CW
CompositesWorld

From the oven to the spool: INITIATING SUSTAINABLE CARBON FIBER PRODUCTION

JUNE 2024

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» ON THE COVER

From the oven to the final spool, Teijin Carbon America's 185,000-square-foot carbon fiber manufacturing plant in Greenwood, South Carolina, focuses on swift innovation integration when it comes to sustainable manufacturing. These initiatives — whether inside or outside the fiber production line — are positioning the company for growth in its materials offerings and its expansion into markets like hydrogen and electric mobility. See p. 32. Source | Teijin

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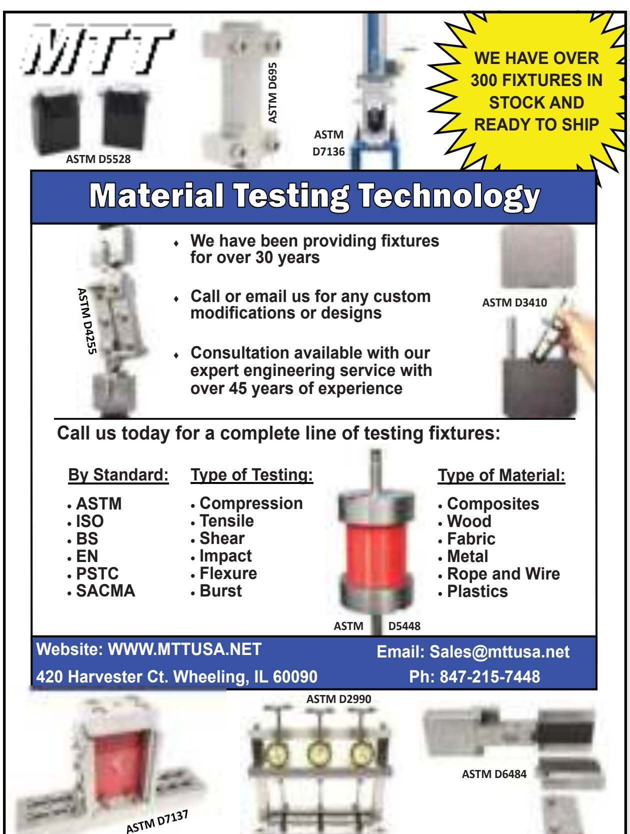

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It's hard to believe that it's been a year since former *CW* Editor-in-Chief Jeff Sloan penned his last "From the Editor" column, stepped into his new role as publisher and brand VP and handed the editorial reins over to me. Since then, this past year has flown by, and it's been a wild ride filled with lots of travel, tons of learning and plenty of lessons that I always try to take to heart. I'm so grateful for Jeff's ongoing mentorship and his unwavering patience as he explores new and growing responsibilities at *CW*'s parent company, Gardner Business Media. I'm also grateful for the support of such a great editorial team — the editors at *CW*, and all of those at Gardner, are the most hardworking, dedicated, creative and fastidious people that I've ever worked with. Every day I'm reminded of how good this crew of writing professionals is at what they do.

The *CW* team is gathering to take a step back and analyze all of our processes, our various story formats and other content types.

Despite having worked on *CW* for a few years and then exploring other areas of manufacturing for another few, there are always new facets to dig into. The *CW* team is always looking for different angles in which to tell stories. This year, we've been looking a little more closely at how Gardner's various brands intersect and look forward to even more future collaborations.

For example, this past year, *CW* launched a new "Fastening and Finishing" column dedicated to exploring adhesive technologies, welding, mechanical fastening, machining and various finishing technologies used in composites manufacturing. The initial idea behind the column came from my work with our sister brand, *Products Finishing* (*PF*). From there, the column has taken on a life of its own, not only through collaborations with *PF*, but also with several contributed stories from companies working in this space. For instance, this month's installment explores a new bolted fastener system for composites developed by researchers at Aalborg University in Denmark that is designed to redistribute the applied force to the adjacent material, thereby improving the overall performance and reliability of the bolted joint (see p. 6).

We've also been working to increase the frequency of our *CW Talks* podcast and corresponding interview column with the goal of bringing you conversations with industry experts on the latest industry trends and developments. Check out this month's offering on p. 14 which, in the wake of the recent collapse of the Francis Scott Key Bridge in Baltimore, delves into the topic of composites use in infrastructure projects today, including solutions for bridge rehabilitation and protecting waterfront structures.

Of course, we always have a host of feature articles in each magazine. In this issue, you'll find three "Work in Progress" articles covering how filament winding is enabling high-performance prostheses (p. 24), a novel injection process that uses continuous fiber to reinforce 3D printed parts (p. 28) and a look at a project aimed at the commercialization of recyclable thermoplastic composite hydrogen storage tanks (p. 38). In addition, you'll find a write-up of *CW*'s recent tour of Teijin's Greenwood, South Carolina, carbon fiber production line, which is currently reported to be the largest capacity carbon fiber line currently in existence (p. 32).

As anyone working in the composites industry knows, whenever you make changes, there will always be plenty of iteration. This month, the *CW* team is gathering to take a step back and analyze all of our processes, our various story formats and other content types. We're constantly striving to streamline our production process, find efficiencies and ultimately improve the quality of the content we provide. If you have suggestions or things you'd like to see us cover, we'd love to hear from you. We hope you enjoy the issue. CW

SCOTT FRANCIS — Editor-In-Chief

FiberJoints innovates composite bolted joints for reduced weight, cost and maintenance

» Connecting composite components is commonly achieved through either adhesive bonding methods or mechanical fasteners. Adhesive bonding stands out as a mechanically efficient means of load transfer across structural elements since stresses are dispersed over the bonded area, resulting in a favorable stress state. Conversely, mechanical fasteners are generally considered less effective for joining composite components because the load transfer occurs locally near the bolt, introducing stress concentrations and making bolted joints less efficient.

The choice of joining method is not always based solely on optimal load transfer — other considerations, such as production constraints and maintenance requirements, also play a crucial role. For example, in certain composite products like wind turbine blades, adhesive bonding emerges as the preferred method for joining shells and webs because typically disassembly isn't needed before the end of a blade's operational life. Conversely, for complex structures like airplanes, disassembly for service and regular overhauls is essential. In such cases, bolted joints become a necessity to facilitate inspections.

New bolted fastener system for composites

Although bolted joining methods offer the advantage of facilitating assembly and disassembly, they often lack efficiency in terms of load transfer in composites. To address this limitation, researchers at Aalborg University in Denmark have developed a novel insert, referred to as a "patch," aiming to enhance the strength of bolted joints while still retaining the benefits of easy assembly and disassembly. The patch has been designed to effectively redistribute the applied force to the adjacent material (Fig. 1).

This innovative patch has been patented by Aalborg University under the registration

FIG. 1 The FiberJoints patch improves static strength and fatigue endurance of composite bolted joints. Source (All Images) | FiberJoints

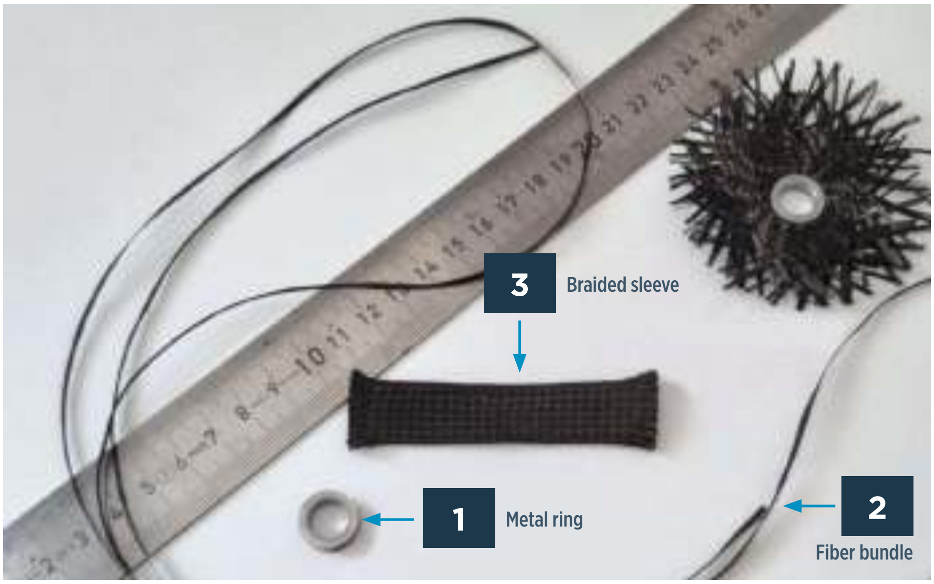


FIG. 2 The FiberJoints patch comprises three simple elements.

WO/2022-053120 and is being commercialized through the company FiberJoints (Aalborg, Denmark). The aim is to improve the overall performance and reliability of bolted joints in composites.

Patch elements and production

The FiberJoints patch comprises three essential elements: 1) a metal ring, 2) a fiber bundle and 3) a braided sleeve (Fig. 2). The choice of materials for these elements can be tailored to meet specific joint requirements. For example, the metal ring may be crafted from high-strength steel, stainless steel or titanium. In certain cases, a polymer ring could be used instead. Similarly, the braided sleeve and fiber bundle can be composed of carbon, glass or aramid fibers. Further, the hole in the metal ring can be customized to be straight, threaded or countersunk, addressing various screw requirements and providing versatility in application. This thoughtful selection of materials and design features enhances the adaptability and effectiveness of the FiberJoints patch in diverse joining scenarios.

Production of the patch involves a series of straightforward steps (Fig. 3, p. 8). The metal ring is positioned on a mandrel »

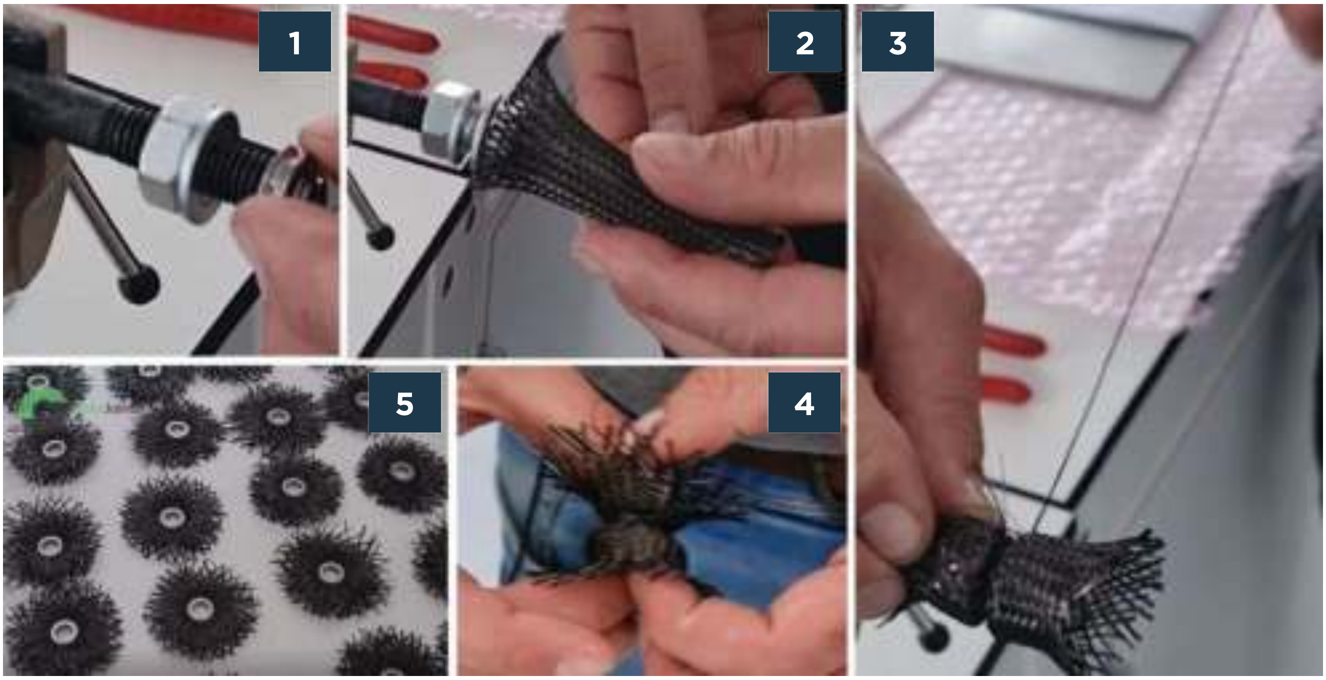


FIG. 3 FiberJoints patch production steps. The patch shown here can be used for a variety of applications, e.g., fastening points in a marine panel.

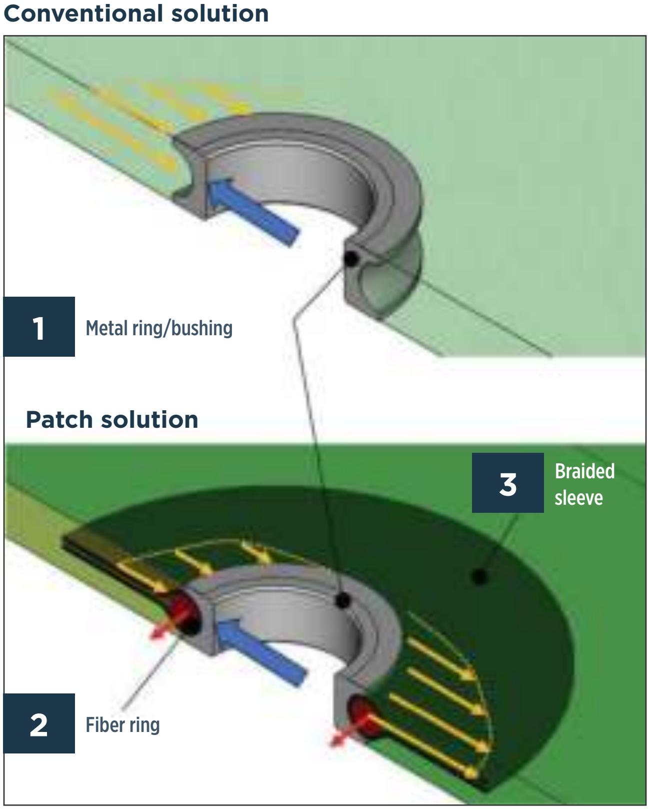


FIG. 4 Stress redistribution achieved by the FiberJoints patch.

between two washers to secure its placement. Next, a braided sleeve is slid onto the mandrel, covering the metal ring. In the third step, the fiber bundle is wound around the sleeve, forming a fiber ring and establishing a mechanical connection between the sleeve and the metal ring. Following this, the patch assembly is removed from the mandrel, and the sleeve is manipulated to achieve its flat configuration, making it ready for insertion into the composite laminate.

The mechanical strength imparted to the joint by the patch is influenced by various factors, and one crucial determinant is the number of windings executed with the fiber bundle, as depicted in the third step of Fig. 3. A greater number of windings results in a stronger fiber ring and a more robust connection between the sleeve and the metal ring. This enables a customizable approach to control the mechanical strength of the patch and, consequently, its effectiveness in reinforcing the joint.

Load redistribution

Understanding the load-carrying mechanisms of the patch and comparing these to a conventional insert is crucial. Consider a composite laminate subjected to an in-plane force generated by a bolt or pin, as illustrated in Fig. 4. In the "conventional solution," the metal ring emulates a grommet-type insert where the redistribution of the in-plane force to the adjacent composite laminate relies solely on bearing stresses.

The challenge in this design revolves around minimizing these bearing stresses to remain below certain design allowables while concurrently avoiding unnecessary additions to the overall weight of the structure. This emphasizes the importance of optimizing the load-carrying capacity of the insert and managing the associated

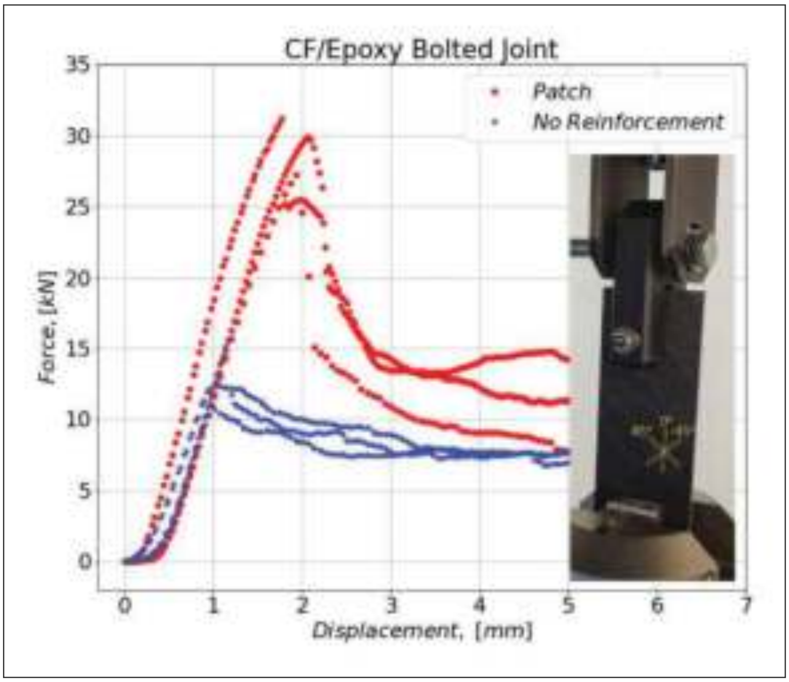


FIG. 5 Static in-plane loaded carbon fiber/epoxy laminate with and without a FiberJoints patch to reinforce the joint.

stresses to ensure structural integrity and performance within specified design parameters.

Conversely, the load-transferring mechanisms demonstrated by the FiberJoints solution are notably different. The patch facilitates the redistribution of joint load into bearing stresses on top of the hole and tension stresses below the hole. The patch's unique ability to carry a portion of the applied force through stresses below the hole is concealed in the folding of the sleeve around the fiber ring (Fig. 4, bottom image). The mechanical performance of the patch is primarily governed by the bearing strength of the laminate, as well as the tensile strength of the fiber bundles in the patch's braided sleeve and within its fiber ring. Through the induction of tensile stress in the fiber bundles, the patch effectively optimizes the utilization of the fiber material, enhancing its load-carrying capacity and overall mechanical performance.

Tests confirming higher load carrying capacity

Numerous tests have been conducted to validate the load-carrying mechanisms of the patch and its associated performance benefits. Tests involved examining carbon fiber/epoxy laminate samples both with and without a patch to reinforce the joint. The carbon fiber/epoxy laminates were constructed using unidirectional (UD) carbon fiber plies in a +45°/0°/-45° stacking sequence and vacuum infused with an epoxy resin. A 10-millimeter bolt was used to introduce the load. The results from in-plane quasi-static loading (Fig. 5) clearly indicate that the patch has a positive and strength-enhancing effect on the joint. On average, the strength gain for this setup is more than doubled compared to an unreinforced joint. This significant increase in strength offers an opportunity to leverage it for weight reduction, subsequently lowering the material cost of a component.

Additional testing has been conducted on glass fiber/epoxy laminates under both static and fatigue loading conditions, as detailed in the technical paper, "Bolted joint method for composites materials using a novel fiber/metal patch…," published in the January 2024 issue of *Composites Part B: Engineering*. This investigation discusses the efficiency of load transfer to the adjacent material when normalized with respect to the laminate strength. The load transfer efficiency parameter serves as an indicator of how effectively the adjacent composite material is used, considering the redistribution of the applied joint force. For samples without a patch, a 30% efficiency is attainable. In contrast, samples with patches demonstrate an enhanced efficiency of 60%.

In that same study, similar samples are subjected to tension-tension fatigue loading. Once again, the patch proves to have a positive impact on the mechanical performance of the bolted joint. The load-transfer efficiency is employed as a measure for comparison among the tested configurations. Samples reinforced with a patch exhibit only a 27% fatigue knockdown compared to the fatigue endurance of the laminate material itself. Conversely, not using the patch as joint reinforcement results in an 85% fatigue knockdown. Thus, the FiberJoints patch improves the fatigue performance of composite bolted joints.

Future development

Ongoing development of the FiberJoints technology includes creation of a prepreg-based patch, with prototypes expected to undergo testing later this year. Additionally, the company is engaged in R&D efforts to integrate sensors into the patch, allowing for health monitoring of the bolted joints. This innovation has the potential to significantly reduce maintenance costs by providing real-time data for optimal planning of service intervals.

FiberJoints and Aalborg University are actively seeking collaborations with industry partners and directs companies interested in evaluating FiberJoints patches to www.fiberjoints.com/contact. CW

ABOUT THE AUTHOR

Johnny Jakobsen is a mechanical engineer with a focus on composite materials. He earned his master's degree in 2005 and obtained his Ph.D. in 2008, both from Aalborg University in Denmark, specializing in the failure of sandwich structures. In 2020, he developed a patented composite bolt reinforcement system and recently co-founded the company FiberJoints, which is responsible for commercializing this new technology.

How AI is improving composites operations and factory sustainability

Source (All Images) | Plataine

» Manufacturers currently face a distinct set of challenges that are putting the resilience and flexibility of their operations to the test. While technology is evolving quickly and global markets are constantly shifting, businesses are dealing with the need to ramp up production rates, which has become more difficult due to the critical shortage of skilled and experienced workers. Supply chain disruptions have also become common, often resulting in longer material lead times and further complicating manufacturing logistics. On top of this, pressure is increasing to meet higher sustainability standards as stakeholders demand more environmentally responsible practices. Accordingly, companies manufacturing composite parts face a multifaceted puzzle in their efforts to maintain efficiency, profitability and sustainability in a world that is constantly transforming.

The rearview mirror of composites manufacturing

Historically, composites manufacturing has relied heavily on human expertise and traditional methods for short-, mid- and long-term planning and execution of production. These methods — including first-in, first-out (FIFO), Kanban and others — were guided by best practices in the 20th century. Now, they've reached a limit in terms of enhancing key performance indicators (KPIs) for production such as throughput and yield, on-time delivery and quality. Such methodologies don't sufficiently account for the dynamic nature of manufacturing environments, where unforeseen changes on the factory floor can present significant hurdles to efficiency, scalability and growth targets. This static approach used in the past often fell short and affected several critical aspects of operations:

- **Manufacturing planning was constrained**, not able to fully consider the variability and unpredictability in composites production processes.
- **Daily execution was often inefficient**, as manual interventions and decision-making couldn't keep up with the need for real-time adjustments.
- **Logistics and supply chain management weren't very flexible**, which led to inefficiencies, disruptions and late deliveries.
- **Decision-making was hindered** at all levels (management and operational), often based on outdated information or insufficient understanding of the current situation on the factory floor, for example, because the data was coming from a variety of unconnected systems (ERP, MRP, purchasing, shift logs and so on).

To be more specific, material selection processes were often manual, which was not only time-consuming but also led to remnants, scrap and lower yield. Material receiving was also typically manual, and often prone to errors and delays. Planning efforts commonly relied on tools like Excel spreadsheets, which resulted in schedules that were quickly outdated, low overall equipment effectiveness (OEE) and subsequent delays in delivery, proving that these methods were just not sufficient to deal with the new, more dynamic nature of the composites industry.

The dawn of digital transformation

Advanced manufacturing is currently going through a major transformation with the arrival of digital technologies, integrating sensors, IIoT and AI. Although still in its early stages, this digital turn promises substantial improvements in workflow, waste reduction and energy use. AI is becoming a key driver, enabling smarter decisions that enhance production efficiency and sustainability. Plataine (High Point, N.C., U.S.) has seen this transformation and has been a part of it for the last decade. We see that by using AI, composites manufacturing is experiencing exceptional advancements in several key areas:

Planning and scheduling: Traditional manual planning tools like Excel are being replaced with AI-driven software to automate and optimize production schedules and keep plans up to date. Software leverages AI algorithms to maximize production throughput and minimize inefficiencies. With AI-based software solutions, this digital change not only improves efficiency but also dynamically adjusts to unexpected changes on the factory floor happening in real time. This guarantees optimal resource utilization and minimal downtime. For example, one of our customers that manufactures composite parts for medical devices, used Plataine software to simulate how the addition of molds will impact their ability to increase volumes. Simulating multiple scenarios enabled them to reach a sweet spot — balancing between the need to increase part volumes versus the cost to purchase additional molds.

Supply chain collaboration: Cloud software enables better communication and collaboration between suppliers and manufacturers. This integration accelerates and simplifies the shipping and receiving processes, reduces delays and improves the overall responsiveness of the supply chain.

Inventory management: AI algorithms are able to analyze trends and predict demand, which then allows material managers and purchasing to maximize inventory efficiency. This approach significantly reduces scrap and waste, which helps these companies to achieve greater sustainability and cost savings.

Equipment and tool management and service: AI-assisted software provides alerts and recommendations to staff responsible for equipment service. This proactive maintenance approach prevents unplanned downtime, extends the life of machinery and ensures that resources are optimally used.

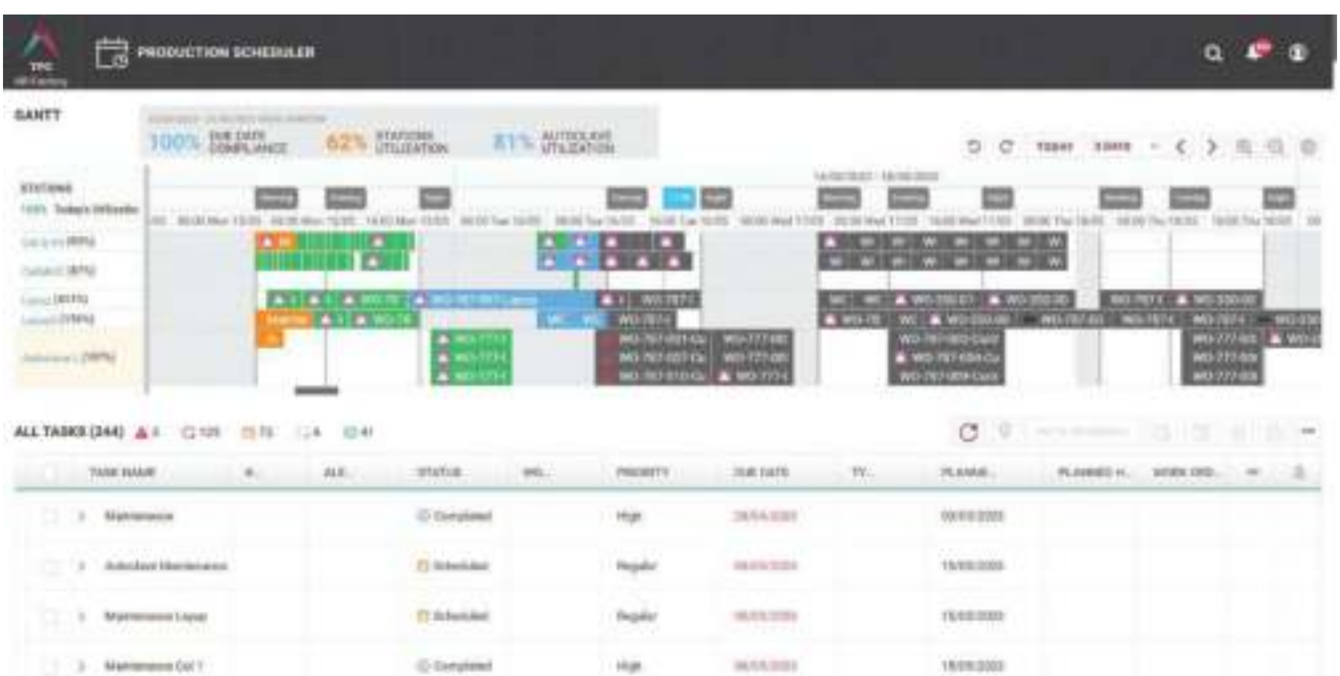
Energy consumption optimization: AI algorithms can play a big part in optimizing energy use, especially in energy-intensive processes like autoclave curing. Plataine is constantly learning from our customers. For example, one recent focus is that autoclave scheduler systems are imperative. We see that AI technology is leading a significant change in autoclave operations management within factories. By optimizing schedules, manufacturers using this technology are substantially reducing the number of autoclave runs, reducing energy consumption.

AI's role in manufacturing for the future

In the same way that AI has become part of our daily life — with our smart phones, Siri, Alexa and more — AI will become a very significant part in our professional life at the factory. We see that AI is a tool being used more and more by factory staff to make their facility's manufacturing processes easier and more efficient. AI is operating as another digital assistant to make day-to-day work a lot easier.

For example, production planners will run simulations of different scenarios and outcomes to reach high efficiency. The future of AI in manufacturing planning will take place across three horizons, each with its own set of possibilities and innovation:

- **Short-term planning (up to 2 weeks):** AI will enable factories to simulate various scenarios, such as different job assignments to machines or operations, and the allocation of inventory and tools for work orders. These simulations can create detailed schedules for each shift and respond »



rapidly to unexpected events on the factory floor. By quickly evaluating multiple scenarios, AI-based software can present the most efficient outcome, ensuring high flexibility and responsiveness in short-term weekly planning.

- **Mid-term planning (2-4 months):** Looking further ahead, AI's capabilities will extend to simulating scenarios for operational adjustments, such as adding shifts, increasing staff per shift or purchasing additional tools or molds. This mid-term planning will help align tactical decisions with predicted demand and operational capabilities. As a result, resource allocation and productivity can be optimized.
- **Long-term planning (1-2 years):** Over the long term, AI-assisted software will fast track strategic expansions and investments, such as purchasing new machines or adding production lines and factory space. These simulations will support long-term growth strategies, making sure that investments are worthwhile and aligned with future market demands.

We also believe that AI will play an important part in encouraging collaboration and connectivity between manufacturing facilities and sites, predicting demand peaks and shortages, as part of the connected factory ecosystem. Even further, AI-based software will aid collaboration between suppliers and customers, streamlining communication, creating transparency and shortening processes.

Fostering innovation to stay competitive and grow

The journey through the current evolution in manufacturing — from reliance on traditional methods to the pioneering adoption of AI — involves a truly transformative shift toward efficiency, sustainability and innovation. There is no doubt that the integration of generative AI (GenAI) will further develop this dynamic. While traditional AI focuses on analyzing historical data and using algorithms to make future predictions, GenAI enables digital technologies to produce new outputs, including images, videos, text, sounds and other media.

New GenAI tools will enable natural communication between humans and machines, making complex software more intuitive, friendly and accessible. Such technology can not only help to streamline production processes, but also to get real-time alerts and smart insights and recommendations — which humans in the factory will learn to trust over time (remember Siri, Alexa and Waze?). Plataine, centered around sustainable, customer-focused production, has experienced how embracing AI has helped factories to enhance their OEE, reduce material waste and save operators time as well as operational costs. As composites manufacturers adopt these innovations, they will move toward more responsive, adaptive and environmentally responsible processes. CW

ABOUT THE AUTHOR

Amir Ben-Assa is responsible for global marketing and product strategy at Plataine (High Point, N.C., U.S.). Over the past 20 years, Ben-Assa directed marketing departments and the development and successful deployment of innovative technologies and solutions for the industrial sector. Prior to joining Plataine, he held various marketing and business development roles at RFKeeper, AeroScout (acquired by Stanley) and Siemens. Ben-Assa holds a B.Sc. in mechanical engineering from the Technion, Israel Institute of Technology and is a graduate of the Executive MBA program at Tel-Aviv University.

CW Talks

THE COMPOSITES PODCAST

EPISODE 45: Scott Reeve; Corey Sechler, *Creative Composites Group*

» Infrastructure in the U.S., particularly regarding the deterioration of a number of bridges across the country, has been a large topic of discussion in recent years, even more so with the Bipartisan Infrastructure Law designating nearly $400 billion in infrastructure investments. Even more recently, the collapse of the Francis Scott Key Bridge in Baltimore, Maryland, due to a container ship accident, has sparked a new round of discussion about bridge repairs. In this installment of *CW Talks*, we interview fiber-reinforced polymer (FRP) composites manufacturer Creative Composites Group (Alum Bank, Pa., U.S.) business development manager, Scott Reeve, and sales manager of waterfront solutions, Corey Sechler, about the company's use of composite materials in infrastructure rehabilitation projects, including bridges and waterfront structures.

This Q&A is excerpted and has been edited for clarity from *CW Talks*: The Composites Podcast, which highlights the people and technologies shaping the world of composites. To hear the entire interview, please visit www.compositesworld.com/podcast, or use the QR Code to the left.

***CompositesWorld* (CW):** The Francis Scott Key Bridge collapse recently brought the problem of the nation's declining bridges into the spotlight once again. Can you talk a bit about this in the context of infrastructure repair initiatives?

Scott Reeve (SR): The bridge itself was not a factor. It's a little over 50 years old. The collapse was due to the impact from the container ship.

There are a number of bridges out of the 600,000 highway (or vehicle) bridges in the U.S., and there is a fairly high percentage that are deficient. What we mean when we say "structurally deficient" is that they don't meet a lot of the codes that are now in place.

The Bipartisan Infrastructure Act has helped in terms of getting more funding out there, and so there are more bridge rehabilitations going on, and generally in those cases they're going through and often replacing some of the steel girders that are part of the superstructure, and then replacing the driving decks. Some of those applications are ones in which composite materials are applicable.

***CW*:** Can you talk about the role that composite materials are playing in bridge rehabilitation, reinforcement and protection today?

SR: Some of the places that FRP composites have been most applicable on vehicle bridges has actually been movable bridges [draw bridges or lifting bridges that allow for the passage of boats or barges]. Because many of them were built many years ago, there are limits to what you can do, even from a superstructure steel side to reinforce it. So, as some of the loads and weights of the vehicle traffic have gone up, work has been done to reduce the weight of the [bridge] decks, so that the bridge itself can take the higher loads from traffic. These are also places where you have the natural long-term benefit of composite materials in terms of no corrosion.

***CW*:** In terms of using FRP to protect waterfront structures, can you describe some of those solutions?

Corey Sechler (CS): Let us lay this out first and foremost. To be fair, there is no product that we currently manufacture that would

Composite bridge fender systems can act as "guardrails in the water" to protect both bridges and boats, and to aid vessel traffic through navigable waterways.
Source (All Images) | Creative Composites Group

(TOP) This bridge features a cantilever pedestrian walkway with composite decking.

(BOTTOM) Waterfront fender systems are comprised of monopiles (installed up to 100 feet below the mudline underwater) and horizontal composite crossmembers that absorb or deflect impacts.

come remotely close to stopping a vessel of that size from impacting the Key Bridge.

Having said that, on a much smaller scale, we are working with state agencies and DOTs to provide solutions for navigable waterways. We provide fender systems and dolphin piles — components like that — to aid vessel traffic (or traffic in general).

CW: Can you talk a bit about how those structures are created and how they work?

CS: One of the challenges that many of our agencies have is that they're accustomed to working with traditional materials like wood, concrete or steel. However, while those materials have many pros to them, there are some cons, including a shortened service life in saltwater or brackish environments.

Fortunately, a product like FRP can provide some of those agencies with a longer service life. We take various components — it could be a round, hollow pipe pile, or a fiberglass sheet pile — and form an entire system out of them.

A fender system would be constructed out of a round, hollow pipe pile, maybe a diameter of 12-24 inches or larger — whatever size load we need to handle. And then that is often coupled with something like a fiberglass whale system or a reinforced plastic lumber system. In some cases, we're working with agencies like the U.S. Army Corps to provide them with larger diameter dolphin or monopiles to help protect either the bridge structure or maybe even part of a ferry system.

SR: These fender systems, you can also think of them as a fence in the water — guardrails. Basically, we make 100-foot-long fence posts that go down below the mud line for support, up through 30 feet of water, and then stick up about 13-15 feet above the waterline. Then there's horizontal plastic lumber or composite crossmembers — and that is what takes the impact.

One of the big benefits of composite materials is the combination of high strength (similar to steel) and medium modulus stiffness compared to steel. The composite fender systems bend but don't break. They can take an impact, deflect or dissipate the energy without breaking — and without breaking the ship or the vessel. Then they return back to shape.

So, lining the channels between bridge piers with these fender systems provides a nice solution. Of course, everything has its place — these systems work in certain waterway configurations and with certain-sized vessels. CW

ABOUT THE AUTHOR

Scott Francis is the editor-in-chief of *CompositesWorld* and *Products Finishing*. He has written for numerous publications including *Writer's Digest*, *HOW* and *Popular Woodworking*.
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GBI activity knocks at the door of expansion in April

April — 49.6

» GBI: Composites Fabricating activity contracted in April but came very close to crossing the threshold to expansion; at an index of 49.6, it was up slightly from March's 49.0, continuing to inch toward a reading of 50. We can only hope that once activity expands, the trajectory will look like the last "crossing" back in September 2020 — shown below where the graph intersects 50 between April '20 and April '21 — which was sustained for more than 2 years before slowing in December 2022 onward.

New orders and production are the main components that saw slowed contraction again in April, driving the overall index. Backlog did the same, but remained at a lower value.

Exports and employment also contracted at slower rates. This marks a turnaround for employment, which had been contracting at accelerating rates for 3 months straight. Supplier deliveries continued to lengthen at an accelerated rate while business sentiment (not included in GBI calculation) was the same positive value in April that it was in March. 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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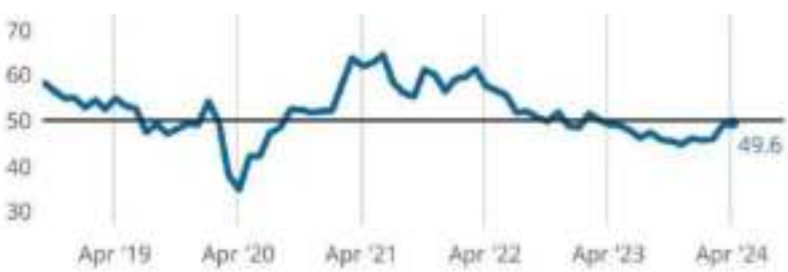
GBI: Composites Fabricating



■ GBI: Composites Fabricating in April was up 0.6 point higher than March.

Source (All Images) | Gardner Intelligence

GBI: Composites Fabricating — Production, New Orders and Employment (3-month moving average)

■ Slowed contraction in new orders and production drove the overall index while employment contraction slowed for the first time in 4 months.

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TRENDS

***CW* calls for *CW* Tech Days Space abstracts; first *Lilium Jet* composite battery packs are being produced for targeted 2024 flight; new Acciona Waste2Fiber facility will process recycled wind blades; NPROXX triples space and capacity for pressure vessel production; the Flirt H_2 train now holds a Guinness World Record title; and more.**

CARBON FIBER

Speak at *CW*'s New Space Tech Days event on Nov. 13

CompositesWorld has announced that the latest installment in its Tech Days online event series will be focused on the use of composites materials and technologies in today's space applications. The event is scheduled to take place Wednesday, Nov. 13, 2024, from 11:00 a.m. to 3:30 p.m. ET.

CW's Tech Days are designed to offer informational presentations from industry experts spanning the entire composites supply chain. The New Space Tech Day will explore the technologies, materials and strategies used by composites manufacturers working in the evolving space market. Presentations from industry experts will emphasize the use of composite materials in applications requiring weight savings, structural benefits and the ability to withstand extreme temperatures.

Composites have been used in space since early developments. Often turned to for their light weight and high strength, composites have a history of use in applications such as payload fairings, satellite structures and heat shields.

Today, private companies are partnering with NASA and the European Space Agency (ESA) in new and exciting ways. Creating everything from telescoping arrays on small satellites to aspects of spacecraft and lunar/planetary landers, commercial space companies have helped to streamline the production of mission-enabling parts and structures. Composite materials are playing an ever-growing role.

Material and equipment suppliers, along with industry experts interested in presenting at the New Space Tech Days event on Nov. 13, are invited to submit abstracts to **press@compositesworld.com**. Please reference "*CW* New Space Tech Days" in the subject line. Submitted abstracts will be considered for inclusion in the event agenda.

ADVANCED AIR MOBILITY

Lilium begins composite battery packs production for Lilium *Jet*

Lilium (Munich, Germany) has started production of the aviation-grade battery packs — featuring composite battery enclosures — that will power the Lilium *Jet* on its first piloted flight, targeted for end of 2024. This next step in development follows extensive testing of battery pack subcomponents from individual cell to stack level with a focus on performance, safety and regulatory conformity.

The Lilium *Jet*'s battery pack comprises lithium-ion cells with silicon-dominant anodes that the company says will enable higher energy, power and fast-charging capabilities than graphite anode cells. They are designed to meet the European Union Aviation Safety Agency's (EASA) stringent aircraft safety requirements regarding shock resistance, heat resistance, containment and redundancy.

The battery packs are being assembled at Lilium's purpose-built battery factory, located at its headquarters outside Munich, with the aid of new digital tools that enable process control, efficient data collection and traceability. Lilium has been supported in the design of the assembly line and initial production ramp-up by suppliers with extensive experience in battery industrialization, especially in the automotive sector.

First units off the battery assembly line will be used for verification testing ahead of the Lilium *Jet*'s first piloted flight. Each *Jet* aircraft will be equipped with 10 independently functioning battery packs.

WIND

Acciona to build wind blade recycling plant in Spain by 2025

Acciona, (Alcobendas, Spain), Acciona Energía (Alcobendas) and RenerCycle (Navarra) have announced the construction of Waste2Fiber, a wind blade recycling plant in Lumbier (Navarra), Spain.

Waste2Fiber, to be operational in 2025, will use proprietary thermal treatment technology for the recycling of composite materials present in wind turbine blades. This technology, based on the use of moderate and controlled temperature and atmosphere conditions, will make it possible to preserve the properties of reinforcement fibers, reuse the organic fractions and transform the composite materials into secondary raw materials with high added value that can be used in new production processes with a quality comparable to that of virgin raw materials. This represents a considerable environmental and safety improvement for the transformation of waste into secondary raw materials in compliance with European waste management directives.

The plant will have a processing capacity of 6,000 tons of material per year, covering all stages of the production process.

HYDROGEN

NPROXX powers up H_2 tank production with move to Alsdorf facility

Type 4 tank manufacturer NPROXX (Heerlen, Netherlands) has completed a move of its operations to significantly larger premises at Alsdorf, Germany. The relocation is designed to support the hydrogen storage specialist's major growth ambitions. "We have about 10,000 square meters in our facility now," explains managing director, Klaus-Peter Kopper. "We have effectively tripled our size and capacity."

In fact, the new facility gives NPROXX the space and capability to boost its production rates of hydrogen storage tanks and tank systems even further, due to improved efficiencies and new machinery. "We could, in theory, grow to five times our current production, to over 30,000 tanks a year" adds Kopper.

The expansion could open new commercial opportunities in 2024 for the manufacturer. Now that NPROXX can handle significantly bigger orders, "we can deliver a storage system much faster than before, and our process stability improvements have already started to bear fruit with increased quality and reduced scrap rates," says CTO Dietmar Müller.

NPROXX is looking at 6-meter-long tanks for rail and truck and also progressing toward compliance with the latest R134 pressure vessel standards.

MASS TRANSPORTATION

Stadler H_2 train achieves Guinness World Record title

Railway rolling stock manufacturer Stadler Rail AG (Bussnang, Switzerland) has been entered into the Guinness World Records for the longest distance achieved by a pilot hydrogen fuel cell electric passenger train — with multiple units — without refueling or recharging. The company's Flirt H_2 train, which has a hydrogen storage system that uses 350-bar Type 4 pressure vessels, traveled a total of 1,741.7 miles (2,803 kilometers).

The Flirt H_2 was presented to the public for the first time in 2022. Stadler notes that a significant number of detailed solutions were developed to integrate fuel cells and hydrogen storage systems into the modern commuter train product line. These solutions have since been tested thoroughly, first in Switzerland and more recently on a dedicated test ring in Colorado.

Close to completing its testing, the company was eager to prove the reliability and capability of its innovative train. To do so, an attempt to set a new record for the range of the hydrogen train without refueling or recharging was undertaken.

The world record journey started the evening of March 20, where the train set out for its first laps around the test track. The team of engineers from Stadler and ENSCO continued driving the vehicle in shifts throughout the night and following day and concluded the successful attempt at 5:23 p.m. (MST) on March 22. Altogether, the train traveled for more than 46 hours on one tank filling.

"This world record establishes the ideal performance range of our hydrogen version of the Flirt Electric Multiple Unit, the Flirt H_2," Dr. Ansgar Brockmeyer, EVP of marketing and sales at Stadler, says. "This is a monumental achievement and we are proud to hold another record title."

The Flirt H_2 for San Bernardino County Transportation Authority (SBCTA) is Stadler's second Guinness World Records title-winning train, showcasing alternative propulsion. In December 2021, the Flirt Akku — the battery-powered Flirt model — set the world record for the longest journey with a battery multiple unit in pure battery mode, covering 139.2 miles (224 kilometers) in Germany.

RECYCLING

Exel Composites, Fairmat sign carbon fiber scrap repurpose deal

Exel Composites (Vantaa, Finland) and Fairmat (Paris, France) have announced a partnership to close the loop of carbon fiber waste. Fairmat will recycle Exel Composites' carbon fiber composite scrap at its Nantes, France, manufacturing facility to produce second-generation carbon fiber-reinforced polymer (CFRP) chips for high-performance composite layups and structures. Beginning in Q2 2024, the carbon fiber scrap will be transferred to Bouguenais from Exel's two plants in Finland.

Traditional waste management techniques involving pyrolysis or solvolysis and use significant amounts of energy, mitigating the environmental benefits of recycling used carbon fiber. In contrast, Fairmat's reconstitution process uses proprietary cutting technologies — aided by robotic tools equipped with machine learning — to dissemble carbon fiber components and convert the pieces into CFRP building blocks.

"Fairmat's innovative recycling methodology enables its products to retain the high strength and stiffness of the original embedded fibers," explains Kim Sjödahl, senior VP of technology and sustainability at Exel Composites. "This is often compromised by other recycling methods that involve chopping and milling carbon fiber. What's more, the successful recycling of process waste also opens possibilities to recycle the end-of-life waste from our customers."

Benjamin Saada, founder and CEO of Fairmat, adds that this partnership with Exel aligns with the company's mission to build a closed-loop ecosystem that keeps high-value products from going to waste.

Using AI tools such as digital twins to model different 3D arrangements during the design phase, Fairmat can assemble its CFRP chips into a variety of layouts and structures. These simulations enable it to customize the mechanical properties of the resulting product, such as low weight for transportation components and localized, unidirectional strength for impact surfaces.

ADDITIVE MANUFACTURING

UMaine's novel polymer 3D printer surpasses former Guinness World Record

Surpassing its own 2019 Guinness World Record for the largest polymer 3D printer, the University of Maine (UMaine, Orono, U.S.) announced the development of a next-generation printer that is four times larger than its predecessor to catalyze the future of sustainable manufacturing.

The new Ingersoll (Rockford, Ill., U.S.) printer, dubbed Factory of the Future 1.0 (FoF 1.0), was unveiled at UMaine's Advanced Structures and Composites Center (ASCC) on April 23. The thermoplastic polymer printer is designed to print objects as large as 96 feet long × 32 feet wide × 18 feet high, and can print up to 500 pounds per hour. It offers new opportunities for eco-friendly and cost-effective manufacturing for numerous industries.

According to UMaine, FoF 1.0 isn't merely a large-scale printer; it dynamically switches between various processes such as large-scale additive manufacturing (LSAM), subtractive manufacturing, continuous tape layup and robotic arm operations. Access to it and MasterPrint, the ASCC's first world-record breaking 3D printer, will streamline manufacturing innovation research at the center. The two large printers can collaborate by sharing the same end effectors or by working on the same part.

"UMaine and the ASCC possess the innovation, capacity and workforce to support the future needs of the DOD in advanced manufacturing," says U.S. Senator Susan Collins.

ASCC executive director, Habib Dagher, adds that FoF 1.0 opens up "new research frontiers to integrate these collaborative robotics operations at a very large scale with new sensors, high-performance computing and AI to create born-certified systems that meet high-quality standards."

The printer will advance various initiatives, including development of bio-based feedstocks from wood residuals abundant in Maine. This technology will advance commercialization efforts such as BioHome3D and the creation of sustainable, affordable housing, while also propelling technological advancements for national security, particularly in lightweight, rapidly deployable structures and vessel technologies. These capabilities will help reaffirm "our standing as leaders in composite materials research and advanced manufacturing," UMaine President Joan Ferrini-Mundy adds.

The FoF 1.0 unveiling comes ahead of this summer's planned groundbreaking of a new 47,000-square-foot research laboratory called the Green Engineering and Materials (GEM) Factory of the Future. Scheduled for August 2024, the facility's primary aim is to facilitate and scale up more sustainable manufacturing practices by introducing next-generation solutions and biomaterials, addressing challenges such as a diminishing workforce and strained supply chains with local solutions. It will also explore novel material systems by prioritizing recycled and bio-based materials.

SPORTS/RECREATION

Syensqo Ixef PARA polymer shapes surfing fin by Kohola Flow Tech

Syensqo (Brussels, Belgium) announces that its Ixef polyarylamide (PARA) resin is being used by plastics company Drake Plastics (Cypress, Texas, U.S.) for molding the Kohola FlowTech 1 Single Fin, enhancing the flow control and efficient forward motion of surfboards to deliver longer and faster rides. The design behind Kohola's fins mimics the flippers of humpback whales. The efficiency of the injection molding process helped to achieve a manufacturing waste reduction of up to 30%.

Partners selected Ixef PARA 1022, a 50% glass fiber-reinforced compound for the FlowTech 1 Single Fin. Syensqo's fiber-reinforced polymer exhibits high strength and rigidity, optimal surface gloss and good creep resistance.

According to David E. Shormann, founder of Kohola Flow Tech, the company's longboard fins require a material that supports the dynamic maneuverability and minimized resistance enabled by the natural whale pattern design, which improves flow control by cutting through turbulences and reducing side-to-side wobbling for a more stable forward ride as well as safer, tighter turns.

Moreover, Drake Plastics arrived at a high-performing high-end product with better resource efficiency and optimal finish straight from the mold, eliminating the time and cost for secondary trimming and polishing.


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Filament winding increases access to high-performance composite prostheses

Steptics industrializes production of CFRP prostheses, enabling hundreds of parts/day and 50% lower cost.

By Ginger Gardiner / Senior Technical Editor

According to the World Health Organization and other groups monitoring amputation and limb loss, 60-100 million people worldwide need a prosthetic limb. This population is expected to double by 2050, driven primarily by the growth in diabetes and vascular disease. Depending on the country and age group, at least 70% of those needing prostheses involve lower limbs, yet only 5-15% of amputees have access to a prosthesis.

"The majority of people with lower limb amputations don't have access to high-quality fiber-reinforced composite foot prostheses due to their high cost resulting from complex, manual manufacturing processes," explains Daniel Kun, managing director and CTO of steptics (Munich, Germany). "The cost for these foot prostheses can be $5,000 or more. If you don't have good insurance, then you can't afford these. Even in Germany, it's not possible for most people to pay for these out of pocket."

Most carbon fiber-reinforced polymer (CFRP) foot prostheses are made by hand laminating numerous prepreg layers into a tool and then curing in an autoclave, followed by trimming and milling. "These kinds of manual procedures are super expensive," notes Kun. "My background is in automotive, developing automation to reduce the cost of CFRP components. I wanted to transfer this approach to prostheses and use the cost savings to make them more accessible. Steptics was founded based on an innovative, automated and patented manufacturing process that cuts manufacturing costs by 50%. What drove me was the idea to make a difference, that by industrializing production, I could really change the performance and price point on CFRP prostheses."

Automotive background and CFRP

"I'm basically a skilled toolmaker," says Kun. After earning an automotive engineering degree and then a master's degree in systems engineering and management, Kun began his career at Voith Composites (Munich, Germany). "I was part of the program to industrialize all the different stages for the production of CFRP automotive parts. Automating the press molding and machining processes for the Audi A8 rear wall/seat back program was pretty much what I had to do in 2009. This was due to my background as a toolmaker, but I also had 8 years of experience with Formula Student racing teams."

The story of steptics began with Kun walking to work every day. "I would pass a company with a typical carbon fiber composite wheelchair in the window and wonder why they made them using the same old methods. One day, I went into the shop and asked to speak to the person responsible for that wheelchair. That started a collaboration with Voith Composites to design more optimized wheelchairs and foot prostheses. And with that project, I had the idea for my patent. When I decided to leave Voith Composites, I was able to buy the patent out of the company, and that's how we were able to found steptics."

But why do foot prostheses have to be CFRP? "Continuous fiber-reinforced composites are the only materials that guarantee both light weight and high energy return for the high performance and fatigue resistance needed [for these applications]," says Kun. "It's all about the energy return. There are prostheses made out of metal and unreinforced plastics, but most patients don't like these because they are heavy and lower performance. They don't return the energy as well, so it makes it harder to develop a normal gait. It's like walking in sand. But if you had a lower limb amputated, wouldn't you want to get the best performance in a prosthesis to try to achieve your former mobility?"

Indeed, loss of mobility for lower limb amputees often leads to health issues, as well as loss of independence, social withdrawal and increased risk of depression. "Our goal is to really restore and maximize mobility, including high levels of exercise and sports," says Kun. "But, as I explained before, the processes behind high-performance prostheses are manual and not scalable, thus these products are unaffordable for the majority of the people who need them."

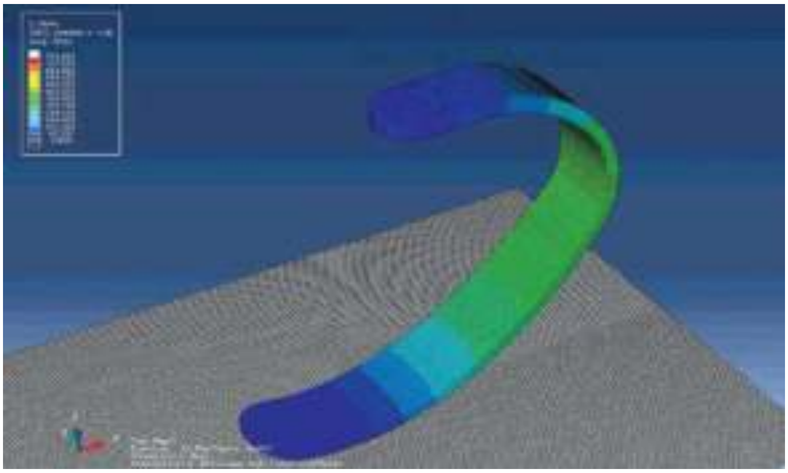
Materials and process

Steptics brings automation to the prosthetics world via the filament winding process. "We first build a mandrel which has the inner geometry of the prostheses," says Kun. »

Steptics uses filament winding to create a large, shaped tube (opposite page, left) which it cuts into slices (this page, top) and then cuts the slices into halves (opposite page, right). These 3D blanks are then machined (above) to achieve high-performance prostheses at a rate of 250-500 per day compared to only 2-3 per day using conventional hand layup prepreg processes. Source (All Images) | steptics

"The fiber is pulled through epoxy resin and then wound onto the rotating mandrel. The resin is typically used for vacuum infusion processes in the aircraft industry, and we use T700 type carbon fiber from Toray [Tokyo, Japan], although we could also use glass fiber or basalt or other fibers. T700 has good properties that are very well known, and it is well proven in filament winding."

"We filament wind a long, shaped tube that we then cure in an oven," he continues. "It's pretty much the same curing process as with filament-wound pressure vessels. We then cut the long tube into slices, and cut the slices into halves to get semi-finished parts. These are then individually machined to tailor the geometry and performance to the individual amputee."



AI-assisted customization

One reason prostheses have been challenging to industrialize is the need to customize each product for the individual amputee. "That's true," says Kun. "We need to know the amputee's weight and whether a left or right foot prosthesis is needed. We also want to know what they want to do with the prosthesis. Are they a walker or a jogger? And that defines the spring characteristics needed in the final prosthesis."

"We solve the problem of an individual product through a two-phase industrial-scaled process," explains Kun. "In the first phase, we define the base material properties needed and use automated filament winding to consistently manufacture high-quality 3D-shaped blanks. In the second phase, we have developed AI that calculates the optimal geometry for the prosthesis based on the individual's parameters, such as the stiffness and energy transfer needed. The 3D blank is then cut and milled to deliver that performance."

The latter phase was developed in partnership with composites machining specialist Hufschmied. However, conventional filament winding limits possible geometries to fairly simple curves, notes Kun. "So, we developed a second major manufacturing process that is similar, but allows us to form the blanks to any geometry, for example wave-like shapes or an 'S.' We can now build every thinkable geometry for a prosthesis."

Initial products and production

For the first process, says Kun, "we have the first production line, and have made a proof-of-concept prosthesis and tested it according to ISO 10328. It performed well and withstood 2 million cycles of loading without any degradation. This first product will be a CFRP blade or sole that is a sports prosthesis, amputation level 270."

Kun explains that amputation level refers to the height of the leg amputation from the ground. "It defines the minimum installation height required for the prosthesis."

"Our target is to go to market in summer 2024," says Kun. "We are starting with these running blades because they must perform better than everyday prostheses, so we can really address that. But also, it's challenging for amputees to resume physical activity, compounded by the fact that such prostheses typically aren't covered by health insurance. Our goal is to offer these high-performance sports prostheses at an affordable cost."

He explains that typical state-of-the-art hand layup produces 1-2 prostheses per day. "But with our manufacturing process, with a mandrel 10-12 meters long, for example, we're able to build 250-500 prostheses per day. That's a significant difference and means we can save roughly 50% of the cost."

Kun explains that steptics will pursue both a business to business (B2B) and business to consumer (B2C) model. "We are collaborating with established prosthesis manufacturers, our B2B

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Steptics has developed an AI that calculates optimal geometry to tailor the stiffness and energy transfer, for example, to meet an amputee's height, weight, activity and usage. Its first product is a running blade sports prosthesis for amputation level 270, but steptics is also developing products for a range of activity levels (above) all with high energy return for maximum mobility.

customers, in white label projects where they can sell our products through their distributor and sales pipeline worldwide. Concurrently, we are developing and distributing our own models directly to consumers. For example, we want to sell the sports prostheses, including our initial running blade, via our homepage worldwide. And eventually, we want to establish subsidiaries in the U.S., India and China with our own employees, to further develop and sell products in those markets."

> "We are starting with these running blades because they must perform better than everyday prostheses, so we can really address that."

As far as product differentiation, there are products focused on higher performance with a slightly higher price and those targeting the large amputee population in developing countries where the lowest price is necessary, demanding a simple design but still made out of continuous fiber-reinforced composites. "So, we are aiming to launch the sport prostheses in summer, the simpler export prostheses in fall to winter of 2024 and then a third product made using the second production process for more complex, tailored geometries. We are actually working now to produce this under white label for a customer's brand." This manifold approach is designed to help steptics meet its financial goals as well as its commitment to make prostheses more accessible worldwide.

Challenges, future development and sustainability

In addition to the challenge of automating production and meeting customized performance needs while lowering cost, these prostheses must meet strict medical requirements and certifications. The latter has been referred to by some in the medical market as more difficult than aircraft certification. "This means it's super difficult to switch materials, for example, because you would have to requalify the whole product and it's very time-consuming and expensive to qualify those kinds of products," notes Kun. Even so, steptics is looking toward making its products more sustainable.

"Our first steps were to reduce costs through automated production and development of AI for individual customization," says Kun. "Now, we want to tackle the issue of sustainable materials. Unfortunately, carbon or glass fiber do not have the best CO_2 footprint. However, many natural fibers don't have the strength and stiffness to withstand the predominant loads. Thus, by themselves, they aren't yet suitable for running blades or even everyday prostheses. We are still researching what reinforcements could work."

However, the company is committed to developing improved materials and sustainability. "This is important because we should have sustainable materials in the prosthetics industry," he adds. "We are working on a project through a German government program and aiming to have, in 2-3 years, results where we can move forward with new fibers and resins. And then we have to complete qualification."

"For now," says Kun, "We are testing our products with amputees and getting certified as a medical devices manufacturer. This all takes time, but we expect to have the first product ready for the market soon. Preliminary tests have already shown that our running blades exhibit very good performance."

"In the coming years," he continues, "steptics will further improve our prostheses and develop new products. We will improve sustainability and also availability of our prostheses in the Global South, where there is significant demand but insufficient purchasing power. Our aim is to use our automated and efficient processes to provide suitable solutions that empower and increase quality of life for amputees and ensure accessibility to everyone who needs them." CW

ABOUT THE AUTHOR

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Reinforce3D's continuous fiber injection process (CFIP) is a post-processing step for injecting continuous carbon fiber and resin into hollow cavities in a finished part (below). An example use case is the automotive brake pedal demonstrator (left), which is made from a transparent, 3D printed polymer reinforced with injected, continuous carbon fiber/epoxy. Source (All Images) | Reinforce3D

Reinforcing hollow, 3D printed parts with continuous fiber composites

Spanish startup Reinforce3D's continuous fiber injection process (CFIP) involves injection of fibers and liquid resin into hollow parts made from any material. Potential applications include sporting goods, aerospace and automotive components, and more.

By Hannah Mason / Technical Editor

» The additive manufacturing (AM) landscape for composites — using both discontinuous and continuous fibers — continues to evolve. Startup Reinforce3D (Tarragona, Spain) is approaching the market from a unique direction, with a technology for injecting continuous fibers *into* hollow, 3D printed components as an alternative to printing directly *with* them.

The company was founded in 2022, but development of what would become the company's continuous fiber injection process (CFIP) technology began in 2013 by a team at Barcelona-based research organization Eurecat led by Marc Crescenti, who is now Reinforce3D's co-founder and CTO.

"Marc has a background in composites and had done a lot of work studying the use of continuous carbon fibers in additive manufacturing," explains Blanca Garro, Reinforce3D's CEO. "One of the problems is that with additive manufacturing, you have to add material layer by layer, which is difficult to do with continuous fibers and [also] get the properties you want. Many methods use short fibers instead because they're easier to layer, or there's a post-processing method involved. But what if the part requires continuous fiber reinforcement not back and forth, layer on layer, but *in all directions* within the part?"

Crescenti and his team sought to find a solution for reinforcing 3D printed components with continuous fiber reinforcement, and ultimately created the technology that would be commercialized as CFIP.

In January 2022, thanks to investment from BeAble Capital, the company Reinforce3D was founded to commercialize this technology. Garro, who came on board as CEO in 2023 with a background in the AM industry, says the first steps for the new company were to demonstrate the mechanical and lightweighting performance of CFIP, to define and develop commercial products and to generate additional patents.

The CFIP process

CFIP, which won a JEC Innovation Award in 2020, is a post-processing step for reinforcing a hollow, typically 3D printed part that could be made from a variety of materials — composites, ceramics, unreinforced polymer or metal. Garro notes that while designed initially to complement AM, CFIP could be used to reinforce any hollow part, such as a pultruded profile.

First, the completed hollow part must be inspected, and the cavities cleared of any debris. Then, the programmable CFIP injection head — which is either moved by hand in the first commercial version, or mounted on a robotic arm in the future version in development — feeds continuous carbon fiber and liquid resin into each hollow cavity.

Currently, the process is compatible with a range of industrial-grade carbon fibers 4-8 millimeters in diameter — supplied by Reinforce3D, as the fibers have to first be treated with the company's proprietary treatment process. A large range of thermoset, thermoplastic or bio-based resins could be used, limited only by the viscosity range compatible with the system, though most applications so far have used epoxy. Garro notes that the company plans to expand its future offerings to include glass, aramid and natural fiber options.

After injection — a process that Garro says takes only minutes — the part is then cured, either at room temperature or in an oven, depending on the specifications of the resin used and the temperature requirements of the application.

How do the exterior materials and interior injected composite react to one another? Garro explains that the company has evaluated and characterized a range of materials, studying the interface between the interior composite and exterior part. "There is both a chemical and physical reaction between any two materials combined in this way, so we've really worked to characterize this interface so we can consider their properties in the design process." The company is also able to conduct simulations and tests with new materials that customers may want to use, particularly for higher performance parts such as aerospace components.

Designing injection trajectories

The key to CFIP is designing "trajectories" for the fibers, to ensure optimized material volume and fiber placement are realized where needed to meet the part's strength requirements.

"We need to find a balance of how many fibers to use to get the needed properties while achieving a cost-effective solution in order to reach real business cases," Garro explains.

Currently, Reinforce3D offers consulting services, working with customers to simulate and optimize trajectories based on part design. A physical prototype may then be built and tested to validate the simulated models.

At the same time, the company is also working on several software solutions that »

The CFIP machine includes a manual or robotic injection head programmed to inject specially treated fibers and liquid resin via designed fiber trajectories.

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will be available to help customers design parts and injection trajectories themselves. The first will be a tool for checking the design of fiber trajectories *before* injection. "If a customer uses their own software to design the fiber trajectories, then they can upload the file into the checker and it'll validate whether or not the design will work with the process or if anything needs to be changed," Garro says.

Benefits: Lightweight, optimized strength, integral joining

"We make applications possible that might not be otherwise," Garro says. CFIP is said to enable lightweight parts with complex and curved shapes, optimized for high strength properties where they are needed. The integration of continuous carbon fiber as a reinforcing material often means the exterior component can be made with less material, potentially reducing overall part weight, or with less expensive material — for example, switching from a higher strength aluminum 3D printed component to a more cost-effective polymer.

In addition, CFIP can be thought of as a *joining* technology, Garro says. "In 3D printing, you are limited by your printing chamber's dimensions. Here, we can use this technology to join multiple 3D printed components with one reinforcement all the way through, enabling the efficient manufacturing of large structures. It's much stronger than adhesive bonding."

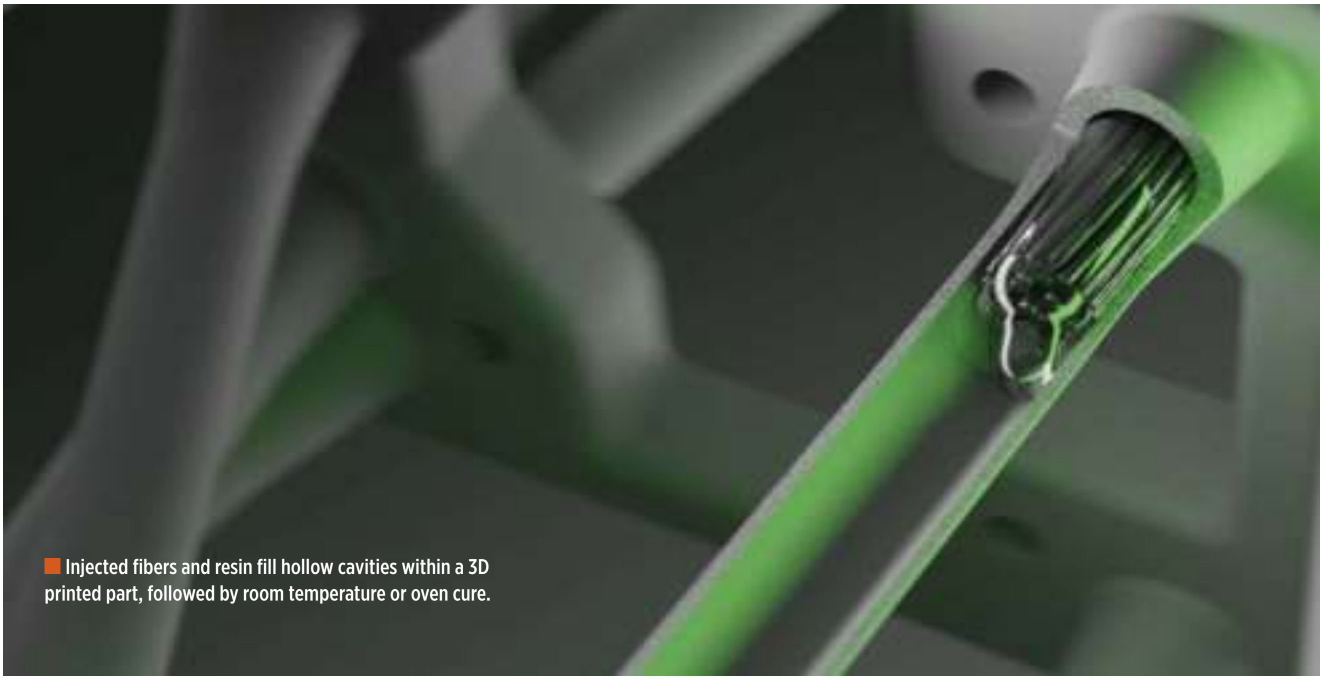
While true that an adhesive or a fixture must be used first to align the different components before injection, the interior composite, once cured, acts as an interior joining mechanism. "It's like a spine connecting the parts of the body together from inside," Garro says. "This technology enables larger reinforced parts than what you can usually make with 3D printing, because you can print each piece separately and then reinforce them together."

Reinforce3D has a physical testing laboratory to test prototype parts to breaking — particularly important for larger parts that are integrally joined using this technology. Although, Garro notes, "When we test parts to breaking, they never break at the joints, as you would expect if the part was only bonded or fastened."

Furthermore, while the process was designed originally for use with 3D printing, it could also be used with other processes. For example, fibers could be injected into hollow composite parts made via pultrusion or filament winding if extra reinforcement was needed in that direction, or injected onto polymer or composite parts made from traditional methods like extrusion or injection molding. Regarding the latter, Garro explains that "this is newer for us, but we are starting to study multi-material parts, and injecting our fibers into polymer molds or onto already finished parts. It's been a very interesting development so far."

Applications across end markets

According to Garro, CFIP has been used in a variety of prototype and R&D projects in a range of industries, including projects for Airbus (Munich, Germany), marine defense manufacturer Navantia (Madrid, Spain) and tooling for automotive manufacturer SEAT (Barcelona, Spain).



Injected fibers and resin fill hollow cavities within a 3D printed part, followed by room temperature or oven cure.

This satellite support demonstrator combines 3D printed PA12 (darker, top left portion of the part) and aluminum (bottom right) parts, joined in the interior with continuous carbon fiber and epoxy. Black-colored fixtures serve to keep the exterior components aligned during injection.

There has also been a lot of commercial interest in sporting goods equipment, especially for high-performance bicycle frame components, but also other types of equipment and elite sports shoes, such as shell and cuff components for Dalbello (Treviso, Italy) ski boots.

Looking ahead, Garro sees opportunities in applications such as interior aircraft brackets, spacecraft and antenna components, automotive brakes and components for race vehicles, fixtures and robotic arm components.

In-house demonstrator: Satellite antenna support prototype

To demonstrate the uses of its technology for customers, Reinforce3D has produced several demonstrators including a satellite antenna support based on a case study design published in 2015 by space equipment manufacturer RUAG Space (which has since changed its name to Beyond Gravity, Zurich, Switzerland).

The original design was for a small support and bracket, measuring 385 millimeters tall × 345 millimeters long, made from 3D printed aluminum and weighing about 950 grams (a reduction from the previous 1.6-kilogram machined metal version). The Reinforce3D team used finite element simulations and its own topology optimization to determine how to integrate CFIP technology to reduce the part weight even further while maintaining the same strength, stiffness and vibration requirements.

Ultimately, a demonstrator was made: The 3D printed outer component was printed in two pieces, one made from aluminum alloy using selective laser melting (SLM) — similar to the original RUAG case study component — and the other made from polyamide 12 (PA12) using MultiJet Fusion (MJF). These two pieces were aligned with external fixtures and then injected with carbon fiber/epoxy using the CFIP system.

The results? The CFIP-enhanced component was mechanically tested and proven to meet the original mechanical requirements while only weighing 484.4 grams — a reduction of 48% compared to the 3D printed aluminum version and a 70% decrease compared to the original machined metal version. The use of reinforcing carbon fiber also enabled them to remove some of the costlier printed aluminum, which reduced material costs.

According to Garro, this prototype serves as an example of how CFIP technology can help reduce weight and costs while maintaining performance, and how it can be used as a joining technology to connect not only two separately printed pieces but two pieces made from different materials.

Next steps toward commercialization

Today, Garro says the young company is working on readying its technology for commercial production. The business model will be two-fold: Reinforce3D currently provides consulting services to companies interested in this technology, and can design and manufacture prototype parts with its in-house system. In the future, the company will also sell machines and spools of treated carbon fibers directly to customers like 3D printing service providers, manufacturers of composite structures or end users. The company will continue providing consultancy services, especially for customers looking for uses with new materials or with complex part requirements.

"Right now, we're in talks with fiber suppliers to solidify our partnerships for materials supply. We're working with 3D printing service providers like Materialise [Leuven, Belgium], to optimize the process for use by customers. And we're doing a variety of consulting projects with customers in various end markets."

Reinforce3D plans for machines to be delivered by the end of 2024 to early adopters of the technology, including those it has worked with on prototypes and R&D projects, and then for the product to launch publicly in 2025.

Garro adds, "We've proven this technology is able to significantly reduce weight and maintain or even increase performance — and not by reinventing how they're manufactured, but by reinforcing in a new way parts that are already there. We're excited to really see this take off in new directions." CW

ABOUT THE AUTHOR

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Teijin's 185,000-square-foot carbon fiber production facility in Greenwood, South Carolina, occupies 12 acres of an expansive 440-acre property, offering ample room for growth. Source (All Images) | Teijin

PLANT TOUR: Teijin Carbon America Inc.

Greenwood, S.C., U.S.

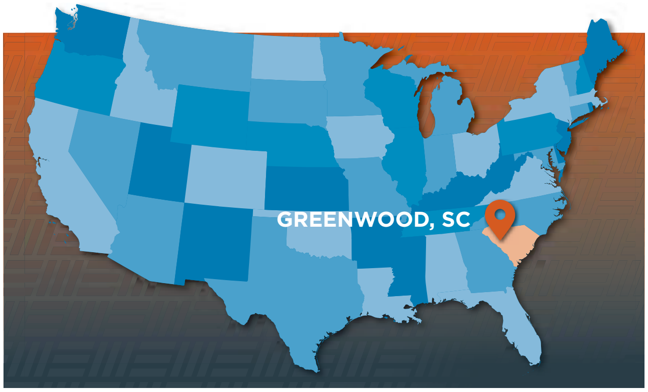
In 2018, Teijin broke ground on a facility that is reportedly the largest capacity carbon fiber line currently in existence. The line has been fully functional for nearly two years and has plenty of room for expansion.

By Scott Francis / Editor-In-Chief

» In 2001, Greenwood, South Carolina, was one of the most economically depressed counties in the U.S. By 2007, six major textile mills in the area ceased operations. The median income plummeted by nearly 28%, and poverty levels in Greenwood County had doubled within a short 3-year span.

During this time, Teijin Ltd. (Tokyo, Japan), a global advanced materials company, was searching for a site for a new U.S.-based carbon fiber production facility. The company previously had a Tenax carbon fiber line based in Rockwood, Tennessee, that was eventually converted to production of the company's Pyromex oxidized polyacrylonitrile (PAN) fiber used in flame-resistant insulation, carbon/carbon brakes and gas diffusion layers for fuel cells. After a number of years, increasing export challenges and shipping logistics motivated the company to invest in a new U.S.-based facility dedicated to Tenax structural carbon fiber.

With 20 potential sites initially under consideration, the focus soon narrowed to six options based on crucial factors such as



access to utilities, skilled labor, infrastructure and governmental support at the state and local levels. "These sites were nearly identical in what they offered us. We chose Greenwood because it was a place where we felt we could make a significant impact in the community and operate efficiently," says Aaron Buchok, business development manager for Teijin Carbon America Inc. (Greenwood, S.C., U.S.). The site also offered a talent pool of people with textiles training as well as rail access to Atlanta, Charlotte and the ports of Charleston and Savannah, providing shipping and logistical advantages.

Room for growth

In addition to these benefits, the site in Greenwood County, at approximately 440 acres, also offered plenty of room for future expansion. Teijin envisioned multiple carbon fiber lines , including the production of precursor materials, thereby ensuring self-sufficiency in the manufacturing process at this facility.

While PAN precursor for the Greenwood plant is currently imported from Teijin's Mishima plant in Shizuoka Prefecture, Japan, the company says that with sufficient growth in the market, such a line could possibly be part of future expansion at Greenwood.

"The site was selected specifically for our ability to expand it," says Buchok. "We have sufficient room to support multiple carbon fiber lines here, as well as precursor — so we could make our own feedstock here as well."

Teijin purchased the property in 2017, and with help from the state of South Carolina expects to create 220 full-time positions by 2030. The company broke ground on the new facility in June 2018 and today the 185,000-square-foot Greenwood plant occupies a little over 12 acres of the expansive property. Its operational carbon fiber lines have been producing materials for almost two years, serving industries ranging from aerospace to automotive.

"We're making sellable material today," says Buchok. "Much of that capacity goes to supporting our prepregging customers or customers who will weave them into dry textiles."

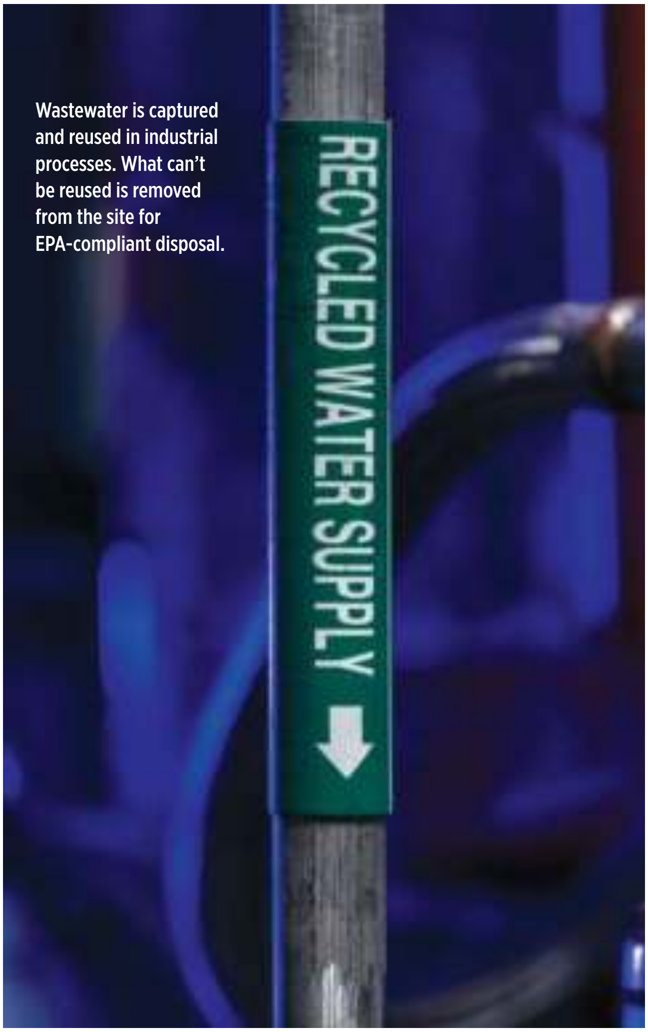
Currently, the Greenwood facility is producing industrial- and aerospace-grade 12K and 24K fibers in standard and intermediate modulus formats. Buchok says the company has done preliminary work to bring high modulus fiber to the plant as well.

"Initially, it was almost 100% industrial," he says. "In our industry, we have to earn our way into an aerospace rating, and we do that by demonstrating stable output over the course of a number of production runs. Once we've exceeded that number, then we're allowed to market that to an aerospace customer base. Our focus during that first year is on completing that demonstration of our ability to produce materials at the quality and consistency that the aerospace customer base expects."

The plant's standard modulus fibers have been at aerospace grade for a little over a year now. While Teijin will not divulge the exact production numbers for the South Carolina plant, it is said to be similar to the 2,700 metric tonne/year line added to its Mishima Plant in Japan in 2008.

An eye on the hydrogen market

Teijin's vision for growth is based on the company's strategic alignment with emerging markets, an example of which is in hydrogen energy storage. As the demand for hydrogen-powered »



Wastewater is captured and reused in industrial processes. What can't be reused is removed from the site for EPA-compliant disposal.

Working the line

It takes at least 6 months to train an operator and a year to train a shift leader. Even with the local talent experienced in textiles, learning how to thread and manipulate carbon fiber production equipment is a specialized skill.

The plant is equipped with several support devices in all the areas where things could commonly go wrong, enabling operators to detect anomalies in the process promptly. These devices also allow safety, operations and compliance technicians to monitor operations remotely.

Throughout the production process, rigorous quality control measures are implemented to ensure that the carbon fibers meet strict specifications for strength, modulus, density and other mechanical properties. This includes regular testing and inspection of raw materials, intermediate products and final products to identify any defects or deviations from standards.

The Greenwood plant's main control room is situated toward the end of the production line near the sizing stage. It is controlled by an operator 100% of the time when that line is running. This job requires a minimum of 7 years of experience and is the most technically intensive job in the plant. This operator is responsible for the safety of everyone on the line as well as constant monitoring of the entire production process, including recipes, temperature, tension and line speed.

The Greenwood plant features redundant control rooms and all processes can be run from either location monitored from several others including the plant manager's office.

vehicles and industrial applications surges, the Greenwood site offers the flexibility to cater to the evolving needs of customers.

"Today, we see automotive manufacturers already putting hydrogen vehicles on the ground," says Buchok. "We've got ground-based Type 4 hydrogen storage facilities for industrial applications already out in the world. This is real, and it's going to heavily influence the composites market for at least the next decade."

How Teijin is positioning itself to serve this market has played into the design of its Greenwood plant. Pressure vessel manufacturers for hydrogen applications generally prefer to work with larger tows — 12K, 24K and higher — which enable them to build tanks faster using less manpower and less machine time. The Greenwood plant is specifically built around larger tow sizes —12K and above — which helps position the company as a frontrunner for providing materials to the hydrogen energy sector in the near future.

Building on experience

Walking from Teijin's Greenwood offices to the plant, the size of the property is readily apparent. The facility is surrounded by fields and woods, and Teijin manages a registered wetland area on the site. Employees frequently encounter deer grazing in areas between the buildings. "We have a very strong wildlife population here that we are obligated to make sure we're treating responsibly," Buchok says.

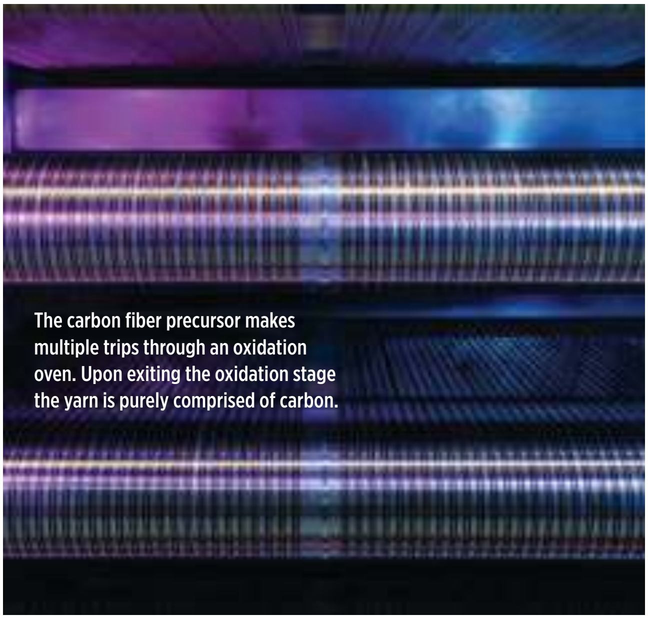
Teijin takes its stewardship of the property very seriously. Buchok says the site was chosen with the intent to manage it in a sustainable and responsible manner. The company drew on the best of its facility designs held internationally in terms of operational output, robustness and sustainability.

The facility's wastewater is also captured and treated with the same care. Teijin recycles as much water as it possibly can from the facility for reuse in its industrial processes. What can't be reused is collected on site for EPA-compliant disposal. None is released into the surrounding environment.

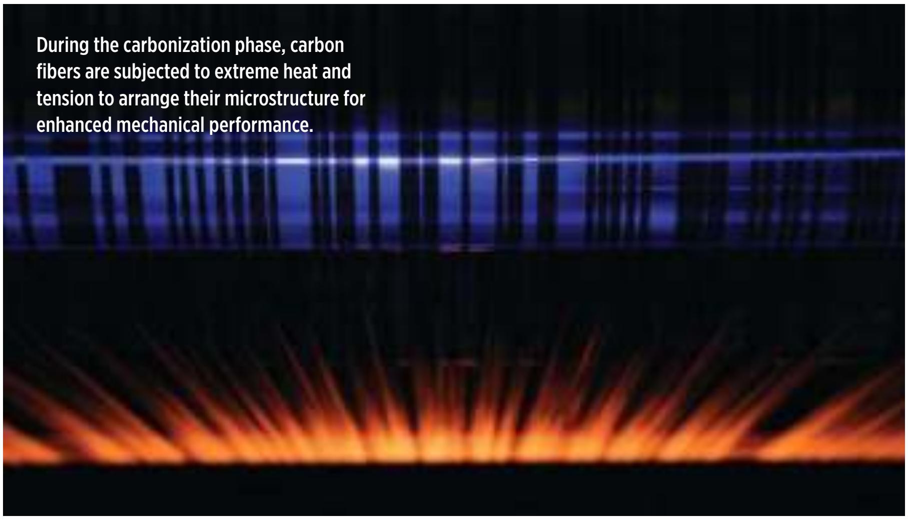
Entering the plant, Buchok reiterates that Teijin designed the Greenwood plant based on a similar structure to its facilities overseas, looking to its plants in Germany and Japan for lessons learned and where they might be applied. One example is the eventual adoption of new technology aimed at reducing energy consumption for carbon fiber conversion, originally developed in another facility. A team has been dispatched to gather insights from that location, with plans to eventually implement the same technology in Greenwood, likely within the next 3-4 years.

The shared architectures and processes among Teijin's plants facilitate swift translation of innovations. In many ways, the Greenwood facility represents the culmination of the company's past efforts and the hope is that future iterations will surpass current standards, leading to continuous improvement in subsequent production.

Teijin's carbon fiber feedstock is produced in a fully ISCC (International Sustainability & Carbon Certification) certified plant. ISCC is a sustainability in manufacturing certification that ensures that there is complete traceability at all stages of the manufacturing process of a product. Teijin plants in Germany achieved



The carbon fiber precursor makes multiple trips through an oxidation oven. Upon exiting the oxidation stage the yarn is purely comprised of carbon.



During the carbonization phase, carbon fibers are subjected to extreme heat and tension to arrange their microstructure for enhanced mechanical performance.

the ISCC certification for their carbon fiber production lines earlier this year and Buchok says the Greenwood facility is currently on track to achieve the certification within the next year or so. The ultimate goal is to have each of Teijin's processes meet the expectations of the ISCC certification process from precursor manufacturing all the way through delivery.

"All of that was integrated into this site when we built it," says Buchok. "It has full energy monitoring capabilities. We can run high-fidelity life cycle analyses. We can tell you in highly precise levels, what our emission and energy consumpiton is from this facility as a function of which product we're making."

Buchok says those tools enable the plant to determine the full impact of any process changes from an energy consumption perspective, which ultimately translates into sustainability and cost.

Oxidation

Up three flights of stairs, the carbon fiber production starts with large creels of PAN precursor — the primary precursor used in the production of carbon fiber due to its exceptional strength and heat resistance. The fibers are drawn through a series of oxidation ovens to remove any solvents or impurities.

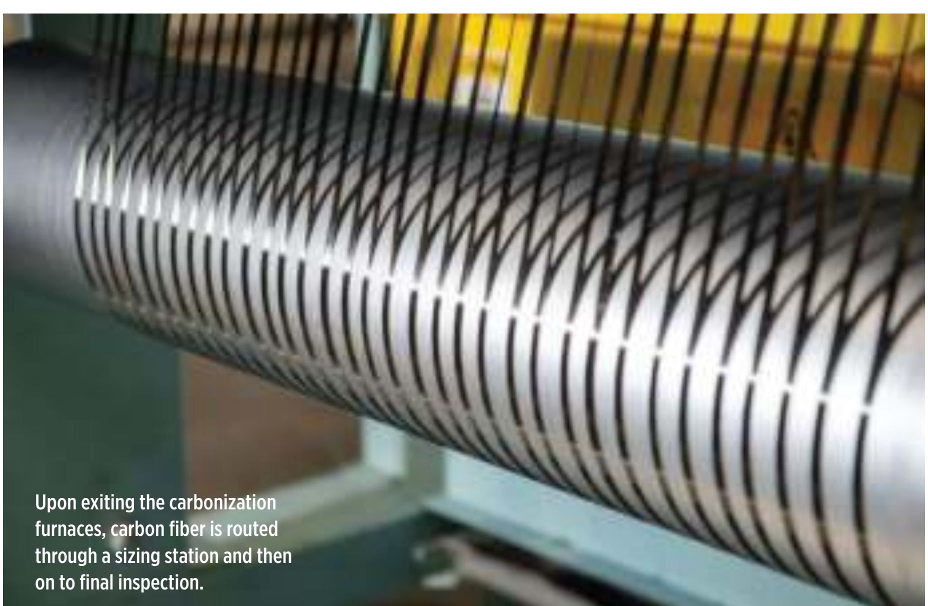
By the time the PAN exits the first oxidation oven, oils have been removed and it has changed to a golden amber color. As the PAN proceeds through additional chambers, the fiber is continuously oxidized and purified, removing anything that is not carbon. In the oxidation process, the strands of fiber make multiple trips back and forth — with each cycle further "cooking" the fiber and gradually darkening it. The fiber is routed through another set of ovens before it is fully oxidized.

Buchok says the oxidation stage is really where the art and science comes into play, with everything past these steps being a fairly well-established process. "Oxidation is where everybody has their secret sauce, and they put their own personal spin on it," he says.

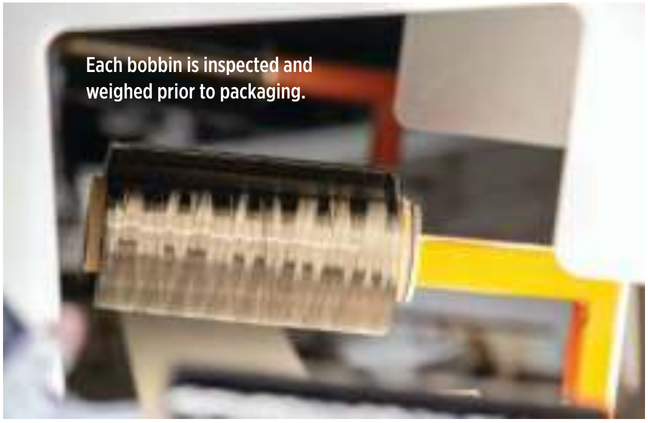
He goes on to explain that oxidation procedures vary slightly from manufacturer to manufacturer, which leads to variation in the performance of different carbon fibers on the market. Teijin specifically engineers its precursors to work in conjunction with its oxidation processes.

By the time the yarn exits the final oxidation oven, it is fully darkened and chemically refined. The later steps of the process use high- temperature furnaces and controlled tension to build and refine the microstructure, or arrangement, of the carbon atoms.

Given the exothermic nature of carbon fiber production, Buchok is quick to point out some of the safety measures that Teijin has in place. "As we oxidize [the fibers], they release more energy than we put in," he says. "With that comes a reasonable risk for fire. All of these ovens are designed with fire sensors inside of them. If one detects that there's a problem with that fiber at all — if any fiber starts to glow like an ember — it will trigger a three-stage fire system which includes fire curtains, a fog system and a water deluge system to prevent a larger safety issue." »



Upon exiting the carbonization furnaces, carbon fiber is routed through a sizing station and then on to final inspection.



Each bobbin is inspected and weighed prior to packaging.

A robot packs spools of carbon fiber into cartons for shipping.

He also points out disposal chutes for smaller broken fibers. Outside the atmosphere of the ovens, the still-reacting fibers can potentially burst into flames. Operators place these broken strands into the disposal chutes which douse them in water, extinguishing them. The fibers then fall to a collection bin in the basement of the plant to be disposed of later or to be recycled.

Finishing the tour through the oxidation stages, Buchok explains how technicians deal with any broken yarns at any given stage of the process. A break in one of the strands will trigger alarms that migrate from zone to zone until the operator locates the break, ties it off, restrings it and then tracks the yarn all the way through the process. In accordance with Teijin's zero waste goal, these shorter yarns are collected and sorted for smaller spools, short bobbins and even chopped products for secondary revenue streams.

Carbonization

After oxidation is the demarcation point between ovens and furnaces. The oxidized fibers will now be refined via carbonization in specialized furnaces at temperatures exceeding 1500°C in a controlled inert atmosphere (nitrogen or argon, depending on the product being run). This atmosphere prevents combustion and ensures the carbon fiber does not bond with outside elements. During this phase, the yarns undergo a series of chemical reactions that transform them, arranging their microstructure for mechanical performance.

At this stage, the fiber is processed at different speeds, different temperatures and different tensions depending on the product being run on the line. Fibers are bundled together in a tighter configuration as they enter the carbonization furnace, allowing for a smaller footprint that translates to energy savings.

Buchok says similar furnace designs are used in each of Teijin's facilities, allowing for redundancies and sourcing of spare parts from other locations.

Surface treatment and sizing application

As the fibers exit the carbonization furnaces, rollers guide them apart from their tightly bundled configuration, through a water bath to wash the fiber and then through a drying oven.

At this stage, the carbon fibers undergo surface treatment to improve handling during composite fabrication, and to enhance adhesion, mechanical properties and compatibility with various resin systems. Teijin maintains a catalog of dozens of different sizings and finishes to meet its customers' different needs.

The Greenwood plant features redundant sizing stations to minimize and even eliminate downtime whenever a sizing change is required. Operators are even able to change sizing midstream if needed. At the end of the sizing station, an oven provides thermal treatment for certain sizings. While it isn't a frequent requirement, it is an important one — for example, many pressure vessel applications require sizings that need this treatment.

Inspection, winding and packaging

Once the carbon fibers are processed and treated, they are routed back up a level for quality inspection performed using optical cameras as well as visual inspection. Each yarn is traceable from the individual spindle back to its precursor batch, enabling Teijin

An operator visually inspects a carbon fiber sample from a production run.

Samples from a production run are tested for density.

to track any problems back to the source and easily identify any other affected products.

Carbon fiber is then fed back down a level, ready to be wound onto bobbins and packaged in a fully automated inspection and packaging line. Bobbin winders are set up to automatically change to a fresh spool when a bobbin is full. Standard packaging is 3, 6 or 8 kilograms per bobbin with the capability to rewind as needed. Each bobbin is then visually inspected for package integrity.

From there, a bobbin goes through a number of stations. First, a barcode with traceability information is applied to the spool — the same barcode was applied to the core earlier in the process. Next, it moves to an automated scaling system to be weighed. Here, computers will extrapolate and record the weight — every spool is provided to the customer with the actual weight of carbon fiber on it. In the final step, spools are shrink wrapped and prepared for shipping.

In the lab

The last stop on the tour is back up to the third level where the facility's laboratory is located. A computer system downstairs keeps track of all the spools that are produced and randomly assigns spools to be pulled for testing. The system is programmed to pull samples based on knowledge of the customer's requirements and will designate a determined number of rolls at the head and tail of each run for testing.

A number of evaluations are performed using a combination of chemical and physical testing. The yarn is tested for weight and density. The sizing chemistry is also checked by using a solvent to take the chemistry back off. The naked fibers are weighed to extrapolate how much sizing was actually added during the process and compared to the prescribed amount. The lab is also equipped with a small impregnation line, enabling specimens to be wetted out with epoxy resin for mechanical testing.

Teijin tends to sample more heavily at the start of a run to ensure its equipment is dialed in correctly before committing to the full production. Results are compared against a database where customer certifications are stored, making it easy for quality control technicians to assess a batch and certify it for shipment to the customer.

Looking to the future

As Teijin looks to expand its operations at the Greenwood site, the company is very measured in its approach, prioritizing efforts to minimize its carbon footprint while maximizing operational efficiency. "We've built this plant to be able to take advantage of every lesson that we've learned throughout our global infrastructure," emphasizes Buchok.

With this first phase of its Greenwood facility fully operational, Teijin is charting an ambitious course to help ensure a steady supply of carbon fiber for both current and emerging markets, reduce the company's environmental impact and align with increasingly stringent global environmental regulations.

Buchok says the site is capable of handling more than half a dozen carbon fiber lines along with facilities for research and raw materials manufacturing, all of which are part of Teijin's goals. "That's probably a plan measured in decades," he says. CW

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More about the making of carbon fiber | short.compositesworld.com/MakingofCF

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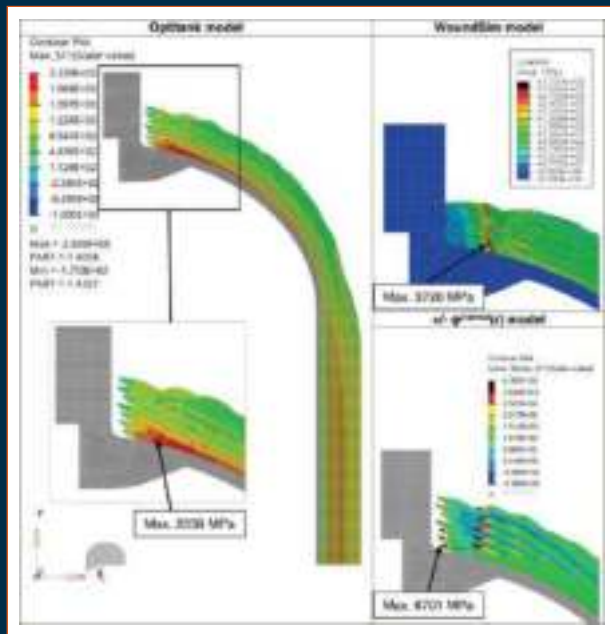

Source | THOR project

THOR project for industrialized, recyclable thermoplastic composite tanks for hydrogen storage

Cetim reviews objectives, tape and liner materials, LATW and recycling processes, design software and project achievements toward commercialization of Type 4.5 carbon fiber TPC tanks.

By Ginger Gardiner / Senior Technical Editor

EDITOR'S NOTE: This article is an excerpt of a larger blog piece. To access the original article, use the QR code provided in the "Learn More" box on p. 40.

» The Thermoplastic Hydrogen tanks Optimized and Recyclable (THOR) project (2019-2022) was funded by the Clean Hydrogen Partnership to develop an industrializable and recyclable thermoplastic composite (TPC) pressure vessel for hydrogen (H_2) storage onboard vehicles and also in multi-tank modules for distribution/transportation. All such current storage solutions are made using thermoset composites. The THOR project produced 15 TPC tanks in collaboration with laser-assisted tape winding (LATW) technology supplier AFPT (Dörth, Germany). These included tanks that held up to burst pressures of approximately 1,500 bar, just 6% short of the 1,580 bar required per the EC79 qualification standard.

The THOR project was led by Faurecia (Nanterre, France) a longtime automotive Tier 1 that is now part of the Forvia Group, the world's seventh largest automotive supplier. Faurecia has developed a range of H_2 storage and drivetrain systems for cars, commercial vehicles and heavy trucks and started production in Allenjoie, France, in a facility with capacity for 100,000 Type 4 tanks/year.

Cetim (Senlis, France) was another project partner, participating via two sites. Cetim Grand Est (Mulhouse, France) worked to demonstrate recycling of TPC tanks at their end of life (EOL) using its Thermosaïc technology. Cetim (Bouguenais,

Industrial partners:
Faurecia (France) Coordinator, lead for industrialization
Air Liquide (France) H_2 distribution tank end-user, expertise in fueling/defueling
Cetim (France) Laser-assisted tape winding process definition, modeling, prototyping of tanks
Cetim Grand Est (France) Recycling process
RINA-CSM (Italy) Testing of tanks
Research partners:
Sirris (Belgium) Winding definition, modeling, optimization
NTNU (Norway) Optical fiber instrumentation, data analysis
CNRS-PPRIME (France) Thermomechanical modeling, material behavior in fire

France) at the Composites Technocampus near Nantes stepped in when the THOR project had to restart mid-term due to withdrawal of original tank manufacturing partner, Covess (Hasselt, Belgium). This Cetim site worked with Faurecia and helped partner Sirris (Brussels, Belgium) adjust its TPC tank design to work with Cetim's LATW technology, called Spide TP. Within 18 months, the team completed production and testing of demonstrator tanks.

"We had already been working with TPC tape manufacturers, for example, to study tape quality and its impact for our process," says Clément Callens, head of Polymers and Composites Engineering Department at Cetim. "But then we started seeing industrial companies wanted to use tape winding to develop H_2 storage tanks. Now, the TPC tape suppliers want to make sure they are developing materials that can be used to make H_2 tanks in the future. This has been a big area of development for several years now."

The TPC tank baseline for THOR was based on a Faurecia state-of-the-art Type 4 *thermoset* composite tank with a nominal working pressure (NWP) of 700 bar and water volume of 63 liters. It featured a rotomolded liner made with PA11 polymer from Arkema (Colombes, France) overwound with T700 carbon fiber (CF) from Toray (Tokyo, Japan) using epoxy resin in a traditional wet filament winding process. THOR's tank, however, would need to be redesigned to use TPC tape and Cetim's process, which uses a laser and achieves in-situ consolidation where no further vacuum bagging, oven or autoclave process is required. The demonstrator tanks made using this process were then tested to validate the feasibility of this technology to meet industry requirements and enable mass production as well as recycling at EOL.

Spide TP process

This is an automated tape winding process developed with AFPT, says Callens. The original system used a KUKA (Augsburg, Germany) robot with a linear rail and a tape winding head from AFPT equipped with a 4-kilowatt laser that can apply TPC tape up to 25.4 millimeters wide. The system also had two external axes for winding — a smaller axis up to 3.5 meters long and a larger axis up to 6 meters long. The process begins with a mandrel or tank liner mounted into one of the rotating axes. The robot then places heated tape along desired paths to create the composite laminate. As the heated tape is placed, a compaction roller applies pressure, which removes air and achieves consolidation. "With in-situ consolidation," notes Callens, "the product is finished at the end of winding. You don't have to put the part in an oven or autoclave." »

THOR project manufacturing of thermoplastic composite pressure vessels at Cetim. Source | THOR project

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"We have proved [through THOR] we can make good laminates with low porosity and sufficient crystallinity for high mechanical properties," he continues. "The issue now is how we can be fast enough to have reasonable costs because the TPC tapes are more expensive than the materials used with wet filament winding. And that's a topic we are also working on because we are investing in a second tape winding line, again with AFPT, but with an optimized head for the laser and tape application to be very fast, specifically for repeatable H_2 tank production with a good industrial cost."

Type 4.5 or 4+ tanks

"Cetim was not really at the beginning of the project, but I think the idea was to go for Type 5 tanks," says Callens. "But, as we developed the tank, we saw that when using TPCs, you can achieve a tank that is in between Type 4 and Type 5 — what we call Type 4+ — because you can weld the first composite layer to the thermoplastic liner. This structural connection helps to prevent the liner from collapsing, which is a problem." THOR partner Air Liquide explained in an end of project summary: "All cylinders are hydraulically pressure tested after manufacturing. To meet ISO 14687 hydrogen gas purity requirements for a fuel cell, cylinders have to be decontaminated to remove water, etc. The best way to do this is repeated cycles of compression and vacuum. In some cases, the plastic liner can collapse during these cycles."

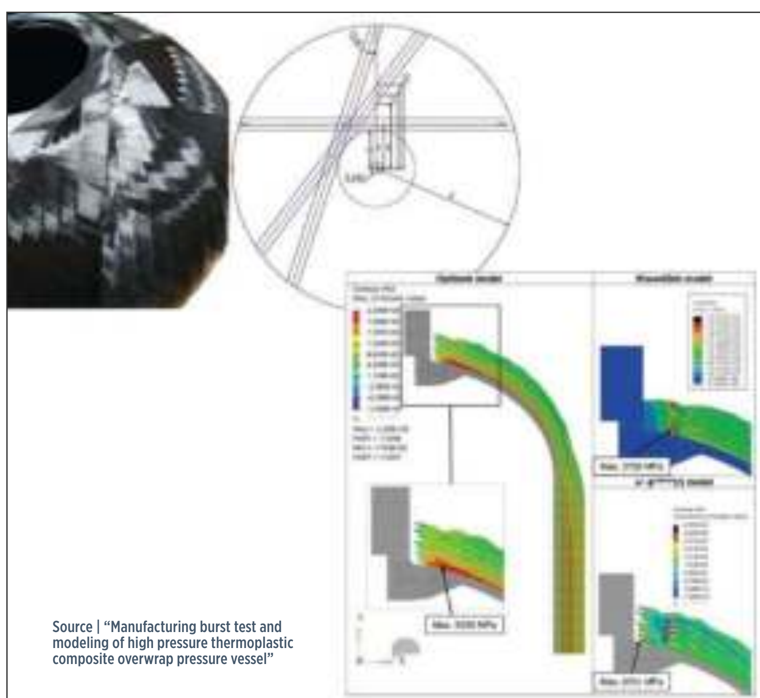
"We didn't really have a choice in what materials to use," says Callens. "When we started the project, it was difficult to find carbon fiber/thermoplastic tape in the market that fit the LATW process." During suitability trials, led by Faurecia, the first material tested produced sub-quality tanks due to poor homogeneity of the tape, which reduced mechanical properties, and also dry fiber in the tape surface, which made it difficult to achieve in-situ consolidation during LATW. The project then sourced off-the-shelf CF/PA12 tape from Suprem (Yverdon-les-Bains, Switzerland), which produced six tanks with reasonably good burst test performance, but the ability to achieve a Type 4.5 tank where the composite laminate is welded to the liner was not really possible. Thus, the project worked with Suprem to procure a specialized CF/PA11 tape to match the PA11 liner and manufactured an additional four tanks.

"We worked a lot in the past with Suprem because their tape quality is very good for the LATW process," adds Clemens. "But that's changing; we see many other manufacturers able to make sufficient quality tape today. Cetim is working with more manufacturers who want to qualify tape materials for hydrogen tanks. There has been a significant increase in interest."

Winding simulation

Project partner Sirris was in charge of the design and used WoundSIM software developed by Dassault Systèmes (Vélizy-Villacoublay, France) with Simulia development partners QustomApps (Ponder, Texas, U.S.) and S Vertical (Châtenay-Malabry, France). (WoundSIM was released in 2019 and is now maintained by S Vertical.) Developed for thermoset composite winding processes, WoundSIM uses classical and well-known theories to describe fiber angle distribution, thicknesses and shape of the layers for a generally assumed thermoset filament winding process. During several design loops, Cetim assisted Sirris to analyze material behavior and LATW process specifics as well as some limitations of the models to evaluate different configurations. Adjustments were made and the tank was modified according to the project schedule. Development phases included:

- Definition of stackings with liner/boss geometries and different tape characteristics (iterations 1 and 2).
- Specific studies on interlaminar shear behavior after first iteration result (burst at 738 bar due to weak processed material performance and consolidation).
- Optimization of a boss design to specific requirements of THOR project.
- Definition of a new sequence of winding angles based on THOR inputs (iteration 3).



Source | "Manufacturing burst test and modeling of high pressure thermoplastic composite overwrap pressure vessel"

Hydraulic Burst

Hydraulic Burst		
Tank n.	Result	Max pressure
1	Burst	737 bar
2	Leakage	327 bar
4	Burst	1446 bar
5	Burst	1476 bar
6	Burst	1256 bar

Accelerated Stress Rupture

Hydraulic Burst				
Tank n.	Pressure	Temperature	Result	Time Elapsed
2	437.5 bar	85°C	Leakage	1,000 h
8	875 bar	85°C	—	ONGOING

Ambient Temperature Pressure Cycling

Hydraulic Burst				
Tank n.	Pressure cycle	Temperature	Result	Cycles reached
7	20 bar to 875 bar	20 (±5°C)	Burst	1,836

Thermoplastic composite (TPC) tanks manufactured in the THOR project and test results. Source | THOR project

Demonstrator tanks and testing

The THOR project built 15 TPC tanks and validated their performance through tests outlined in EC79 qualification, including:

- **Burst test —** Fill tank with water, hydraulically pressurize until leak or burst occurs.
- **Accelerated stress rupture (ASR) —** Fill tank with water, hydraulically pressurize at 85°C to 125% NWP without rupture for 1,000 hours or until leak occurs.
- **Ambient temperature pressure cycling.**

The target burst pressure was 1,575 bar. Tanks #4 and #5 achieved the highest burst pressures, the latter within 6% of the target value. "At Cetim, we believe there is still a big improvement that we can achieve on the design of the tank and winding that would allow meeting this target," says Callens.

Recycling

Recycling was a key part of the THOR project. "The idea was to show that you can recycle the EOL tank, with added value," says Callens. "This is compared to just crushing all of the tanks and making a new material for injection molding. That approach is quite low in terms of value because you start from a high level of composites performance, and you finish with recycled short fiber-reinforced polymers. Instead, we showed technology where you can make chips from the the EOL tanks that keep the length of the carbon fibers. We then put these chips into the Thermosaïc and make new panels that have an intermediate mechanical performance between short fiber compounds and classic continuous fiber composites. These panels can then be used for new stamped parts."

Due to time constraints, this recycling work had to be done in parallel with tank testing. Thus, actual tanks were not used but representative CF/PA11 materials were used to validate the recycling approach. After various trials, a process was identified that allowed chips with fiber lengths of 60-200 millimeters and a thickness of 0.3-0.4 millimeter. »

Despite a reduced time for developing this new design, tanks #4 and #5 produced by Cetim achieved 1,466 and 1,476 bar, respectively, in burst testing.

However, the LATW process using TPC materials is quite different from thermoset wet winding. Notably, in-situ consolidation of medium-width tape has a strong sensitivity to process parameters (temperature, compaction pressure) and tape characteristics (homogeneity in width, thickness and compressibility during consolidation). WoundSIM was not able to predict the right shape for TPC materials near the boss, which affected failure analysis.

During the correlation phase of the design work, Cetim used its in-house developed software, Optitank, to fill a gap in the detailed modeling specifically for TPC pressure vessels. Optitank uses a new theory to model composite tape stacking and geodesic paths around the dome area, including adapted thicknesses and angles to correctly model the geometry and stiffness of the wound composite.

Best results were achieved when PA11 powder was added for 37% fiber volume. There was no thermal degradation, and the bending performance was similar to compression molding and SMC materials, but Cetim notes further improvements are possible. These panels were then tested in stamping trials and showed good processability into complex shapes and in trimming/machining.

New, faster HySpide TP system for hydrogen tanks at Cetim Technocampus.
Source | THOR project, Cetim

HySpide TP new machine for H_2 tanks

Cetim continues its developments in H_2 tanks, including design and simulation tools and has invested in the HySpide TP system that enables 10 times higher winding speeds. Installed in September 2023, it features a new, optimized tape winding head from AFPT with a 150-kilogram payload KUKA robot and a rail/track with 4.1 meters of linear movement. Cetim reports that the tape laying speed for tanks will reach up to 100 meters/minute in the cylinder and 15 meters/minute in the domes, with also a new machine axis allowing design optimization in this area. The machine can also lay 40-millimeter-wide tapes and has an external tape supply unit that can accommodate winding reels holding 8,000 meters of tape, the maximum production capacity offered by suppliers.

"Today, the cost of materials used in wet winding is quite low because it's been used for many years," says Callens. "While thermoplastic composites tapes are more expensive now, we believe they will be lower in 2-3 years with the materials manufacturer developments that we are seeing, but there is still a need for higher process speed machines."

TPC tanks, recycled panels and stamped parts from THOR project trials.
Source | THOR project, Cetim

Proven feasibility, future industrialization

"We showed from a technical point of view that you can make TPC tanks that are able to reach the required specification," says Callens. "That was the first challenge of THOR — that this is feasible compared to thermoset solutions. However, we still have to show that this TPC manufacturing process can be an industrial solution in the future — which means showing we can optimize a specific TPC design and make tanks with a short cycle time to reach a cost target that fits the industry." The first such tanks with optimized design, manufactured using HySpideTP were displayed by Cetim at JEC World 2024 (March 5-7, Paris, France). CW

The THOR project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (JU) under grant agreement No 826262. The JU receives support from the European Union's Horizon 2020 research and innovation program and France, Belgium, Italy, Norway.

ABOUT THE AUTHOR

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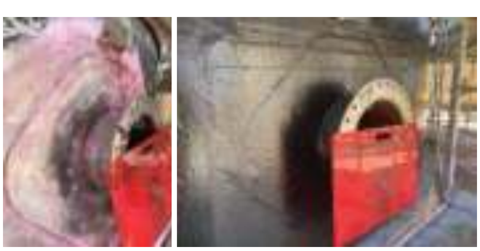
APPLICATIONS

Composite wrap system combats corrosion in industrial tank repair

A fiberglass and carbon fiber composite wrap system enabled an Australian nickel mine to quickly repair a stainless steel ammonium sulphate feed tank and protect against future corrosion.

A fiberglass/composite wrap system from coatings and composites supplier Belzona curbs corrosion under insulation for a nickel mine industrial tank application.
Source (All Images) | Belzona

The stainless steel tank before (left) and after (right) repair. See the bottom of the tank beneath the scaffolding.



The polymeric repair system (shown during repair at left, completed at right), helped mitigate the need to replace corroded portions of the tank.

» A global blue-chip nickel mine in Australia required a solution for repairing and preventing corrosion of its stainless steel ammonium sulphate feed tank. Industrial maintenance company Rezitech (Melbourne, Australia) was able to provide a full turnkey solution in the form of an industrial composite wrap system.

The mine's stainless steel ammonium sulphate feed tank, measuring 2 meters tall from ground level and 9.5 meters in diameter, was suffering from corrosion under its insulation as well as chloride-induced stress corrosion cracking. The company required a solution that would not only restore the integrity on the substrate, but also protect the asset against future corrosion damage. Not only this, but as the tank operates at elevated temperatures of approximately 70°C and processes highly corrosive media, the repair solution would need to be able to withstand these harsh conditions.

Having already worked for more than 5 years with Rezitech, an authorized distributor of Belzona (Harrogate, U.K.) coatings and composites, the mine contacted Rezitech again for advice and a system recommendation. Following an inspection by Heath Westell, sales engineer at Rezitech, the composite wrap system, Belzona SuperWrap II, was specified.

"This composite wrap system is comprised of a fluid-grade epoxy resin system, a bespoke hybrid reinforcement sheet, based on fiberglass and carbon fiber, as well as a release film to compact and consolidate the application," Heath explains. "The system is specially formulated to restore the strength of holed, weakened and corroded pipe and tank walls, making it the ideal solution for protecting the asset against corrosion under insulation for the long term. In addition, thanks to the cold-curing properties of the composite wrap system, this mitigates the need for hot work, making it a reliable alternative to welding."

To perform this procedure, all traces of oil and grease contamination were first removed using a suitable Rezitech degreaser. Next, the surfaces were grit-blasted to provide a surface cleanliness compliant with ISO 8501-1 SA 2 1/2 (ASNZ 1627.4 class 2.5) with a minimum 75-micron (3-millimeter) rough angular profile. Once the surface was prepared, the dry glass/carbon fiber Belzona 9381 reinforcement sheet was measured out and then wetted out on-site with the Belzona epoxy resin system. The resin was then systematically applied to the areas to be repaired. Following this, the Belzona reinforcement sheets were applied to the tank in three layers, and the compression film added to the top of the application area. Finally, using a roller, the Belzona SuperWrap II composite wrap system was spread, rolled and compressed to the surface of the tank. The system was then left to cure for approximately 8 hours.

The Belzona composite wrap solution enabled the customer to bypass the need to replace the corroded asset, and instead prolonged the lifespan of the asset for years to come. CW

SHOWCASE / MARKETPLACE

SHOWCASE

MANUFACTURING SUPPLIERS

NEW PRODUCTS

» Construction panels

Composite-structural insulated panels enable weather-resistant building construction

Modular Brands (MDLR Brands, Chattanooga, Tenn., U.S.), a company dedicated to reshaping modern living, introduces LiteSIP panels, eco-friendly and efficient composite-structural insulated panels (C-SIPs) designed to create disaster-resilient homes. The panels use a fiberglass mesh combined with a polymer that is either baked on or spread on as a solvent, as well as either a PIR or EPS core, providing strength, durability and energy efficiency.

Reusable and recyclable, LiteSIP panels are easy to assemble and durable enough to withstand hurricanes, earthquakes, tornadoes and fires. They work equally well in hot and cold environments, are mold- and termite-resistant and offer 20 years of UV protection, which can be reapplied every two decades.

According to MDLR Brands, what sets the composite panels apart are their versatility and adaptability, enabling them to be seamlessly integrated into various housing solutions. One suggested solution is Boxvana, a housing concept by MDLR Brands that leverages LiteSIP panels to create customizable, sustainable modular homes. **mdlrbrands.com**

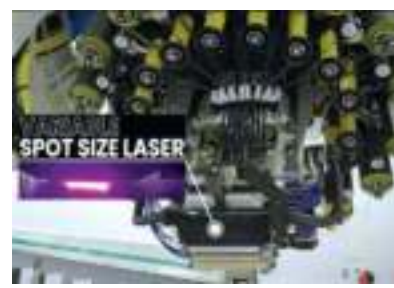
» Automated fiber placement

AFP 4.0 technology increases quality, reliability and machine utilization

Electroimpact's AFP group (Multikeo, Wash., U.S.) introduces the variable spot size laser (VSSL).

The VSSL is noted for its lamination quality. The system delivers the right amount of heat for each individual tow, resulting in consistent tow tack even when adding at 4,000"/min. Tow end placement is highly accurate and consistent due to improved tension and tow tack.

Optimized tack means no missed tows, Electroimpact emphasizes, especially short tows, and thus a more reliable process. The servo-creel is a high-performance tension system that assures no slack, and therefore no tow twists are possible. Because only the active tows are being heated and because the heat arrives at the moment the new tow meets the nip, there is no chance for a compaction roller wrap.



The VSSL laser and servo-creel enable 4,000"/min adds and 3,000"/min cuts, enhancing performance capabilities. **electroimpact.com**

» UD tape

Polyamide-based UD thermoplastic tape strengthens high-performance applications.

Toray Advanced Composites (TAC, Morgan Hill, Calif., U.S.) introduces Toray Cetex TC915 PA+ into its extensive portfolio. The Cetex material is well suited for sporting goods, high-performance industrial applications, automotive, energy (oil/gas and hydrogen), urban air mobility (UAM) and unmanned aerial system (UAS) applications.

The latest addition to the Toray Cetex product line, Toray Cetex TC915 PA+ is a thermoplastic UD tape that uses a high-performance polyamide resin. It can be processed by ATL and AFP, wrapping and thermoforming. It introduces enhanced performance attributes, offering increased strength, higher stiffness, higher temperature stability and lower moisture absorption. This high-performance thermoplastic material complements Toray Cetex TC910.

"TC915 offers mechanical properties higher than typical polyamide-based composites and nylon materials," says Mark Mielke, director of product and market strategy, USA. "These characteristics allow structural components to perform well in high-stress conditions at elevated temperatures, which is crucial for demanding markets." **toraytac.com**

» 3D printing

Reinforced, unreinforced polyamide materials advance industrial 3D printing

Materialise (Leuven, Belgium) has expanded its AM portfolio with the introduction of PA 12S and PA 11 for HP MultiJet Fusion (MJF) and carbon fiber-reinforced polyamide (PA-CF) for fused deposition modeling (FDM).

According to Materialise, PA-CF for FDM brings a notable advancement in lightweight, high-strength components. Consisting of a thermoplastic filament reinforced with 35% chopped carbon fiber by weight, PA-CF offers high flexural strength for an improved stiffness-to-weight ratio. This combination makes it a favorable alternative, particularly for tooling, prototyping and end-use part applications.

PA 11 for HP MJF features biocompatibility, durability and flexibility for the production of orthotics, prosthetics and machinery components. In addition, PA 12S has been introduced for volume prototyping and parts requiring good surface quality with minimal post-processing needs.

materialise.com

» Automated preforming

Compact composite preformer designed for small parts production

Loop Technology (Dorchester, U.K.) has launched FibreLINE 2X1, an automated composite preforming system designed specifically for smaller parts. This system is devised to manufacture car parts, train doors and aircraft wing components.

Existing within a smaller cell than the company's standard FibreLINE system, it uses a single robot equipped with an automatic toolchanger to complete the entire cycle of preforming. From deposition and cutting through to shaping, tacking and consolidation, the system lays up onto a 2 × 1-m tool.

The composite preforming system features material deposition rates of 200 kg/hr. It provides millimetric precision and repeatability when measuring, cutting, shaping and placing material, according to Loop Technology, while also handling large carbon fiber plies efficiently without damaging them. **looptechnology.com**

» Recycled carbon fiber

3D printing filament is reinforced with rCF

Carbon Conversions Inc. (CCI, Lake City, S.C., U.S.) offers re-Evo TDR, a 3D printing filament reinforced with recycled carbon fiber (rCF). TDR offers optimal stiffness, strength and dimensional stability at a competitive price, the company says, and prints with ease on "practically all 3D printers."

Similar to all CCI products, the company says it will continue to pedigree and reclaim carbon fiber from all of its waste streams to produce TDR products, making the material affordable for customers.

CCI is founded on the development of 3D preforming of reclaimed carbon fibers (such as from decommissioned parts) for a zero-waste, closed-loop manufacturing process at commercial scale. In terms of individual fiber performance, 95-97% of the original mechanical property is retained during this process. CCI has also commercialized the first generation of its recycled carbon fiber-loaded PLA and PA12 products.

carbonconversions.com

» Composites publication

Composites recycling study released in English

"The Composites Recycling Study," published by AVK – the German Federation of Reinforced Plastics (Frankfurt, Germany) in collaboration with the Institute of Plastics and Circular Economy (IKK), Leibniz University Hannover (Germany), is now available in English.

The publication offers a comprehensive overview of composites waste volumes by application sector. It presents the recycling solutions that are currently available and those being developed for the future. The advantages and disadvantages of the various processes are evaluated, and relevant legal requirements and standards are also considered.

The study was published in German in 2023. It was compiled by professor Hans-Josef Endres and Dr. Madina Shamsuyeva of IKK with the support of industry representatives from AVK's Expert Working Group.

AVK is a founding member of Composites Germany, which is a national association member of EuCIA.
avk-tv.de, ikk.uni-hannover.de/en

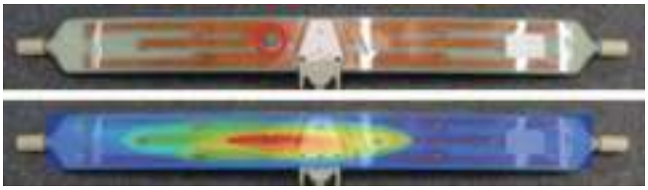
POST CURE

Highlighting the behind-the-scenes of composites manufacturing

Leaf spring with integrated SHM system supports comprehensive damage monitoring

» Under the Kosel research project, in collaboration with various partners, Invent GmbH (Braunschweig, Germany) developed a reusable carbon- and glass fiber-reinforced polymer leaf spring, along with an integrated structural health monitoring (SHM) system, for automotive applications. The integrated SHM system includes 14 piezoelectric transducers, which are alternately used as actuators and sensors. By applying a high-frequency alternating voltage of several hundred kilohertz via the system, Invent was able to evaluate the leaf spring's structural integrity, comparing it with the signals detected from the original, undamaged structure, directly after manufacturing. The SHM system's integration, therefore, enables continuous monitoring of the component to warn about damage, or to even assess the leaf spring at the end of a vehicle's life. For leaf springs that return with no damage results, they can be reused in another vehicle without restrictions.

Compared to conventional constructions, the production of the leaf spring is very resource- and energy-intensive.



However, due to its design and the integrated SHM system, the leaf spring can be used for up to three life cycles. As a result, the generated manufacturing-induced emissions are lower than those leaf springs with only one life cycle.

For the proof of concept, clay was applied to the surface of the leaf spring. The clay causes local signal damping and simulates a delamination within the leaf spring. As shown in the image above, the damage was successfully identified.

This project was funded by the German Federal Ministry of Education and Research. CW

For more information, reach out to Oliver Huxdorf at ***Oliver.Huxdorf@invent-gmbh-de***

Source (All Images) | Invent GmbH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