compete with foils made using only hand layup?

"It is a bit more expensive," says Marchandise, "but we also make much more efficient use of materials. For example, HM carbon fiber is twice the price of IM fiber. We tailor the laminate to use HM fiber only where we need stiffness. This is harder to do in hand layup, where they typically end up with three-fourths of the laminate in HM fiber. Thus, we actually reach the same price with our technology."

"But," he points out, "our structure is much better in strength because it is a truly 3D-optimized structure. The fact that we are using both types of fibers in all the directions gives a

SIDEBAR

Massive AFP mast for next-gen cruise ship



■ 1.2 metric tonnes of CFRP

Avel Robotics produced the 65-millimeter-thick section of a demonstrator mast for the SilenSeas cruise ship concept.

Source | Chantiers d'lAtlantique (left), Avel Robotics © Antoine Louce (right)

The largest structure Avel Robotics has made was for the SilenSeas sailing cruise ship concept developed by the French shipbuilder Chantiers de l'Atlantique (Saint Nazaire). The 200-meter-long cruise ship will have three 80-meter-high CFRP masts that can be tilted at 70° to pass beneath bridges. Each mast will rotate 360° and be equipped with a CFRP solid sail, made from rigid panels that fold like an accordion when lowered. This system, referred to as Solid Sail/AeolDrive, is designed to reduce fuel consumption by 30% versus a conventional ship.

In 2021, Avel Robotics joined a Lorient-based consortium including composite multihull boatbuilder Multiplast, CFRP mast and spar fabricator Lorima, composite mold builder SMM and Avel's neighbor CDK Technologies, which specializes in prototyping novel offshore sailing yachts. The companies collaborated to build one section of the 25-meter-high demonstrator mast, representing just the top section of a SilenSeas rig. The demonstrator, equipped with a 550-square-meter CFRP sail, was installed in 2021 and tested in 2022. The next step will be construction of a full-scale mast and sail.

Avel produced the AFP layup for a 10-meter-long mast section half-shell that weighed 1.2 metric tonnes with a 65-millimeter-thick laminate. "That was the first time we built such a big part," says Talbourdet, "and it was also the biggest part built with a Coriolis C1 machine. We needed some help, actually, because we were beyond the limit of the machine, and we worked with Coriolis to amend the software."

Was the large size a challenge? "I don't think size is ever really a limit," says Talbourdet. "There's always a way with rails and gantries." Avel's C1 machines are based on KUKA (Augsburg, Germany) robots and mounted on rails with a build envelope of 3 x 10 meters. "We have pushed the limits of the C1 machine more in terms of tight radius and complexity of the layup paths," he adds. "We are always pushing limits, but Coriolis has used our feedback and made the machines better."

Where will this project lead? "Neoline [Nantes, France] has placed an order and Chantiers de l'Atlantique is talking to other potential customers," says Talbourdet. "But this project showed that Avel can produce such a large, demanding prototype on time and on budget. So, why wouldn't we do this now for series production?"

performance that we wouldn't be able to achieve using hand layup alone. Our structures are much less susceptible to delamination, so damage tolerance is much higher. And that was the whole goal in the beginning — to have foils that won't fail. For example, if you hit something very hard in the middle of the tip in a typical hand layup structure, the result is delamination, and it will then zipper along the foil. In our construction, any break at the impact point is localized. You just unglue the battens, replace the damage at that location and reassemble the edge insert."

4D composites

Avel Robotics describes the structures it makes as 4D composites. "We must optimize our structures not just for loads in three dimensions, but also over time," explains Loeva Malacarne, business development manager, who joined Avel Robotics in 2021 after 11 years at Safran. "We analyze the performance of our products closely during design, production and in service so that we can get a better lifetime prediction for the composites, which we use to improve our designs and processes going forward."

The tour has now moved back through the production hall and up onto a mezzanine at the far end, where dozens of test coupons (Fig. 5) are stored. The 4D process, says Marchandise, starts with design. "We do coupon tests as well as full-part tests with full-scale loads at the University of Southern Brittany, which is local," he explains. "The coupon tests supply the FEA [finite element analysis] with accurate input data — the goal is to manufacture what you design. For this to be realistic, we manufacture actual subelements and extract coupons from those in order to reflect the manufactured part including AFP, curvature, thermal profiles during cure, etc. This can't be left to others because it's *our* manufacturing process."

"The second testing approach is to use very large coupons to check that the structure behaves the way we want it to behave," continues Marchandise. "In certain load cases, we want compressive strength on the inner surface and we want strain before interlaminar delamination. We use larger scale testing with more representative loads to check this and also the damage mechanisms in the material as manufactured. We also extract coupons from the different parts of the subelement and send their test values to the naval architect for integration into the FEA."

Some of the test samples on Avel's mezzanine are broken and covered in a random paint pattern indicative of digital image correlation (DIC), which captures and analyzes images during testing to produce full-field strain distributions.

Marchandise explains that Avel uses DIC "to check that the strain field looks like what we have on the FEA model. It's more a qualitative check versus quantitative. We use more accurate strain gauge sensors for quantitative results and when we break these subelements, we will have eight acoustic emission sensors to give us a fuller picture of the damage."

Is this testing done for every new design? "Yes," says Marchandise, "but not so much is needed if we're just scaling in size."

At this point in the tour, Talbourdet picks up the discussion. "Now we're implementing static tests of the existing foils to increase our knowledge and get the full loop back into the design and manufacturing process, including digital twins of the structures we make. We have recruited people to do just that through a Bureau Composites department. And this also helps us to stay in partnership with our clients and understand what they will need for the next design." This new department in Avel will also explore bio-sourced materials for its AFP machines.

Flying, from foils to aircraft

The quality built into Avel's structures via its 4D approach has brought success. The company has built 19 pairs of foils since »

FIG. 5 4D composites

These subelement test specimens (including DIC samples, top) are used to provide as-manufactured material data, plus structural and failure data used as input and validation for FEA, improving design accuracy and Avel's ability to predict a part's performance through its service life. Source | *CW*

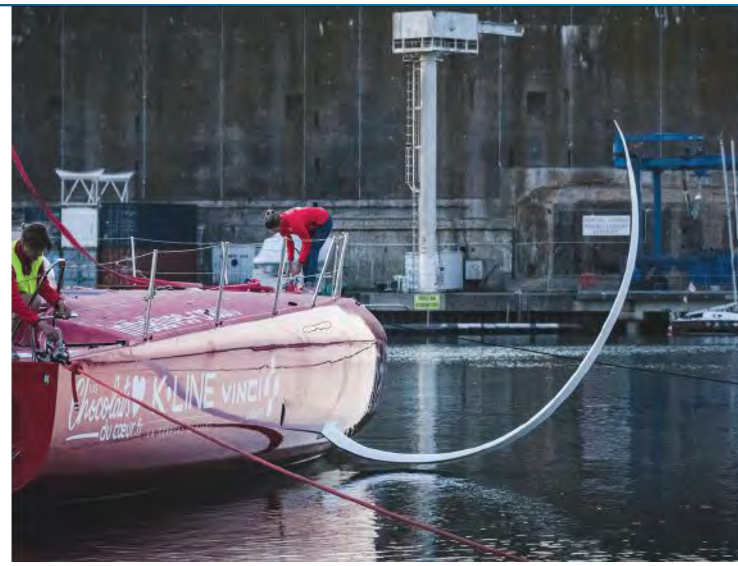


FIG. 6 **Static tests, durable foils**

Static test of an Avel Robotic CFRP foil and subsequent boat launch with that foil installed. Source | Avel Robotics © Antoine Louce

2017 and attracted similarly innovation-focused partners, like the designers Mer Concept (Concarneau, France) and the IMOCA teams L'Occitane and Apivia, the latter placing first or second in six major races since 2019. "The Mer Concept design company started with us in 2018," says Talbourdet. "They saw what they could get from the quality of our parts, and now we have built parts for four boats. If we had not delivered value, that business would not have continued."

The goal now, he says, "is to continue increasing our market share of structural parts for IMOCA, Ultim and other racing boats. We see continued growth in the yachting and naval markets because customers are also looking for a lower CO_2 footprint — Avel Robotics delivers at least a 50% reduction in carbon fiber composite waste compared to traditional hand layup."

Talbourdet acknowledges that Avel must stay in tune with the nautical industry's innovators and their push forward. "But we are also moving forward," he says, "and becoming more efficient in our designs and processing." Indeed, in 2020, the company bought its second AFP machine and reported a significant improvement in layup time. Now Talbourdet believes Avel can offer this quality, reliability and innovation to the aircraft industry.

Why aircraft? "Because we've got the skill and tools to make aeronautical parts," says Talbourdet, "and we also have a unique AFP capacity. And if you look at the market, there are maybe 10 or 15 AFP machines in Europe, but not many companies that will commit to deliver aerospace-quality AFP parts at a fast pace for a set price. There are a lot of Tier 2 suppliers still using manual methods."

Why is Avel's AFP capacity unique? "Because we can produce serial parts, for diverse applications," says Malacarne. "We are not a technical center or a fab lab focused on prototyping. If tomorrow a customer wants 100 identical parts, we'll deliver." This capability also includes expertise in structures that are complex and highly loaded, but may also scale up in size (see sidebar "Massive AFP mast for next-gen cruise ship," p. 34).

"We're targeting small to medium aircraft companies that are moving toward more sustainable aviation and either can't or don't want to invest in AFP robots," he continues. "So, we're filling a gap, but we're also changing how value is delivered. We are building a fully digital chain that doesn't currently exist, even in parts of the aerospace industry."

Talbourdet explains that it is still common, even among some aero-industry companies, "to get data where you don't know how it was built — you don't have one set of files going from the start of the process to the end."

"We are already designing parts for AFP and producing those parts," says Talbourdet. "The companies we are meeting with are very surprised at what we know and the parts we're making and they are very interested." He adds that Avel is seeking to complete a demonstration project with aircraft manufacturer Dassault Aviation (Paris, France) and is in negotiations with some European OEMs for CS-23 airplanes (an EASA certification for certain types of general aviation and commuter aircraft) and next-gen decarbonized aircraft projects.

LEARN MORE

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

If we were normal

In the end, says Talbourdet, this next step forward is the same as what Avel has taken in marine. "When you come with a new solution, people will say it's not realistic, technically feasible or affordable. But we entered the market and succeeded. And now it is the same in the aeronautical industry. I mean, if we were a normal company, we wouldn't do this, because it's more risky than just doing the same thing. But now aviation is asking for innovation and demanding it. To move away from hand layup was a big step and our success was not guaranteed. But we believed in our approach and we are now enabling even further innovation. We understand the process of disruption — you can't go forward if you're staying in place." CW

ABOUT THE AUTHOR

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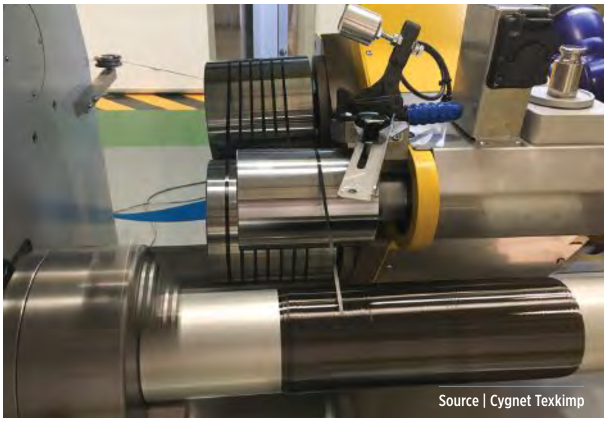
New Products



Source | Cygnet Texkimp

» FIBER WINDING

High-tension fiber winding achieves more accurate, uniform components

Composites technology company **Cygnet Texkimp** (Cheshire, U.K.) has developed a high-tension fiber winding solution to create lightweight rotating parts with greater dimensional stability at higher speeds.

The technology, which has evolved through the company's filament winding capability, has been developed to achieve more power from high-speed rotating machinery by wrapping it in carbon fiber under high tension. This reportedly enables the final part to rotate more quickly without expanding, and means that more power can be achieved from lighter parts. Applications include high-speed motors for automotive, motorsport and aerospace and fly wheels for energy recovery.

The solution can generate up to 2,000 N of tension and wind consistently in excess of 60 m/min and up to 100 m/min, although this is dependent on the type of fiber used, according to the company. Winding at tension enables manufacturers to pack fibers more tightly and uniformly around a mandrel or part, pulling the filaments closer together within the winding pattern. The effect is that the fiber-volume ratio is increased — in this case, to more than 70% — to create a lighter part that achieves maximum strength with minimum thickness.

The technology combines a driven creel system with a sequence of servo-driven rollers to generate and control high levels of force while ensuring minimal damage to the fiber. This is said to be a crucial element of the design and is reminiscent of all Cygnet Texkimp's fiber handling technologies.

An automatic, real-time electronic tension control system is used to monitor and match torque and vary speed, while a purpose-engineered winding head withstands increased force. The carbon tows themselves are an elastic element in the process, adding a further level of complexity for the technology to manage.

The solution is capable of processing single- or multitow carbon, glass or ceramic fibers and can accommodate dry winding, wet winding and thermoplastic or thermoset towpregs. cygnet-texkimp.com

Source | Altair

» DESIGN SIMULATION

Updated simulation portfolio meets lightweighting objectives

Altair (Troy, Mich., U.S.) releases the latest updates to its simulation portfolio Simulation 2022.1. These updates are designed to enable more efficient, innovative products by applying advanced simulation, cloud-based computing and optimization for cleaner, more sustainable product lifecycles. Simulation 2022.1 is meant to help companies meet corporate social responsibility (CSR) objectives, drive design decisions and bring the power of open-source technology to users around the world.

Simulation 2022.1 brings a variety of updates to bolster Altair's sustainable product design capabilities. Updates to Altair Material Data Center, OptiStruct, Multiscale Designer, HyperWorks and SimLab are said to help companies meet lightweighting objectives, design requirements, budget constraints and regulatory requirements. These updates also assist Altair's topology optimization, lightweighting, design certification and high-performance computing (HPC) capabilities, the company notes, enabling users to save resources, scale workloads and reduce project complexity.

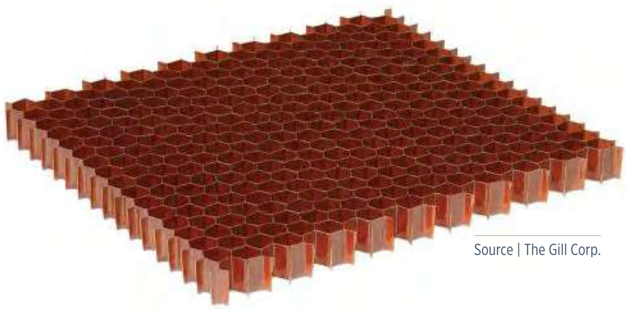
Simulation 2022.1 is also said to help users apply simulation earlier in design lifecycles so they can reduce errors and access tools in a seamless, connected environment. In this update, enhancements were introduced to Altair Inspire for an improved design creation and optimization experience. Altair SimSolid also received updates for more rapid simulation, reviewing design scenarios and parametric modeling upgrades.

Additionally, this update enriches Altair's modeling and visualization capabilities. HyperWorks workflow streamlines the process of building a reduced order model for early conceptual optimization. Simulation 2022.1 lets users simplify models and perform topology optimization with quicker turnaround times, facilitating more design studies. Simulation 2022.1 also strengthens model interpretation with 1D inflation capabilities.

Radioss, employed by global industrial, research and development, and educational organizations to solve complex linear and nonlinear engineering problems, is now available as an open-source solver called OpenRadioss.

Simulation 2022.1 brings more open-source updates as well. Within the new UI Designer toolkit in Inspire, users can assemble designs with predefined objects, modify designs and save designs as a Python code skeleton that can be further developed.

Lastly, the update encourages users to take advantage of Altair Exchange, a collaborative forum where users can use shared spaces for fine-tuning models, finding better scripts, optimizing virtual workspaces and workflows, and more. altair.com



Source | The Gill Corp.

» CORE MATERIALS

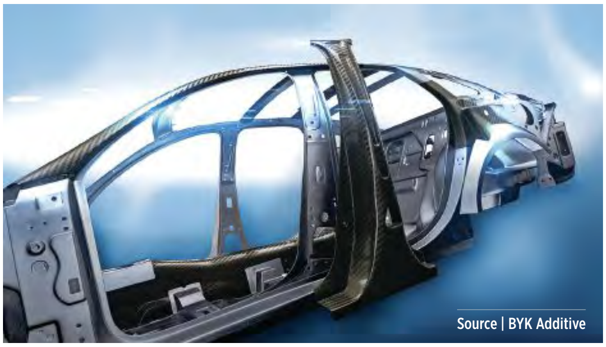
High-temperature fiberglass honeycomb core

The Gill Corp. (TGC, El Monte, Calif., U.S.) announces its new Gillcore HF fiberglass honeycomb core, which, developed in response to industry demand from aerospace customers, meets all AMS 3715 requirements. The core is produced with a substrate consisting of woven fiberglass cloth reinforced with heat-resistant phenolic resin for improved moisture resistance over traditional aramid fiber substrates. TGC says it is suitable for high-temperature applications that require a high degree of forming and high-moisture areas.

TGC processes rolls of fiberglass cloth through the same manufacturing equipment as aramid honeycomb cores. In addition to completing its own AMS 3715 test requirements, the company is working with other customers to meet their own qualifications.

Testing performed includes:

- Plate shear strength and modulus, ribbon and transverse
- Stabilized compression strength and modulus
- Flatwise tension
- 65F, RTA, 180F, 250F, 350F
- Wet – RTA, 180F, 250F, 350F. **thegillcorp.com**



Source | BYK Additive

» SPECIALTY ADDITIVE

Polyamide-applicable additive for lightweight construction applications

BYK Additives (Wesel, Germany) is launching BYK-Max CT 4275, a novel, specially developed additive that can be used in a wide variety of polyamides. The optimized surface treatment and distinctive morphology of the silicate provides improved dispersion and incorporation into the thermoplastic matrix while ensuring reportedly near-perfect exfoliation in polar systems, according to the company.

The additive's high reinforcing mechanism improves, among other things, flexural modulus, yield strength, tensile strength and heat deflection temperature, while ensuring improved flow behavior of the composite. This makes it possible to form thinner components and thereby reduce weight, BYK Additives notes.

In mineral and glass fiber-filled thermoplastic composites, the additive enables a lower total content of mineral and glass fibers without comprising mechanical properties; it is said to be the ideal solution for lightweight construction applications. In addition, BYK-Max CT 4275 also exhibits a positive effect on surface properties, scratch resistance and flow behavior. The additive is miscible and requires no special processing steps. **byk.com/en**

» COMPOSITE REPAIR, FILLER MATERIALS

UV-curable repair and filler resin

Applied Molecules LLC (Dexter, Mich., U.S.), a manufacturer of UV-curable adhesives and sealants, has launched the AJ13 Series of UV-curable composite repair and filler materials. Delivered in an easy-dispense bottle, AJ13 can be applied directly to a composite sandwich or laminate edge to provide a seal against water and other fluid ingress. AJ13 can also be applied to repair small defects in finished composite parts.

Applied Molecules CEO Paul Snowwhite says AJ13 conveys two significant advantages in composites-related applications: First, because it's UV-curable, it can be quickly applied and cross-linked in just seconds with any UV light source. Second, AJ13's chemistry — based on acrylic, urethane and epoxy — is highly tunable and can be modified to match the CTE of the base resin in the composite part to which it is being applied.

Snowwhite also reports that AJ13 can be applied in repair applications without the use of a fiber reinforcement patch, as is common for traditional composites repair. He adds that the largest damage AJ13 has repaired was about 1" diameter. Further, AJ13 can be sanded and painted immediately after cure and has been used by customers to seal or repair SMC, carbon fiber and other composite parts.

Source | Applied Molecules

David Whitinger, business development at Applied Molecules, says AJ13 has been tested and qualified by four suppliers in the automotive supply chain and one manufacturer of composite structures for the marine industry. The company is working on new versions of AJ13, including one that will change color when fully cross-linked to help the user know when cure is complete. **appliedmolecules.com**

CFRP tubes enable lightweight advanced fuel-sensing gauges

Liquid Measurement Systems' carbon fiber composite-based capacitance probes provide durable, corrosion-resistant fuel gauging for a variety of aircraft, including a newly launched onboard processing probe (OPP).

Source (all images) | Liquid Measurement Systems

Founded in 1989, Liquid Measurement Systems (LMS, Fairfax, Vt., U.S.) designs and manufactures fuel quantity gauging on rotary- and fixed-wing aircraft. Among the company's product offerings are a range of capacitance fuel gauging probes, which each feature two concentric carbon fiber composite tubes that act as two conductive plates with dielectric current running in between.

A conventional capacitance fuel gauging system consists of two pieces of hardware connected by wires: a sensor (also called a probe) and a signal conditioning unit (SCU). "The probes are passive devices which are excited and measured by an SCU to monitor and report fuel height in the tank. The SCU conditions the signals coming from all of the probes in the tank(s) and factors in probe location, tank geometry, attitude [orientation of the aircraft], fuel temperature and other variables, to calculate the total quantity of fuel in the tank — expressed in weight rather than volume," explains Steve Pickering, director of technology at LMS. Embedded software in the SCU converts all of the data received into a value for pounds of fuel in each tank and transmits this information to a display unit in the cockpit or on a refueling panel.

LMS has been using carbon fiber-reinforced polymer (CFRP) composites for the main structural components on its fuel gauging probes since its founding in 1989, despite aluminum being the conventional material. The company fabricates all of its fuel gauge tubes on site using a roll-wrapping process, in which layers of prepreg are rolled and taped by hand onto a mandrel and oven cured. The tubes are then untaped, cut to length and machined to a uniform diameter and wall thickness prior to assembly. For these tubes, LMS says it chose carbon fiber prepreg with a proprietary resin system for its mechanical and electrical performance properties, as well as its resistance to the corrosive and oxidative effects of jet fuel.

Compared to aluminum, use of carbon fiber composites for these parts amounts to a 40% lighter part, LMS says. Plus, composites are resistant to dents, scratches, cracks and corrosion, and don't absorb hand oils, which can affect performance. Aluminum tubes also require riveted connections to the probe's electrical components, which can wear over time due to friction, whereas the composite tube is bonded to the electrical components.

LMS' carbon fiber fuel gauging probes offer options that are adaptable to a range of aircraft tanks. Most recently, the company decided to develop a product specifically catered to small aircraft, aiming for higher safety, more accuracy and higher reliability within a small tank.

The resulting onboard processing probe (OPP) was launched in summer 2022. Featuring the same carbon fiber composite two-tube design as LMS' other offerings, the OPP is an all-in-one system that combines a level-sensing probe with an SCU, eliminating the need for two pieces of hardware or complex wiring. The system is designed to act independently in a single-tank aircraft with simple tank geometry or work as one of several independent units gauging fuel quantity in one or more tanks, each unit returning its respective fuel quantity to the specified aircraft data destination. CW

MANUFACTURING SUPPLIERS

SHOWCASE

Showing off multi-material joining, natural fiber composites

With three iterations in development and poised to go on the market, KTM Technologies' new motorcycle brake disc covers demonstrate potential for its Conexus joining technology to combine thermoset parts with thermoplastics.

Source (all images) | KTM Technologies

Thermoset-thermoplastic joining, natural fibers enable sustainability-focused brake cover

Award-winning motorcycle brake disc cover showcases potential for KTM Technologies' Conexus joining technology and flax fiber composites.

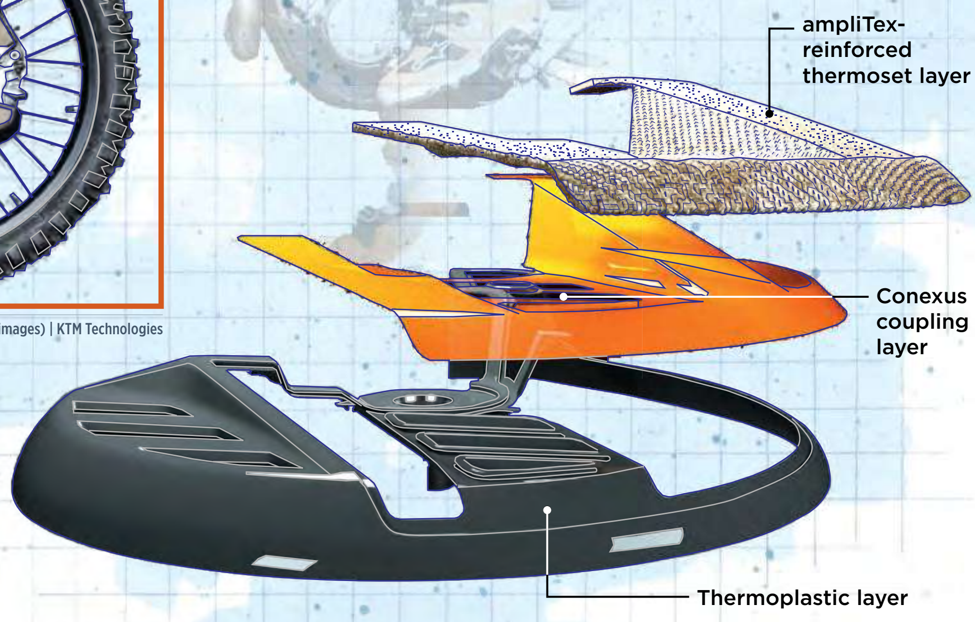
By Hannah Mason / Technical Editor

» "Sustainability" was the official theme of the JEC World 2022 exhibition in Paris, France. One project that exemplified this theme, and that took home the 2022 JEC Innovation Award in the Sports, Leisure and Recreation category, is a motorcycle brake disc cover that aims to demonstrate three sustainability-focused technologies in one part.

The cover, a circular panel designed to mount to the wheels of a racing motorcycle to protect the brake system from debris or impact, was entered into the competition by flax fiber supplier Bcomp Ltd. (Fribourg, Switzerland) and built by KTM Technologies (Salzburg, Austria), the R&D and innovation unit of motorcycle manufacturer KTM AG (Mattighofen, Austria).

The part combines three technologies: a compression-molded flax fiber/epoxy base structure, an injection overmolded thermoplastic outer layer and an innovative technology to join the two layers together without the use of adhesives.

Source (original images) | KTM Technologies



DESIGN RESULTS **Multi-material natural fiber-based brake cover**

- Flax fiber-reinforced thermoset base layer adds stiffness and impact resistance.
- Overmolded thermoplastic outer layer adds functionality fitted with metal bike inserts.
- Molded-in coupling layer technology joins the materials without bonding or fasteners.

Susan Kraus / Illustration

Stefan von Czarnecki, director of sales and business development at KTM Technologies, explains that the entire company is emphasizing sustainability initiatives, including manufacturing, part design and end-of-life (EOL) solutions, starting with R&D initiatives designed to qualify and evaluate opportunities for series production. One of these initiatives was the creation of an innovative joining technology called Conexus, which the award-winning brake cover demonstrates.

Conexus: Adhesive-free, multi-material joining solution

Thermoset composite parts — in motorsports and many other end markets — are often combined with parts made of other materials, such as unreinforced plastic or metal. Multi-material joining with thermoset composites generally involves either mechanical fasteners, which add weight to the part, or adhesives. In addition to adding weight, the latter includes chemicals that are generally not considered to be sustainable, and often requires pre-treatment and challenging process and quality control imposed by stringent nondestructive testing standards.

KTM Technologies sought a joining solution that would avoid the use of fasteners *and* adhesives. The basis of the Conexus technology that KTM ultimately developed over the past few years is a thermoplastic film — called a "coupling layer" — that can be added to a traditional thermoset composite layup in a curing process, such as, in this case, prepreg compression molding. During the cure process, the Conexus layer bonds to the thermoset composite part, acting as a chemical release agent *and* serving as an outer, unreinforced thermoplastic layer onto which the thermoplastic material can be directly joined. "You can then *functionalize* the part by injection molding, 3D printing or welding," explains Michael Heider, lead engineer at KTM Technologies. Conexus can also be used with a variety of resin and fiber types.

The brake cover: Carbon fiber first

The brake disc cover project originated as a way to demonstrate the Conexus technology, and is in serial production at KTM as a carbon fiber/epoxy version that features a metal insert directly joined to a thermoplastic component via injection molding. Based on this serial part and the processes and tools used to manufacture »

Testing material samples

Before proving out its technology on its brake disc covers, KTM started with coupon-level testing of Conexus on a range of fibers and plastic part combinations.

Conexus layering

Conexus technology was developed to be a thermoplastic coupling layer in between a molded thermoset component and a thermoplastic material, integrated via 3D printing or injection overmolding.

it, the more sustainable flax fiber/epoxy demonstrator presented at JEC World was manufactured.

Heider explains: "We were looking for a semi-structural part to showcase the feasibility that the connection is working on the same level as a structural adhesive. The brake cover was chosen because it's a very visible part on the motorcycle."

KTM's industrial design department began with technical specifications for one of the company's standard brake disc covers. Generally, these covers are made from metal or injection molded plastic, and include several holes to allow airflow to the brake disc underneath. Metal inserts fit into the bottom of the cover to enable the cover to mount and latch to the bike.

With the new design, the goal was to develop a part with three layers. The top outer layer would be an epoxy thermoset-based composite to increase the overall impact resistance and stiffness of the part, and a bottom layer would be unreinforced thermoplastic that would be fitted with the metal insert, with the Conexus coupling layer in between joining the two halves together, acting as the third layer. The thermoset and thermoplastic layers ultimately overlap slightly — "but this isn't for connecting," Heider explains. The overlap protects the edges from moisture and wear over time.

> "We don't need a gluing step, or rivets or bolting or screwing. Directly out of the process we have a part."

The design team began with CAD files of the existing design and used digital simulation to design a new part, with the goal of incorporating the right materials in the right place. Additional simulations were performed to help avoid warping and assure good filling and temperature distribution for the coupling layer during the injection molding process.

"Design for manufacture was key," Heider notes. To be able to serially produce the covers, the manufacturing process had to be relatively fast, with part costs as low as possible. "We knew we wanted to produce an attractive optical part and give visibility to the hybrid construction, but we also needed a part that can be produced using known and approved processes, to give us the opportunity to make parts very quickly and efficiently," he explains.

For speed, compression molding was chosen for the thermoset part, and injection molding for the thermoplastic part. "We designed the process for easy processability and low scrap," Heider adds.

The original design of the cover involved a compression molded, carbon fiber/epoxy top layer joined via Conexus to an injection molded bottom layer made from a blend of polyamide 6 (PA6) and acrylonitrile butadiene styrene (ABS) from INEOS Styrolution (Frankfurt, Germany). KTM Technologies developed tooling for the thermoset part with partner Alba Tooling & Engineering GmbH (Forstau, Austria), and for the injection molding tool with Altendorfer Kunststofftechnik GmbH (Neureichenau, Germany).

First, the thermoset composite layer is formed via compression molding. During layup, a single layer of the Conexus film, about 100 microns thick in the final part after processing, is applied as the bottom layer in the mold. The Conexus layer uses a copolymer that works with the selected thermoplastic and thermoset — in this case, epoxy and polyamide — to join them together. Additionally, the Conexus layer acts as a release film in the tool. The carbon fiber fabric is then added on top, and subsequent molding at 150°C (302°F) creates a bond between the thermoset and Conexus layer. After molding, the part and a central metal insert are transferred to an injection molding station, where the PA6/ABS layer is injection overmolded directly onto the Conexus film, creating an additional bond between the coupling layer and thermoplastic.

First iteration: Carbon fiber/epoxy

The initial carbon fiber/epoxy brake disc cover successfully proved out the technology for end-use parts. From there, KTM Technologies went back to the drawing board to use even more sustainable materials.

Second iteration: Flax fiber/epoxy

For its second iteration of the brake disc cover, which won a JEC Innovation Award in 2022, KTM Technologies swapped carbon fiber for Bcomp flax fiber/epoxy.

"We don't need a gluing step, or rivets or bolting or screwing. Directly out of the injection molding process we have a part that we can directly mount to the motorcycle," Heider says.

A more sustainable, flax fiber version

The carbon fiber version of the cover was a successful demonstrator of the Conexus technology, Heider says, but "one of our goals is to reduce the overall carbon footprint of our components, so we thought next about how to make a more sustainable version. As a first step, we decided to replace the carbon fibers since it was the material with the highest CO_2 footprint."

KTM had worked with flax fiber supplier Bcomp on motorsports projects in the past, so a trial version of the cover using Bcomp materials felt like an obvious next step.

First, the two companies went back to the drawing board to perform coupon-level testing on an identical version of the carbon fiber/epoxy component, this time using Bcomp's ampliTex 5040 300-gsm twill flax fabric combined with epoxy and a Conexus layer via compression molding. Again, this was followed by an injection overmolded PA6 bottom layer. A series of tests were performed to prove that the flax fiber was compatible with the Conexus technology and that the combined parts would stay joined over time and in a variety of conditions. Heider notes that although the overall mechanical performance of the flax fiber is lower than that of carbon fiber, the material offers advantages like improved damping behavior. Further, it does not splinter when broken, which increases safety.

Once validated at the coupon level, the same tooling and part design as the original carbon fiber cover were used to manufacture new demonstrator covers.

For the carbon fiber-reinforced polymer (CFRP) and flax fiber covers, KTM Technologies ultimately demonstrated the technology on in-house specimen- and part-level tests to prove adhesion for the »

Production-ready

KTM Technologies plans to produce its carbon fiber and flax fiber composite brake disc covers commercially. Beyond motorsports, the company plans to use its now-proven Conexus technology for automotive and even urban air mobility (UAM) applications in the future.

Third iteration: Flax fiber/bio-resin

Aiming to continue making its product more sustainable, the KTM Technologies team most recently developed a cover that replaces the thermoplastic with a bio-based version.

joined parts, impact resistance, UV resistance and more, according to the company's internal quality standards. "Our parts go directly onto the motorcycle where they're tested by actual riders," Heider says. "We do mechanical tests on the component separately, then test real-world performance on the motorcycle."

Real-world testing is key, von Czarnecki notes. "You can predict or simulate a lot of scenarios but there are a range of situations — impacts, weather events, stone chipping — that you can't guess."

According to Heider, the materials' CO_2 footprint is reduced up to 60% by switching to flax fiber from carbon fiber. "We wanted to show that we can use our Conexus technology to produce aesthetic and performance parts on the one hand, and to be able to fulfill sustainability targets on the other hand. By using established manufacturing methods where we can easily implement other fibers or thermoplastic materials, we have an innovative joining technology ready for the market, which can adapt easily to the needs of every customer without the necessity to invest in additional machinery," Heider says.

Next: Flax fiber *and* bio-based resin

The JEC Award-winning flax fiber/epoxy part was only the first step toward demonstrating the use of sustainable materials for brake disc covers. In October 2022, KTM Technologies was awarded an SPE (Society of Plastics Engineers) Automotive Award in the "Body Exteriors" category for a new version of the cover that uses flax fiber in combination with a bio-based, glass-filled polyamide.

For this part, KTM Technologies partnered with Akro-Plastic GmbH (Niederzissen, Germany), a company that specializes in plastic compounds and that recently introduced a product line of bio-based thermoplastics. Again, the teams began by testing materials at the coupon level, and for the SPE-presented part, decided to demonstrate the brake disc cover using Akro-Plastic's Akromid Next 5.10 3 GF 30 glass fiber-filled PA6, chosen for its high bio-based content and higher mechanical properties due to the additional glass fiber. This version of the brake disc cover is said to enable up to 70% CO_2 reduction for the materials compared to the series model.

Of the overall process, von Czarnecki says, "We start our parts basically as a demonstrator as a first step, then to small series application, then to higher volumes. This is how we enable and qualify new technologies for the company and then scale it up."

The carbon fiber version of the brake disc cover is now available for the aftermarket and will be equipped on some special edition motorcycles beginning in 2023. About 5,000 CFRP covers will be produced annually for KTM's MX and enduro full-size models, Heider says. The company says the natural fiber cover may be introduced into KTM's PowerParts portfolio as an aftermarket option once tests are completed.

"The strategy driving the whole process on our side was to enable us to use these materials together, and to use each material for what it does best," von Czarnecki explains. "That is, to use the thermoset for the mechanical properties where they were needed, and where the customer can see it to really appreciate [the flax fiber], and to use thermoplastic for functions such as ribs and integration of inserts, and by this we achieve the most cost-efficient design."

End of life: Recycling vs. energy recuperation

In addition to demonstrating natural fiber materials, thanks to the Conexus coupling layer, the flax fiber composite cover "has a drastically reduced global warming potential, and a very nice end-of-life scenario compared to the carbon fiber version," Heider says.

The Conexus coupling layer is designed to have a *lower* melting temperature than the thermoplastic part in a given application, he explains. At the part's EOL, if heat is introduced at the coupling layer's melting temperature, the Conexus layer will melt and allow the thermoset and thermoplastic parts to be easily separated without damaging or melting either part.

In this case, the thermoplastic component could then be melted and reformed for additional use, while the flax fiber component would ideally be pyrolyzed, with the energy recaptured for another use such as cement kiln coprocessing or waste-to-energy cogeneration plants.

Why not recycle or repurpose the flax fiber thermoset component? Johann Wacht, manager of motorsports and supercars at Bcomp, explains, "With recycling, you need to think about your base materials." He claims that the company's flax fiber materials are produced as CO_2-negative materials, whereas any of today's recycling methods would *consume* energy and result in a *larger* overall carbon footprint. "In this case, simply recovering energy from the natural fiber and epoxy [at the part's EOL] is the better solution, because you can recuperate 80% of the energy stored in the material. It makes a lot of sense from a CO_2 footprint perspective."

However, with the *carbon fiber* version of the brake disc cover, "it's another game," Wacht says, "because carbon fiber is very energy-intensive to produce. Carbon fiber makes absolute sense to recycle." Depending on the specific recycling method, the energy consumption that goes into recycling carbon fiber generally still results in a lower overall carbon footprint for the material, he notes.

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Heider notes that the Conexus technology both assures a strong chemical bond between the thermoplastic and thermoset materials involved, and, because it is thermoplastic-based, enables separation at the correct temperature.

Future applications: Urban air mobility and more

The brake disc cover project, and motorsports in general, is only the first step for Conexus technology, says von Czarnecki. "This enables the possibility to combine materials without bonding, increasing sustainability and reducing complexity in the process. It is offering a whole new range of applications."

Currently, KTM Technologies is investigating several racing motorsports projects and exterior automotive non-structural parts using the Conexus technology. In addition, as demonstrated in a joint research project with Airbus' Composite Technology Center (CTC, Stade, Germany), which focused on the use of Conexus technology with ultrasonic welding, one goal for Conexus is to enable smart and efficient manufacturing in emerging industries such as advanced air mobility (AAM).

Von Czarnecki emphasizes that the process and technology haven't only been designed for use by KTM: "Our strategy is to qualify the technology and de-risk it for ourselves, and then enable our production partners to use it in other industries."

This project also demonstrated natural fiber composites as a good fit for Conexus. Von Czarnecki notes, "Expecting carbon fiber shortages, the Conexus technology offers an opportunity to use less carbon fiber on one side [of the part] and more natural fiber on the other — still light and cost-efficient."

For Bcomp, Wacht says that this project has been "a perfect example to show the design freedom you have thanks to this process. When you think about the potential of this technology, you can see how it could be used for an even more complex shape, such as in a supercar interior or in larger bodywork components." CW

Demonstrating strong joining + sustainability

Conexus technology is said to provide a strong joining capability on part with adhesives, while allowing potential for separation of the parts at their end of life.

ABOUT THE AUTHOR

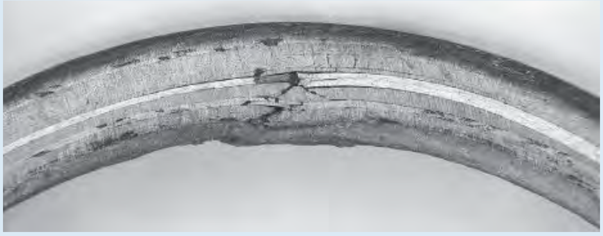
Technical editor Hannah Mason has been writing and editing about composites for *CompositesWorld* since 2018. She has a Master's degree in professional writing from the University of Cincinnati. **hmason@compositesworld.com**

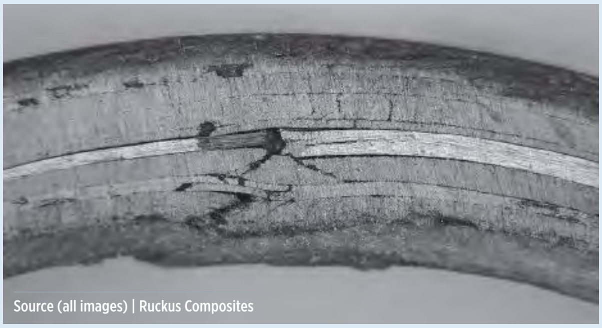
Post Cure

Highlighting the behind-the-scenes of composites manufacturing

Providing service for nondestructive technology investigations, repairs of carbon fiber structures

Ruckus Composites (Portland, Ore., U.S.) is a small composites inspection and repair facility that performs phased array ultrasonic testing (PAUT) of damaged composite structures for the bicycle and aerospace industries. The steering tube, for example — the mechanism that connects the handlebars to the fork blades on a bicycle — is a single-point failure mode for cyclists. Ultrasound data verified the structural damage to the 2.5-millimeter-thick carbon fiber steering tube presented in the image series at right, the result of an overzealous torque wrench. After inspection, Ruckus Composites sectioned and micrographed the cross sections to further understand the damage propagation extent, part of the company's commitment to better understand carbon fiber damage and failure modes.





Source (all images) | Ruckus Composites

Show us what you have!

The *CompositesWorld* team wants to feature your composite part, manufacturing process or facility in next month's issue.

Send an image and caption to *CW* Technical Editor Hannah Mason at hmason@compositesworld.com, or connect with us on social media.

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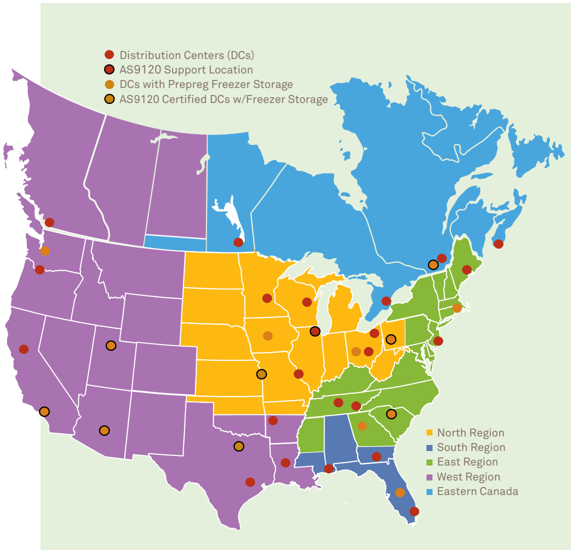

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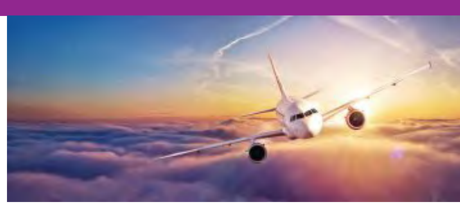

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