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RTM composite domes: BREAKING WATER PROTECTION PARADIGMS

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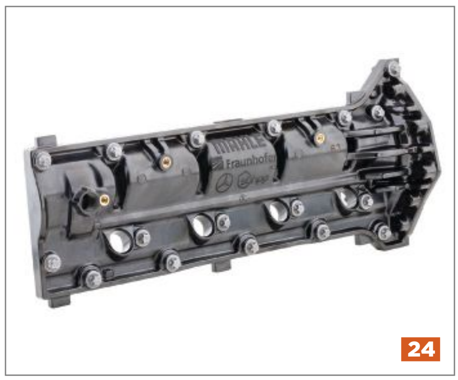
COLUMNS



FEATURES

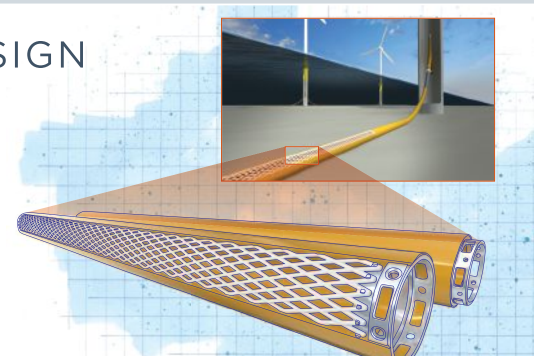
» DEPARTMENTS

» ON THE COVER

The Casablanca tank in Bogotá, Colombia, which holds 38 million gallons of treated water, is one of 59 tanks constructed by Empresa de Acueductos y Alcantarillados (Company of Aqueducts and Sewers, EAAB, Bogotá). Workers installed 840 composite covers (in blue) manufactured via resin transfer molding (RTM) by composites fabricator Soling over a period of 7-8 months. See p. 28

Source | Soling

FOCUS ON DESIGN



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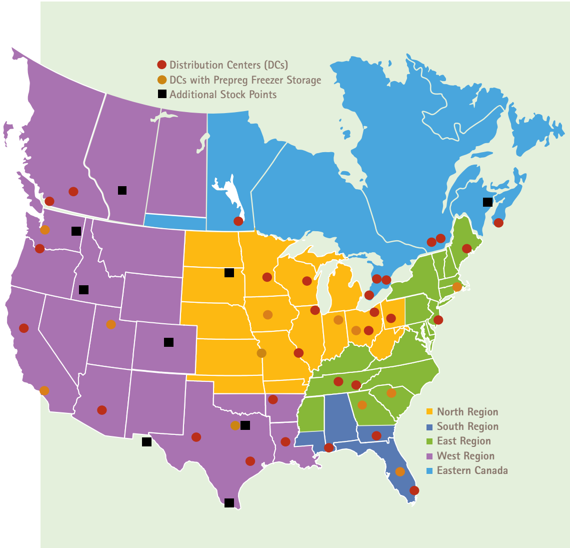
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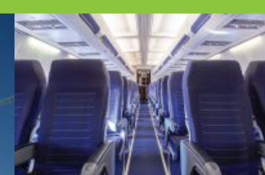

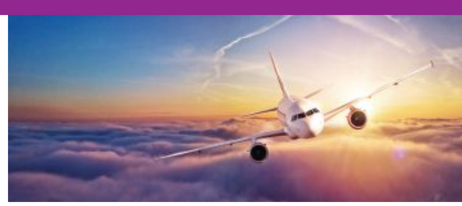

In February 1997, I was a senior editor (writer) at *Injection Molding* magazine, a now-defunct trade publication that, as the name implies, served the plastics injection molding industry. That month I took a trip to Oshkosh, Wis., U.S., to visit an injection molder that agreed to let me observe a machinery and process audit being performed by an industry consultant.

Like many injection molders, this facility operated a number of machines of various sizes and clamp tonnages, ranging in age from new to 20 years old, with the variation in technology and capability that such a time span implies. The purpose of this audit was to assess the mechanical health of some injection molding machines that the molder was concerned were not performing as well as desired.

CW has launched a new column called The Troubleshooter.

At the time, I was new to *Injection Molding* magazine, but not new to the plastics industry. Still, this was my first visit to an injection molding facility and I was eager to learn all that I could. In particular, I was interested to learn how machinery health was assessed and diagnosed.

Most of my time at this facility with the consultant was spent with one injection molding machine — a 20-year-old HPM system with a 1,500-ton clamp. The molder was struggling to get the machine to consistently fill the mold, which led to mold cavities being partially filled ("short shot"). This led, in turn, to an increased scrap rate, which is one of many banes of a molder's existence.

The plant manager knew this HPM machine had a problem, but he could not pinpoint the cause(s). It was the job of the consultant to perform an assessment, identify the cause and recommend a remedy. If you are an engineer who spends any time on the plant floor, you probably know what followed: A systematic, step-by-step measurement and analysis of each machine component and function. We assessed the capability of the injection ram, barrel temperature control, checked ring and hydraulic systems. We even used a UV camera to identify potential shorts in the electrical control cabinet (and found several).

So, what was the culprit causing the short shots? If you've operated an injection molding machine, you know that one of the control parameters is injection rate. It turned out that the injection rate setpoint on the machine's controller was not actually being performed by the hydraulically actuated injection ram. A simple distance/time calculation helped us make that determination. This then led us to the hydraulic system itself, which, being 20 years old, simply could not produce the pressure it once did. In short, no matter the injection rate setpoint, the machine could not meet it.

The lesson? What I learned was that any system — even a complex one — can be deconstructed and systematically analyzed to verify that it is meeting fundamental performance requirements. Further, I learned that such analysis can and should lead to good troubleshooting to bring the process back into compliance.

It is in this spirit — systematic problem assessment and systematic correction — that *CW* has launched a new column called, appropriately, The Troubleshooter. We actually launched it in the February 2021 issue, and it continues this month on p. 6. It will appear in even-numbered months throughout the rest of the year.

The first Troubleshooter, authored by Lou Dorworth, direct services manager at Abaris Training Resources (Reno, Nev., U.S.), focuses on troubleshooting failures in adhesively bonded composite joints. This month's Troubleshooter, authored by Yehiel Shaham, an Israel-based engineer and consultant, reviews potential trouble spots in laser-assisted tape winding of thermoplastic composites.

The overarching goal of The Troubleshooter column is to help you, our audience, identify, assess and correct the technical challenges that can plague composites manufacturing operations. To that end, and to ensure the utility of The Troubleshooter, I would like to know the kind of material, tooling or processes problems you face in your composites manufacturing operations. Are there challenges that you would like to see addressed by one of our Troubleshooters? If there are, please email me at jeff@compositesworld.com and tell me, in as much detail as you can, the trouble you need help with. I will then work with our columnists to have your challenge addressed. I look forward to hearing from you.

JEFF SLOAN — Editor-In-Chief

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Challenges of laser-assisted tape winding of thermoplastic composites

» Thermoplastic composites (TPCs) have been promoted extensively in recent years due to their high potential to increase production rates and enable weight reduction. One of the most discussed topics for increasing production rates with TPCs is in-situ consolidation (ISC) during automated fiber and tape placement (AFP/ATP).

ISC was actually first demonstrated with constrained structures such as tubes, and continues to offer great potential for overwrapped pressure vessels and storage tanks. These structures can be produced using laser-assisted tape winding (LATW), which comprises a laser-assisted tape placement (LATP) machine and a rotating mandrel (Fig. 1).

The AFP/ATP head is installed on a CNC six-axis robot and uses a laser to heat the incoming tape and substrate to melt the thermoplastic polymer. The tape is then pressed onto the substrate using a roller to promote interlayer adhesion and consolidation.

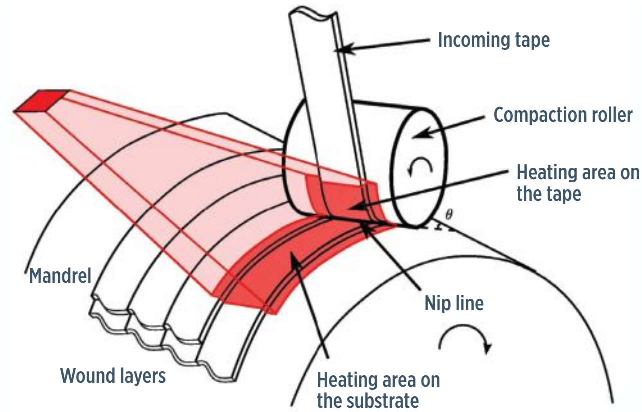


FIG. 1 LATW process

LATW process. Source | Hosseini, Baran, van Drongelen and Akkerman. "On the temperature evolution during continuous laser-assisted tape winding of multiple C/PEEK layers: The effect of roller deformation." Int J Mater Form (June 2020).

First-ply strategies

Like any additive manufacturing process, the first ply in LATW is an issue that should be addressed. For a tube produced on a metal mandrel (aluminum is preferred), mandrel extraction post-winding should be considered and a release agent applied.

Another consideration is fixation. If hoop winding is applied to the first ply (versus a helical or axial layup, Fig. 2), adhesive tape can be manually placed at the beginning and the end of the course to improve stability and adhesion to the incoming tape. If a helical or axial layup is required, then complete tape rings should be applied and fixed at the edges of the cylinder, using adhesive tape to prevent slippage.

For a Type IV pressure vessel (plastic liner with carbon fiber composite overwrap), or when overwrapping a plastic pipe, the incoming tape will be fused to the liner. This eliminates the need for adhesive tape fixation, but the plastic liner and TPC tape should have the same base polymer to ensure proper bonding.

Issues may arise with heating the plastic liner. For example, if it cannot absorb the laser heating, or if a metal mandrel is used, consider adjusting the laser angle to fully heat the incoming tape. In other words, instead of the typical positioning so that the laser is distributed *between* the incoming tape and the substrate (Fig. 1), angle the laser *more toward* the tape. This will avoid laser reflections, ensure more uniform heating of the tape and reduce energy consumption.

Laser distribution changes with ply angle or changing geometry

As described above, typically during LATP and LATW processes, the laser is distributed between the incoming tape and the substrate. This distribution is constant in cases where the radius geometry and layup direction are constant. However, there are considerations. For example, during an *axial* layup on a tubular mandrel (which would be roughly equivalent to the flat mold in Fig. 3), the incoming tape will receive the *same* radiation compared to a hoop layup while the substrate will receive *more* laser projection than in a hoop layup. Note, this is negligible in large-diameter tubes.

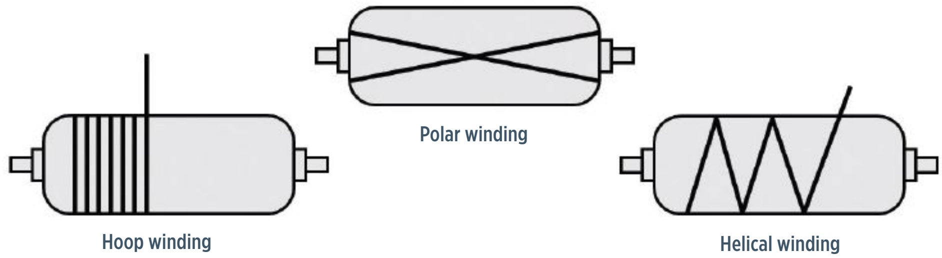
During heating, the thermoplastic tape spreads and becomes wider and thinner, depending on the temperature and layup speed (heating time), due to reduced polymer viscosity. In a system with closed-loop control — where *temperature* is kept constant on the heating area — an axial layup will end up with a wider tape than in a hoop layup. Alternatively, in a system with constant *power* control, the axial layup will develop under lower temperatures, and thus the tape will widen less. This is important to understand and address because uneven changes in tape dimensions can result and cause undesired gaps and overlaps that might increase void content.

When wrapping tubes, geometry is constant, but with pressure vessels the geometry changes due to the end domes. While entering or exiting these dome areas, the robot slows down and the size of the laser spot decreases on the substrate. Both actions can cause a sharp increase in temperature, which may cause thinner sections, different material properties or even damage to the polymer.

Another consideration is that as the part's fiber layers are built

FIG. 2 Hoop winding

Hoop winding is at roughly 90° to the mandrel axis, polar winding is at an angle much closer to 0° (or the axial direction) and helical winding is at an angle in between. Source | *CW*



up during winding, the dimensions of the core being wound onto (mandrel plus plies so far) are changing. Thus, layup angles should be adjusted to avoid gaps. An LATP/LATW system with software that updates the mandrel diameter might be available from some suppliers. If not, the winding will have to be inspected manually or with an inline inspection system and corrected as necessary.

Although addressing the above considerations helps, it isn't possible to achieve 100% elimination of defects such as gaps, overlaps and thickness variations. The winding process, therefore, should be developed to achieve the part's design allowables rather than pursuing a "perfect part," which may add unnecessary cost.

Maximizing mechanical properties, interlayer adhesion and crystallinity

Thermal management is a key factor to achieve adequate interlayer adhesion as well as full potential crystallinity in the thermoplastic matrix. First layers are close to the mandrel, which acts as a heat sink. This may prevent molecular interdiffusion and promote poor interlayer adhesion, low crystallinity and higher void content. To overcome this challenge, one should consider reducing layup speed, increasing temperature and adjusting laser angle to enable a longer heating time to ensure molecular diffusion.

This does not ensure, however, full crystallinity. This is because molecular diffusion — reforming molecular re-entanglements after melt during cooling — is a much faster process than crystallization, where molecules are aligned to form an ordered crystalline structure. If the part being made is thin (roughly less than 2 millimeters), one would expect lower crystallinity than for a thicker part, which receives more consolidation passes and less heat loss to the mandrel. For both thin *and* thick parts, consider slower layup speeds for initial plies.

To reach full crystallinity, consider the following:

- After winding, anneal (heat soak) at a temperature between the thermoplastic matrix T_g (glass transition temperature) and T_m (melt temperature). As a rule of thumb, the middle between the two temperatures provides the fastest crystallization kinetics.
- Use a heated mandrel that will promote crystallinity of initial layers. This is not always possible and it may be more expensive. If a heated mandrel is used, be sure to consider that the mandrel might undergo thermal expansion.

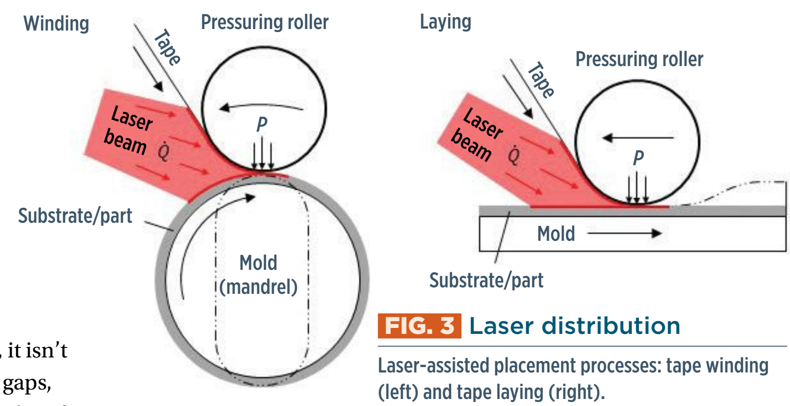


FIG. 3 Laser distribution

Laser-assisted placement processes: tape winding (left) and tape laying (right).

Source | Fig. 1.5, "Thermal Skin Effect in Laser-Assisted Tape Placement of Thermoplastic Composites" by Thomas Weiler, Jan. 2020.

- Program passes for consolidation — in other words, include winding passes without incoming tape but with laser fully projected on the substrate. This is mostly done on latter plies that receive fewer passes but can also be done on first plies to improve interlayer adhesion.

Tape dimensions – design flexibility and production rates

Tape dimensions are a crucial parameter in tape winding. Obviously, receiving constant tape width and thickness from the supplier will enable repeatable and uniform products. However, tape dimensions also define design flexibility. For example, with an axial layup on a tubular mandrel, the tape width should be narrow enough to be compliant with the mandrel curvature. The larger the mandrel diameter, the wider the tape that can be used. Wider tape means faster throughput while narrower tape is more design-friendly since it is more compliant to curvature changes and easier to steer.

Although there are more issues and challenges with LATW, good parts are possible, and this method of manufacturing will continue to advance as composite tubes and tanks are used for hydrogen and other gas storage applications. CW

ABOUT THE AUTHOR

Yehiel Shaham is a plastics and polymers engineer with nearly 12 years of experience in development and manufacturing of thermoplastics from leading Israeli plastics and defense companies. During 2016-2020, he was the thermoplastic composites lead engineer in RAFAEL, where he specialized in TP-AFP. Currently, he is aiming to promote TPCs in Israeli industry.

Durability testing of adhesively bonded composites

» Three types of coupon-level test methods may be used to assess the performance of bonded joints. *Strength-based tests* typically involve lap shear specimens, as they best represent the primary loading of typical bonded composite joints. Standardized lap shear test methods have been developed for use with metal, rigid plastic and fiber-reinforced plastic (FRP) adherends. *Fracture-based tests* used to evaluate bonded composites are based primarily on the existing Mode I double cantilever beam (DCB) test for composite laminates, ASTM D5528[1]. *Durability-based tests* also focus primarily on Mode I-type tests, but subject the adhesive-bondline crack tip to high stresses for an extended period of time, ranging from several hours to several days.

Currently, there are no standardized durability-based tests for bonded composites, but test method development is currently underway. In this column, I'll focus on the development of a durability-based test for adhesively bonded composites commonly referred to as the *composite wedge test*.

Currently, there are no standardized durability-based tests for bonded composites.

This test method is based on the well-established metal wedge test, ASTM D3762[2], used for durability-based assessment of aluminum-bonded joints.

This test method consists of a 152-millimeter-long and 25-millimeter-wide-bonded aluminum specimen with a 19-millimeter initial disbond length produced in the adhesive bondline at one end of the specimen using a thin separation film. The specimen is loaded by forcing a metal wedge — inserted a fixed distance — between the adherends, causing the initial disbond to propagate from the end of the separation film in the adhesive bondline (Fig. 1). The wedge is retained in the specimen and the initial crack length, a, is measured. Specimens are then exposed to a selected environmental condition, typically high humidity at elevated temperature. After environmental exposure for a specified period of time (ranging from hours to days), specimens are removed from the environmental chamber and the final crack length, $a + \Delta a$, is measured. The adherends are forcibly separated and the percent *cohesion failure,* defined as failure within the adhesive, is estimated within the region of environmental crack growth (Fig. 2). Environmental durability is assessed based on the length of crack growth during environmental exposure as well as the percent cohesion failure within the region of

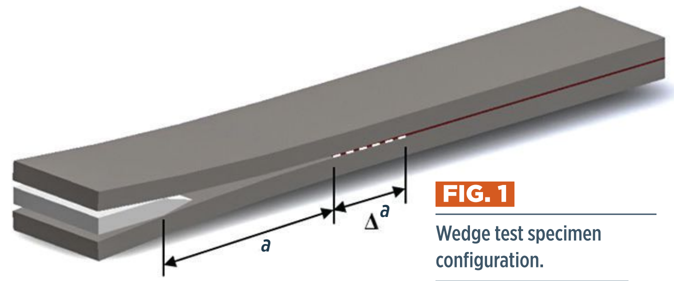


FIG. 1

Wedge test specimen configuration.

Source (all images) | Dan Adams

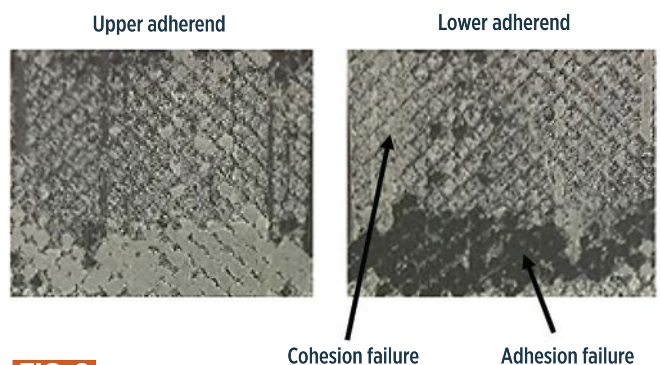


FIG. 2

Adhesion and cohesion failures within the region of environmental crack growth.

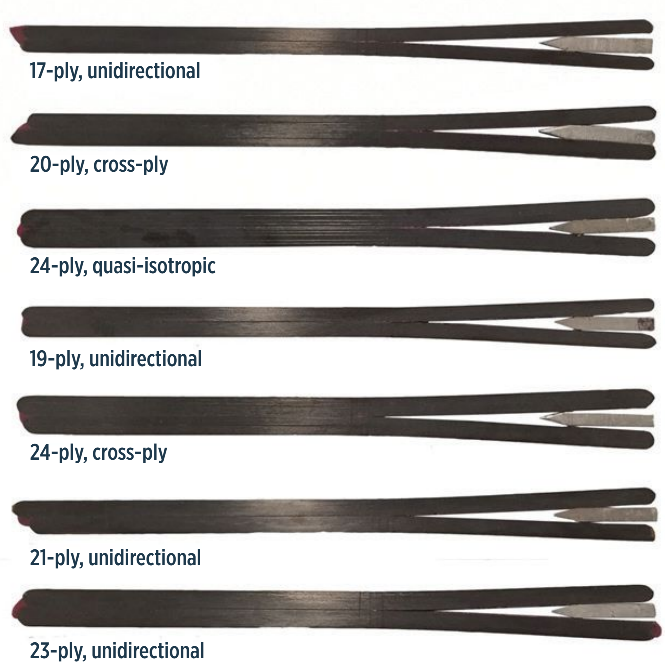


FIG. 3

Composite wedge test specimens of varying adherend thicknesses and laminate ply orientations.

environmental crack growth[3].

While hydration of the adherend surfaces is a primary concern associated with the durability of metal-bonded joints[4], other sources of durability concerns exist for adhesively bonded composites. Two of the more significant concerns are improper surface preparation and contamination of the bonding surfaces prior to adhesive bonding. Recent research investigations[5,6] suggest that a composite wedge test may be well suited for evaluating the long-term durability of bonded composite joints. However, the use of composite adherends produces additional complexities due to their differing flexural rigidity, $E_f I$, defined as the flexural modulus E_f of the composite adherend multiplied by its area moment of inertia I. For composite adherends, variations in $E_f I$ may result from differences in composite materials, volume fractions, ply thicknesses, number of plies and laminate ply orientations. Differences in $E_f I$ between sets of specimens will result in differences in both the initial crack length and the length of crack growth during environmental exposure, preventing the use of crack length in durability assessment.

An important advancement in the development of the composite wedge test was the transition from using environmental crack growth as a measure of durability to the use of an estimated fracture toughness, G_C. Using beam theory, G_C from a composite wedge test specimen may be determined using the equation

$$G_C = \frac{3\,E_f\,t^2\,h^3}{16\,a^4}\left(\frac{1}{\left(1+0.64\,\frac{h}{a}\right)^4}\right)$$

where E_f is the flexural modulus of the adherend material, t is the thickness of the wedge, h is the thickness of the composite adherend and a is the crack length. A correction factor to the beam theory expression for G_C (in parentheses above) was identified to account for the rotation of the adherends at the plane of the crack tip[7]. Using this equation, an estimate of the fracture toughness following environmental exposure may be obtained from the composite wedge test by measuring the final crack length. Additionally, an estimate of the fracture toughness of the adhesive bondline at room temperature/ambient conditions may be obtained by using the crack length prior to environmental exposure in the above equation.

Note that the use of the above equation requires that the adherend flexural stiffness E_f and thickness t must be measured. An alternative approach is to write the above equation for G_C in terms of the flexural rigidity $E_f I$ producing

$$G_C = \frac{9\,(E_f\,I)\,t^2}{4\,b\,a^4},$$

where b is the specimen width. In-situ measurements of the flexural rigidity, $E_f I$, may be obtained using representative wedge test specimens subjected to DCB-type loading following wedge testing. The slope of the load versus deflection curve, $\Delta P/\Delta\delta$, corresponding to the measured final crack length a, is used to calculate the flexural rigidity, $E_f I$, using the equation

$$E_f\,I = \frac{2\,a^3}{3}\left(\frac{\Delta P}{\Delta\,\delta}\right).$$

Using this methodology, G_C values obtained from adhesively bonded, carbon fiber/epoxy composite wedge test specimens were found to be relatively constant across adherend thicknesses and laminate ply orientations producing $E_f I$ values that vary by 250% (Fig. 3). These results suggest that the wedge test may be performed using composite specimens with differing adherend flexural rigidities, and the results compared directly.

In summary, the composite wedge test appears to be a well-suited test method for evaluating the durability of bonded composite materials. As with the ASTM D3762 metal wedge test, the procedure is simple to perform and multiple specimens can be tested concurrently without the use of mechanical testing equipment. The development of a standardized test method for the composite wedge test is currently in its initial stages. For additional information, please contact me. CW

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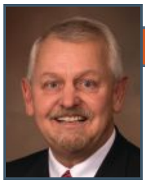

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Dr. Daniel O. Adams is vice president of Wyoming Test Fixtures Inc. (Salt Lake City, Utah, U.S.) and emeritus professor of mechanical engineering at the University of Utah, where for 22 years he directed the Composite Mechanics Laboratory. He holds a B.S. in mechanical engineering and an M.S. and Ph.D. in engineering mechanics. Adams has a combined 40 years of academic/industry experience in the composite materials field. He has published more than 120 technical papers, is vice-chair of ASTM Committee D30 on Composite Materials and co-chair of the Testing Working Group for the Composite Materials Handbook (CMH-17). He regularly provides testing seminars and consulting services to the composites industry. **dan@wyomingtestfixtures.com**

Slow supply chains and strong demand elevate material prices

February—58.3

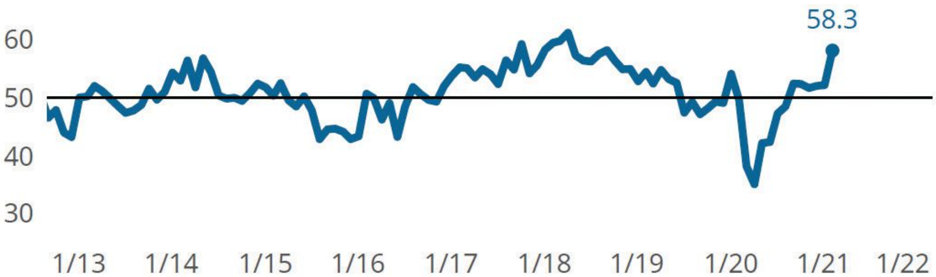
» The Composites Index rallied six points during February to close at a 2 ½-year-high reading of 58.3. The month's gains were driven by a 10-point increase in new orders activity followed by a seven-point increase in backlog and supplier delivery readings and a six-point increase in employment. Backlog, new orders, supplier delivery and employment activity all set multi-year records during the month.

February also marked the third consecutive month in which supplier delivery activity readings exceeded the prior record set in mid-2018. Generally, rising readings occur as a result of slowing order-to-fulfillment times which have been caused, in part, by COVID-19 disruptions. Making this situation more difficult is the strong rebound occurring in new orders activity which, presently, is just shy of setting its own all-time-high reading. Moreover, the combination of strong demand and sluggish supply chains have resulted in only mild gains in production but a rapid expansion in backlogs. These industry conditions have also caused a rapid rise in material prices, which will hurt profitability for those fabricators who are unable to increase prices. CW

ABOUT THE AUTHOR

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

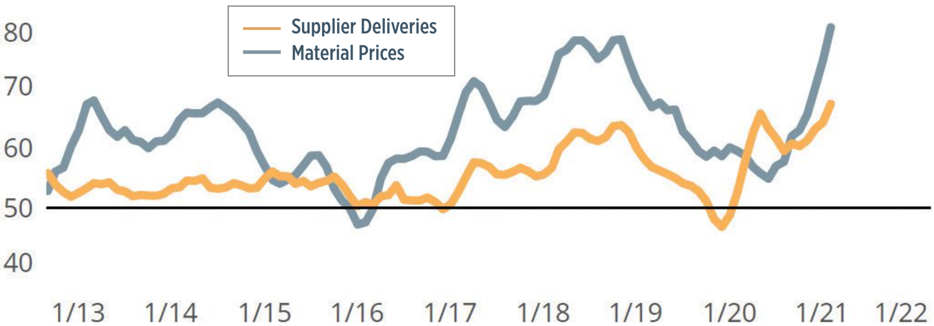
GBI: Composites Fabricating



Composites Fabricating Business Index

The Composites Fabricating Index set a new multi-year high resulting from accelerating activity in new orders, employment, backlogs and supplier deliveries.

GBI: Composites Fabricating — Supplier Deliveries and Material Prices (3-month moving average)

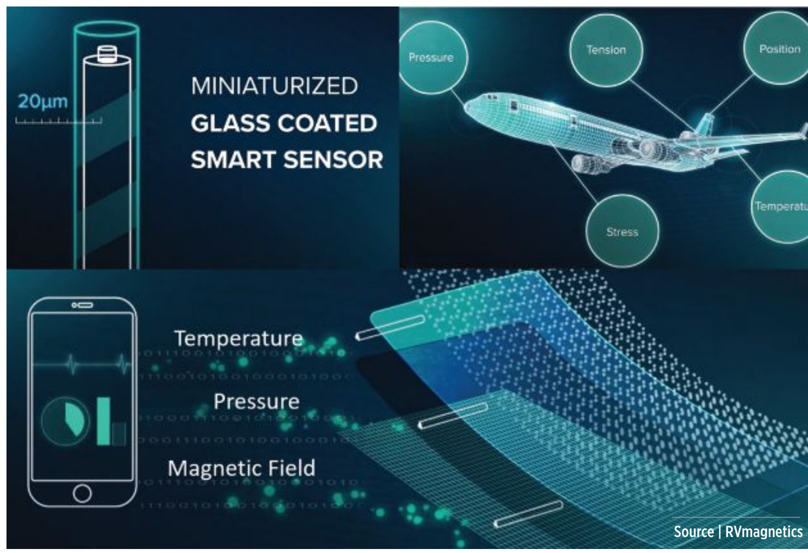


Index activity divergence

The history of the Composites Index indicates that even modest changes in supplier delivery readings can have amplified affects on material prices. Fabricators should expect material prices to remain highly volatile the longer that supply chains remain disrupted.

Solvay and Vertical Aerospace expand on a previous agreement for the VA-1X eVTOL aircraft, composite applications continue to progress in the automotive sector, RVmagnetics' microwire sensors monitor composite processes and structural health and GE is to demonstrate an integrated AM process for high-performance wind blade design.

Contactless monitoring of temperature and pressure inside composites



Source | RVmagnetics

Studies targeting magnetic microwires actually started in the 1970s, and extensive progress has been made, especially during the last decade. For example, AvPro (Norman, Okla., U.S.) has validated its microwire-based ThermoPulse sensors through projects with the U.S. Air Force (see *CW*'s 2018 report, "Measuring temperature inside composites and bondlines"). Dr. Rastislav Varga, who cofounded RVmagnetics (Koice, Slovakia) in 2015, began his research with microwires in 2000. The company now has 16 employees and is developing unique sensors for a variety of markets, including composites.

RVmagnetics' sensors are very small, 3 to 70 micrometers in diameter or roughly the size of a human hair. They comprise a ferromagnetic metallic core — most often including iron and cobalt — with an insulating Pyrex glass coating 0.5 to 20 micrometers in thickness. When placed in a composite, they are typically 1 to 4 centimeters long. The glass coating protects the metal microwire from corrosion and also makes it biocompatible.

"Microwire is ideal for composites," says Varga. "Not only is it difficult to monitor the structural health of composite structures in service, we also see a need to monitor the processes used to make composites." Typically, sensors placed inside composites create defects. "A strain gauge has an area of only 1 square centimeter," says Varga, "but even so, the composite will break along this sensor. The advantage of microwire is that it does not decrease the performance of the composite. In fact, you cannot find our sensors *without* a magnetic interrogator working under special conditions.

"If you use electrical sensors in composites," he continues, "you must make a hole in the laminate to connect the wire to interrogate the sensor. Microwires fit *in between* the fibers in a laminate and you do not need to contact them to retrieve their data. We have compared samples of coupons with and without microwires, and there is no difference in mechanical properties." This is also what AvPro (Norman, Okla., U.S.) reported for its ThermoPulse sensors.

Continuous microwire up to 10 kilometers long can be produced at a very low cost: 1 kilogram of metal alloy can produce 40,000 kilometers of glass-coated microwire at several hundred meters/minute. Microwires exhibit magnetostriction, meaning they change their shape when subjected to a magnetic field. They also have only two states: $+M_S$ and M_S, where M_S is the saturation magnetization. Switching between these two states occurs at the value of the applied magnetic field called the switching field (H_{SW}). For microwires, this switching field is very sensitive to external parameters including temperature, mechanical stress and magnetic field.

RVmagnetics uses a specially designed system that transforms the measured value (e.g., temperature or mechanical stress) into the switching *time*, enabling it to distinguish between the contribution of the magnetic field and that of the value being measured, namely temperature or mechanical stress. This has been demonstrated by Professor Varga and his co-authors in various technical papers. RVmagnetics also has demonstrated remote interrogation of microwires from up to 10 centimeters. "If you need to be further away," says Varga, "then you may need more power, but we try to keep the interrogation frequency below 10 kilohertz for safety reasons. We try to keep the sensing system simple and cheap: just two coils, a couple of wires and a small amount of simple electronics."

RVmagnetics has developed cure monitoring and placed microwire sensors inside 3D-printed parts. "You can measure temperature gradients inside the composite in each layer," says Varga. The company has also placed microwire sensors in composite rebar without changing how it is made. "The wires are discontinuous but are placed automatically on a continuous basis as the rebar is produced," he notes. "We have also performed tests in our lab proving the low influence of *induction welding* on our microwire sensors," Varga continues, "and are currently running tests with a manufacturer of induction-welded and induction-heated composites to further assess our technology on a larger, industrial scale."

RVmagnetics touts a wide array of sensing capabilities including vibration, resin flow and electric current. "Vibration is simply measuring stress at a higher frequency," says Varga. "For resin flow, we measure the change of pressure and strain. When placed on a surface, microwires will bend during flow. For electric current, we just measure electromagnetic field. Our microwire usually measures two parameters simultaneously — either temperature/electromagnetic field or stress/electromagnetic field. We are able to measure all three by placing two microwires together, and we use the same interrogation process to monitor the output." RVmagnetics has developed PC-based software to process this output as digital data.

"Composite companies haven't had contactless solutions to measure temperature and stress inside of a composite, thermoplastic weld or adhesive bondline," says Vladimír Marhefka, RVmagnetics chief marketing and strategy officer, "but now they do."

Read the full article online at **short.compositesworld.com/RVmagsensr**

AUTOMOTIVE

Composites race toward increased automotive applications


Source | Porsche

Composites continue to play a role in automotive applications, including the newly developed McLaren *Artura*, the Porsche *911 GT3* and the limited-edition T.50 supercar from Gordon Murray Automotive (Surrey, U.K.).

The *Artura* is based on a new platform, called the McLaren Carbon Lightweight Architecture (MCLA), a notable development borne of years of experience. It is a fully McLaren execution, designed and built in the McLaren Composites Technology Centre (MCTC) in Rotherdam, U.K. Its primary development was to reduce hybrid component mass — the motor and the battery pack, in particular.

Specifically, the MCLA considered three elements, two of which are the carbon fiber monocoque and the chassis and suspension structures. For the monocoque, McLaren is using four new carbon fiber materials, a new resin system and a new structural core material. Details have not yet been released.

To meet internal combustion engine (ICE) requirements, Cosworth (London, U.K.), a leading supplier of powertrains and components, is using a metal-matrix composite (MMC) material to produce pistons for the T.50 supercar.

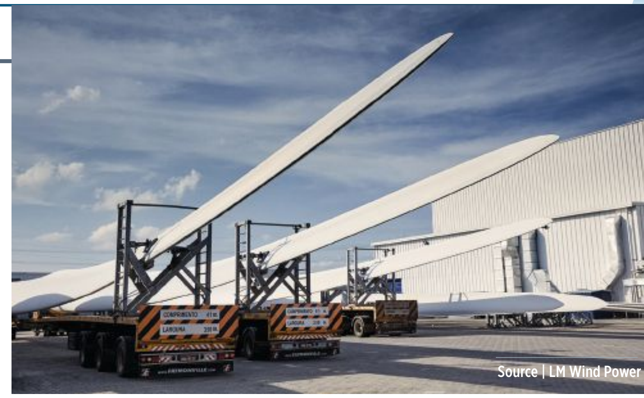
The material combines silicon carbide reinforcement in aluminum. It is sourced from Materion (Mayfield Heights, Ohio, U.S.), which named the material SupremEX. The material is said to have a specific stiffness of at least 40% more than other piston materials, contributing to reduced mass. Further, it has a 25% lower coefficient of thermal expansion (CTE) than conventional aluminum alloys used for pistons.

The seventh generation of the Porsche *911 GT3* has made an even more extensive use of carbon fiber-reinforced plastics (CFRP) in the vehicle, for a curb weight of 3,157 pounds.

The hood, rear wing and fixed wing are all CFRP. A carbon fiber roof is optional, as are carbon fiber mirror caps. Another weight-saving option is full carbon seats: Compared to the standard seats in the *911 GT3*, the composite seats represent a 26-pound mass reduction.

ENERGY

GE to research AM for wind turbine blades


Source | LM Wind Power

GE Research, GE Renewable Energy (Paris France) and LM Wind Power (Kolding, Denmark), a GE Renewable Energy business, were recently selected by the U.S. Department of Energy (DOE) to research the design and manufacture of 3D-printed wind turbine blades. The GE business units will partner with the Oak Ridge National Laboratory (ORNL, Knoxville, Tenn., U.S.) and the DOE's National Renewable Energy Lab (NREL) on a 25-month, $6.7 million project to develop and demonstrate an integrated additive manufacturing (AM) process for novel high-performance wind blade designs for large rotors.

"We are excited to partner with the DOE Advanced Manufacturing Office, as well as with our world-class partners to introduce a highly innovative advanced manufacturing and additive process to completely revolutionize the state-of-the-art of wind blade manufacturing," says Matteo Bellucci, GE Renewable Energy Advanced Manufacturing leader.

The project will deliver a full-size blade tip ready to be structurally tested, as well as three blade tips that will be installed on a wind turbine. The proposed project will focus on a low-cost thermoplastic skin coupled with printed reinforcement.

The project will also advance the competitiveness of both onshore and offshore wind energy when commercialized, by reducing manufacturing cost, increasing supply chain flexibility and providing lighter weight blades made with more recyclable materials. The goal is to reduce design cycle time as well, potentially enabling more wind farm optimization, which will yield further increases in farm annual energy production and reduce levelized cost of energy.

"Through GE's Research Lab, we have an entire business portfolio for wind," adds Todd Anderson, principal investigator at GE Research. "Over the years, GE scientists have been successful at applying our legacy of materials and composites expertise in aviation to the wind energy space. We were the first to introduce lightweight composite fan blades in our jet engines more than two decades ago. Today, with our business partners and leading national laboratories, we're bringing that experience and more to deliver a more advanced wind blade to take wind power to the next level."

AEROSPACE

Solvay, Vertical Aerospace expand on UAM agreement


Source | Vertical Aerospace

Solvay Composite Materials (Alpharetta, Ga., U.S.) and urban air mobility (UAM) aircraft manufacturer Vertical Aerospace (VA, Bristol, U.K.) announced in early February an agreement to collaborate on the development and manufacture of Vertical Aerospace's VA-1X electric vertical take-off and landing (eVTOL) aircraft. Under the agreement, Solvay will provide access to its portfolio of composite materials, including resin systems, prepregs and adhesives. *CW* spoke recently with Solvay representatives and Michael Cervenka, CEO of VA, to learn more about the collaboration.

VA was founded in 2016 by Stephen Fitzpatrick, who had previously founded the Manor F1 racing team. For the first three years of its existence, VA operated in "stealth" mode, developing early eVTOL designs and test flying several prototypes. In 2020, says Cervenka, VA formally introduced the VA-1X, a piloted, four-passenger all-electric tiltrotor aircraft with a range of 160 kilometers/100 miles and a cruise speed of 240 kph/150 mph. The first flying prototype of the VA-1X is expected in September 2021, followed by entry into service in 2024.

Cervenka says Solvay was chosen as a partner because of the material supplier's robust array of product solutions, shared values and strong U.K. presence. In addition, he notes that VA was looking for assistance with process development, particularly getting to rate. Further, Cervenka says VA is paying close attention to weight management on the VA-1X; Solvay is expected to help with that effort.

Sam Hill, EMEA customer engineering manager at Solvay, reports that Solvay's MTM45-1 toughed epoxy prepreg will be deployed for the VA-1X, chosen because it is highly and widely qualified and offers flexibility for use in or out of the autoclave. Other material types Solvay expects to provide include tooling prepregs, surfacing materials, lightning strike materials and adhesives.

Cervenka says prototype aerostructures for the VA-1X will be fabricated by already identified suppliers, with assembly done by VA. Cervenka says VA expects to produce about 100 aircraft in low-rate production, with rapid ramp up to larger totals — "quickly reaching low thousands" — at full rate. When that happens, composites fabrication will be allocated to a Tier 1 fabricator. Along the way, Cervenka and Hill say they expect materials and process selection will evolve to potentially integrate more out-of-autoclave options — such as thermoplastics — and automation such as automated fiber placement (AFP). VA is using the Dassault Systèmes (Waltham, Mass., U.S.) 3DEXPERIENCE suite of design software to optimize design engineering on the VA-1X.

Although Cervenka is philosophical about the UAM market and recognizes that VA has much to learn, he also knows that the VA-1X represents a novel type of flying vehicle that demands much of the OEM: "The VA-1X must be 100 times safer than a helicopter, quieter than a helicopter, have no single point of failure, be less expensive to operate, have lower maintenance costs, possess significant redundancies and be emissions free. That's a challenge."

Still, he says the potential of the UAM market is too big to ignore. VA plans to achieve flight certification in Europe first, followed by the VA-1X entering service in cities and regions that are "geographically challenged" and thus stand to benefit from the point-to-point ridesharing service that UAM vehicles are designed to provide.

Once that model is established, and assuming public acceptance follows, Cervenka expects the VA-1X will be deployed in other large cities with poor or challenged road infrastructure. He says that by 2030 there will be "many major cities throughout the world served by large UAM fleets." Like other new technologies, Cervenka says UAM aircraft will initially provide a premium service, but over the next decade it will become democratized and more affordable.

Finally, there is one technology on the VA-1X that the company will hold very close: the batteries. "There is no off-the-shelf battery system for this application," Cervenka notes. "It's very important that we do this work ourselves." So, battery development and manufacture for the VA-1X will be fully vertically integrated for the foreseeable future. "We don't see any killer batteries coming along that disrupt this market," he contends. "It will be highly incremental."

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

Automated weaving system targets high-performance, high-volume applications

Startup WEAV3D Inc.'s technology produces highly tunable, woven lattice reinforcements for cost-effective, high-volume automotive composites and precast concrete applications.

By Hannah Mason / Associate Editor

»One long-held barrier to widespread composites adoption, notably in the automotive industry, is the need for high-volume production and lower costs than are feasible with many types of composites manufacturing processes. Startup company WEAV3D Inc. (Norcross, Ga., U.S.) is seeking to solve these issues with its continuous, thermoplastic composite reinforcing lattice structures manufactured in an automated weaving process designed to be waste-free, cost-effective and, WEAV3D Inc. predicts, an enabler for high-volume production.

From concept to commercialization

Christopher Oberste, founder and CEO of WEAV3D Inc., developed the initial concept for his technology while earning his Ph.D. in materials science and engineering at the Georgia Institute of Technology (Georgia Tech, Atlanta, Ga., U.S.) in 2014. His studies in polymer and fiber engineering and a co-op internship at GKN Aerospace North America (Tallahassee, Ala., U.S.) sparked interests in thermoplastics and high-volume processes like compression molding and aerospace composites. This work led to the development of his first iteration for a high-speed, automated weaving process for thermoplastic composite reinforcing lattice structures. With the help and support of his Ph.D. advisor, Dr. Ben Wang, Oberste applied for and received grant funding to develop and commercialize his idea from the Georgia Research Alliance and the National Science Foundation's Innovation Corps (NSF I-Corps) program.

New automated process for higher-volume manufacture

Startup company WEAV3D Inc. has developed a patented, automated machine and process for weaving thermoplastic composite lattice structures at high volumes, for use as reinforcements in concrete, plastic or composite components in a range of industries. Source (all images) | WEAV3D Inc.

For the next two years, Oberste worked with MBA and law students to commercialize the technology through a collaborative program at Georgia Tech called TI:GER (Technological Innovation: Generating Economic Results). By 2017, with more funding from Megawatt Ventures and a U.S. Department of Energy Clean Tech University Prize, Oberste and co-founder Lewis Motion, a former U.S. Coast Guard helicopter pilot, founded WEAV3D Inc.; today, the company employs three full-time and four part-time staff.

Given Oberste's and Motion's backgrounds in aerospace, the initial plan was to qualify WEAV3D's thermoplastic composite materials as reinforcement structures in aerospace components. However, Oberste explains that as part of the NSF I-Corps grant, he and his team had to perform a series of 100 interviews with potential industry customers, which led them to take a different direction. "We did a lot of discovery interviews in aerospace but we heard time and time again that the path for startups going into aerospace, especially with a new manufacturing process, is very difficult. The adoption time is really long, and it's very expensive. A lot of companies die before they can even make it to market," he explains.

After speaking to companies in other industries, Oberste and his team decided to change their focus to the automotive and construction markets. He says, "Once we started talking to folks [in automotive], we realized there was a really big unmet need in that space, in that the automotive folks have a lot of pressing demand for weight reduction, but they are also sensitive on price. They told us that most of the conventional composite manufacturing processes available weren't able to provide the volume they needed at the costs they wanted." From there, Oberste set out to evolve his technology to be an enabling solution for producing high-volume composite parts at low cost.

The result is WEAV3D's trademarked Rebar for Plastics concept. Using an automated weaving and consolidation process, WEAV3D manufactures dimensionally tunable, thermoplastic composite lattice structures designed to be easily integrated as a reinforcing material in a plastic or concrete part via compression molding, injection overmolding or other common high-volume processes. Based on simulation models, Oberste says this approach enables the production of automotive parts with performance on par with steel or aluminum sheet metal, but which are lighter weight and 30-75% less expensive to produce versus composite parts formed via organosheet, automated tape laying (ATL) or hand layup processes.

The WEAV3D process

The WEAV3D process starts with off-the-shelf, thermoplastic unidirectional (UD) tapes. Oberste says the process can handle any type of thermoplastic and reinforcement fiber: "Our sweet spot for most of the work we've been doing in automotive and construction is in the polypropylene [PP], polycarbonate [PC], polyethylene terephthalate [PET] or polyamide [PA] space. We're very agnostic in terms of reinforcement fibers, too, although glass and carbon fiber are of course the most popular." He says the team has also done some work with conductive metallic tapes and is researching tapes with embedded fiber optics.

WEAV3D's full-scale pilot machine is standardized to process a 25-millimeter-wide or 1-inch-wide tape, though Oberste says the machine can handle tapes as small as 5 millimeters (0.2 inches) wide with the use of adapters, and wider tapes with retooling. On the current machine, lattices can be produced up to 1.5 meters wide (60 inches), and up to five layers thick, at any length required by the application.

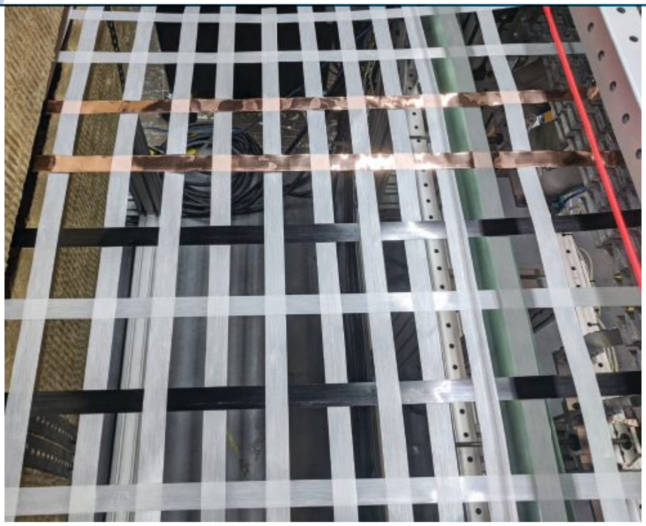
The company's November 2017 patent filing describes the WEAV3D system as "a machine for continuously fabricating a woven composite with controllable internal fabric geometry." From spools loaded onto the machine, UD tapes are threaded into an array of independently controllable warp heads. Each head »

Material flexibility

WEAV3D uses thermoplastics for its lattices to achieve formability. Lattices can be supplied as rolls, sheets or as semi-finished preforms.

The first-gen system

WEAV3D's pilot machine, designed to continuously form 25-millimeter-wide tapes into woven lattices up to 1.5 meters wide, uses IR heat and compaction rollers to consolidate the interlocking tapes together. The next-generation system will use ultrasonic welding.



Mixing it up

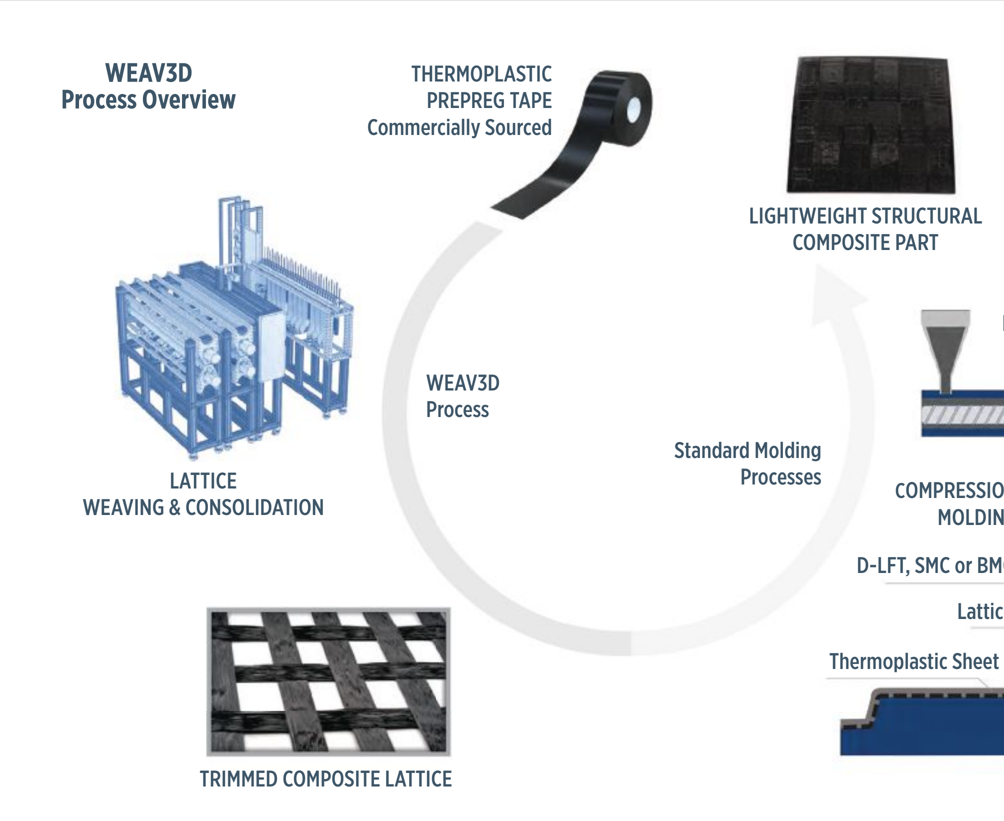
One of WEAV3D's advantages is the high level of tunability available per application, including a mix of different materials within the same lattice. Shown here is a mix of carbon fiber/PP, glass fiber/PP and copper tapes.

contains multiple tape channels, forming a warp shed, a space between the warp tapes for the weft-direction tapes to be threaded. An inserter stack dispenses UD tapes in the weft direction through the warp shed to form a composite weave. The woven lattice is then pulled under an infrared (IR) light source and then through compression rollers to consolidate and bond the layers of tapes together at the interlace points. Depending on customer requirements, the resultant structure is provided as a flat sheet or as a roll. WEAV3D also offers additional trimming and preforming services.

One of the most important benefits of WEAV3D's process, Oberste says, is the high level of tunability of the lattice structure for different applications. This includes mixing different materials at different locations, as well as adjusting the density, or distance between the tapes, of the lattice structure. "We can really optimize the lattice structure for the requirements of the final product while minimizing overall costs."

Once delivered to the customer, the lattices can be integrated into polymer concrete components, or compression molded, thermoformed or injection overmolded to form a final automotive composite part. The WEAV3D process can also accommodate varying levels of complexity. Oberste explains that for relatively simple parts, "this lattice can be combined with a lamination process and then thermoformed, just as a co-forming step. For moderately complex parts, we can do co-forming or preforming in compression molding, whether that's thermoplastic compression molding or SMC compression molding. And then for the very complex parts, we can actually preform the lattice into whatever shape it needs to be, place it into a tool and then do injection overmolding on that part."

"The big focus for us in the composites ecosystem is that we are a game-changer for high-volume production," he adds. The



From tape to final part

WEAV3D's tape lattices are designed for use in high-volume molding processes like thermoforming, compression molding or injection molding.

exact volume depends on the application, but Oberste estimates that for lattice parts sized for reinforcing automotive door panels, WEAV3D's machines can produce between 200,000 and 500,000 units per year.

In addition, the WEAV3D product has also exhibited enhanced mechanical properties when reinforcing a composite or plastic part. "Combining a WEAV3D lattice with existing short fiber plastics or long fiber composites can significantly increase the strength, stiffness and toughness of the resulting product," Oberste says, though he adds that the amount of increase varies widely by the specific materials used and design of a particular part. "In some applications, this increased performance allows for part thickness or ribbing to be substantially reduced, which translates to reduced weight."

Reinforced concrete trenches: First commercial application

For the first few years, the startup company's focus has been on producing a manufacturing method and materials suitable for the automotive industry specifically, though Oberste has ideas about how this technology might be used in commercial aerospace interior components, unmanned defense aircraft, rail, cargo transport and marine applications.

For its first commercial application announced in November 2020, however, WEAV3D began with the construction market, using glass fiber/PET reinforcements for a polymer concrete trench system manufactured by Oldcastle Infrastructure (Atlanta, Ga., U.S.).

Oldcastle's trench system, used for routing utility cables in urban areas, train stations or industrial plants, must be able to withstand 16,000-pound loads from vehicles driving over top of it. Previously, the trench was reinforced with custom-welded steel wire cages embedded into the concrete. However, according to Oberste, these steel cages were both expensive to custom manufacture and, as Oldcastle makes trenches of several different sizes, the steel cages were not always the correct dimensions to properly »

First commercial application

The company's first commercial application is a U-shaped glass fiber/thermoplastic lattice preform used to reinforce a polymer concrete utility trench. WEAV3D plans to expand into more construction and automotive applications in the near future.

reinforce the trench's drainage holes. "With our process, because we can really optimize the lattice for the application's requirements, we were able to tune the lattice geometry — for example, to make sure we added reinforcement around the drain holes at the bottom of the trench, and reinforcement at the ends of the trench so that it's protected against impact during handling," he says.

> The big focus for us, in the composites ecosystem, is that we are a game-changer for high-volume production.

In addition, one of the most challenging aspects of the project, Oberste says, was to identify a thermoplastic tape material that could form an adhesive bond with the polymer concrete, rather than relying on just a mechanical interface, as is the case with steel cage reinforcements. The polyethylene terephthalate glycol (PETG) material WEAV3D selected forms a true adhesive interface between the two materials, which helps with stress transfer and decreases the likelihood of fracture. "Even if fracture does occur," he adds, "that fracture is much less likely to propagate through the structure because it has to overcome that adhesive interface."

WEAV3D produces the lattices designed for this application as a U-channel preform, which Oldcastle then places into a casting mold where polymer concrete is poured over it, followed by cure and demolding to produce the final reinforced concrete structure.

Within construction, WEAV3D has plans to expand its lattices into other polymer concrete applications such as enclosures and lids. In October 2020, WEAV3D, in a joint proposal with Western Ontario University (London, Ontario, Canada) and structural engineering firm Entuitive (Toronto, Ontario), was awarded a grant from the National Sciences and Engineering Research Council of Canada to conduct research evaluating the use of WEAV3D's lattices as reinforcement in traditional Portland cement-based concrete as well. The goal is to develop lattices that can be used as reinforcements for non-residential building slabs and facades, Oberste says.

Next-generation WEAV3D: Automotive speeds

A next-generation version of the WEAV3D system, designed to meet the needs of automotive manufacturing, is in development with research funding from NSF. Oberste says it will likely come online in 2022. Improvements in the new system are designed to triple the production speed of the current system, including the replacement of IR heating and compression rollers with more efficient ultrasonic welding.

At the same time, Oberste and his team have begun discussions with U.S. and European Tier 1s and OEMs in the automotive industry about the use of WEAV3D products to reinforce plastic panels, ranging from interior components to pickup truck tailgates. "One of the goals is to add a lattice as a structural skeleton within molded plastic components in order to improve their strength and stiffness and to replace metallic brackets and stiffeners that designers currently rely on," Oberste says. WEAV3D is also working on demonstration articles of automotive body panels and other components to showcase benefits of the material. CW

LEARN MORE

Read this article online | short.compositesworld.com/WEAV3D

ABOUT THE AUTHOR

Hannah Mason joined the *CompositesWorld* team in 2018 after working as an editorial intern for sister magazine *Modern Machine Shop* and earning a Masters of Arts in Professional Writing from the University of Cincinnati.

CALL FOR NOMINATIONS

MOST INNOVATIVE USE OF PLASTICS AWARDS

The Automotive Division of the Society of Plastics Engineers (SPE®) is announcing a "Call for Nominations" for its 50th-annual ***Automotive Innovation Awards Gala,*** the oldest and largest recognition event in the automotive and plastics industries. This year's Awards Gala will be held Wednesday, **November 10, 2021,** at the Burton Manor in Livonia, Mich. Winning part nominations ***(due by September, 15, 2021)*** in 10 different categories, and the teams that developed them, will be honored with a **Most Innovative Use of Plastics** award. A **Grand Award** will be presented to the winning team from all category award winners.

A special category has been added for the 50th-annual Automotive Innovation Awards: **INNOVATIVE AUTOMOTIVE INDUSTRY PLASTIC SOLUTIONS FOR COVID-19 PROTECTION,** recognizing the outstanding effort by the plastics and automotive industries to support the international needs for battling this terrible menace that has cost so many so much.

SPONSORSHIP OPPORTUNITIES

This annual event currently draws over 800 OEM engineers, automotive and plastics industry executives, and media. A variety of sponsorship packages - including tables at the banquet, networking receptions, advertising in the program book, signage at the event and more are available. Contact Teri Chouinard of Intuit Group at **teri@intuitgroup.com.**

For more info and to submit nominations, go to: **www.speautomotive.com/innovation-awards-gala.**

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Glass fiber and phenolic prove their mettle in camshaft module

Replacing aluminum, a fiberglass/phenolic module reduces mass and NVH in a prototype structure and speeds assembly line installation.

By Peggy Malnati / Contributing Writer

»In the race to reduce tailpipe emissions and improve fuel efficiency of passenger vehicles, automakers are exploring alternative powertrain options like electric and fuel cell vehicles. Meanwhile, they're also working to increase conventional internal combustion engine (ICE) efficiency — for both gasoline and diesel variants — plus trim as much mass as possible from vehicle components. The engine itself is a good lightweighting target since it is still largely steel and aluminum. Recently, a German consortium investigated the viability of converting a metallic camshaft cover to composite, with encouraging results.

Lightweighting opportunities

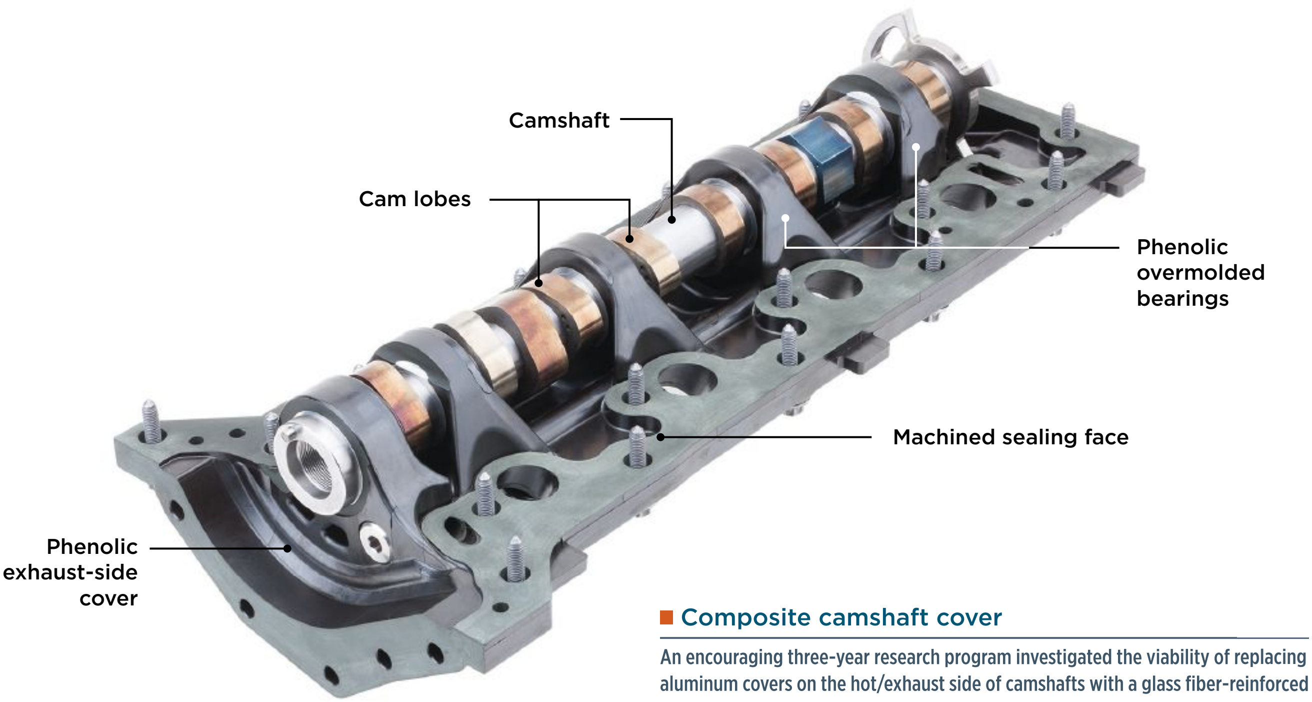
Camshafts are important elements of ICE-powered vehicles. As the shaft rotates, cams (ovoid disks or lobes) push intake valves open/closed in sync with the crankshaft gear. Depending on engine construction, valves feed either air or an air/fuel mixture into pistons where ignition occurs, spinning the crankshaft and propelling the vehicle forward or backward. Typically, camshafts are mounted between split bearings — a shaft bearing made in two pieces that are bolted together and held in cups or bearing blocks — on intake and exhaust sides of either the base of V-engines or between cylinder banks on flat engines. A cover on each side of the camshaft and its bearings protects from water and debris.

The benchmark for the study discussed here was an aluminum camshaft cover on a four-cylinder production gasoline engine with a delta-design cylinder head. The research team focused on replacing the camshaft's exhaust-side cover, whose proximity to the hot exhaust system makes it the more difficult cover to tackle.

This research was completed under Germany's "New Vehicle and Systems Technologies" program, funded by the Federal Ministry for Economic Affairs and Energy (BMWi) and administered by transportation consultant TÜV Rheinland (Köln, Germany). The project consortium was led by Tier One Mahle AG (Stuttgart, Germany) and research institute Fraunhofer Society – Institute for Chemical Technology (FhG-ICT, Pfinztal, Germany), plus a German automaker, a composites supplier and a toolmaker. Mahle was both project coordinator and tier integrator.

Material/process selection

The project began with discussions about materials and processes to meet OEM specs. "Given the rigors of the underhood environment — especially mounted to the engine and incorporating camshaft bearings — we needed a material with excellent mechanical properties to handle high loads at elevated temperatures (up



Composite camshaft cover

An encouraging three-year research program investigated the viability of replacing aluminum covers on the hot/exhaust side of camshafts with a glass fiber-reinforced phenolic. Not only was the composite cover lighter and quieter, but it incorporated more components, leading to assembly time and cost savings. The module is shown with the camshaft (above) and without (left).

Source, all images | Fraunhofer Society – Institute for Chemical Technology

to 180°C) in the presence of engine fluids, so thermoplastics were quickly eliminated in favor of thermosets," explains Thomas Sorg, FhG-ICT research associate–new drive systems.

"We chose injection molding to demonstrate the application could be used in a large-volume-capable process," continues Justus Himstedt, Mahle head of camshaft technology. "Injection molding repeatedly produces complex 3D parts in short cycle times and permits insert molding to reduce secondary operations."

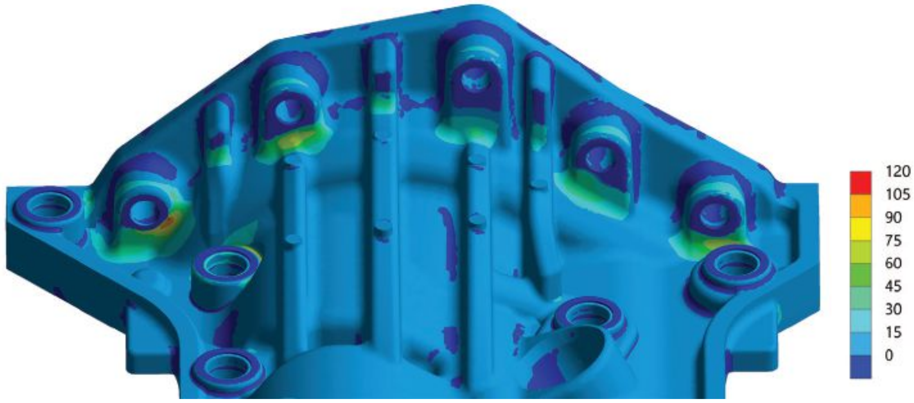
The composites supplier, which made final material selection based on extensive experience, chose a short glass fiber-reinforced phenolic with 55% fiber-weight fraction (FWF). The grade already had OEM approvals for underhood applications and has been long used in water- and oil-pump housings. Phenolics also provide excellent flame, smoke and toxicity (FST) properties and are competitively priced versus vinyl esters. Additionally, the material offers high compressive strength at low density, has nearly zero creep over the projected service life of the camshaft module and its coefficient of thermal expansion (CTE) is similar to that of aluminum, helping reduce thermal stresses during engine operation since, with the exception of the steel camshaft itself, most mating structures were aluminum.

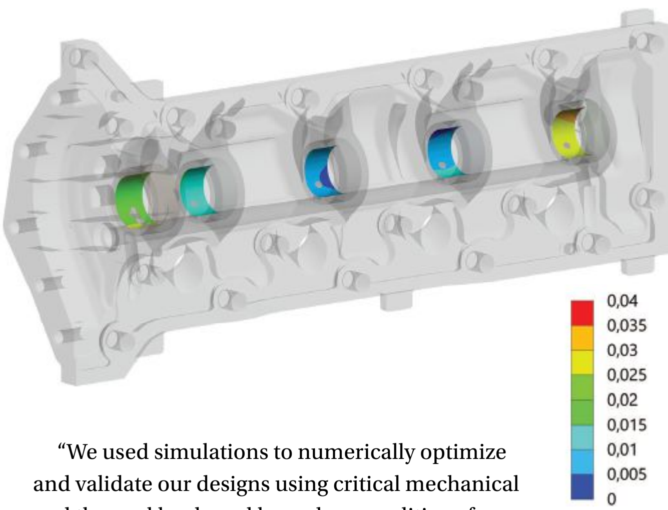
The team carried over sealing areas on the cylinder head and control-housing cover to speed implementation should they be successful. The original metal design was completely reworked, including changing wall thicknesses and redesigning around the cylinder head to ensure the composite module, when mounted, would properly index to the camshaft and hold it tightly to prevent it from flexing as it rotates and controls engine aspiration. As the design evolved, they focused on improving functional requirements (i.e. meeting thermo-mechanical and dimensional requirements, cost targets, assembly efficiency during engine build, etc.).

Detailed CAD models were developed for several design options to assess which produced the best results; next, physical prototypes were 3D printed for further evaluation. Providing most of the project's simulation work, FhG-ICT used OEM-supplied computer-aided design (CAD) data from similar metal parts and mating surfaces from the benchmark engine. Modeling tools Siemens NX (Plano, Texas, U.S.) and ANSYS (Canonsburg, Penn., U.S.) were used to understand loads and performance requirements. Additionally, the composites supplier conducted mold filling analyses to ensure that tool design, gating, mold inserts/slides and process settings (e.g., temperatures and pressures) were appropriate to mold parts. »

FEA module simulations

The camshaft module was designed iteratively so local tensile stress maximums at the screw connections met fatigue strength requirements (right). FEA simulations of the module at total deformation of bearing surfaces under critical load also were conducted (below).





"We used simulations to numerically optimize and validate our designs using critical mechanical and thermal loads and boundary conditions from the engine," explains Dr.-Ing. Lars Fredrik Berg, FhG-ICT deputy head of department–new drive systems. "Maintaining permissible bearing displacement was challenging, since phenolic's Young's modulus was lower than that of aluminum. At first it was difficult to meet our targets, but after several design iterations, module stiffness was so improved that bearing displacements remained in the allowable range and local peak stresses were minimized, so we met fatigue targets. While the composite is only one-quarter as stiff as aluminum, our design measures enabled us to meet maximum allowable deformation with a much less stiff material."

Key design innovations include integration of the lower half of the unsplit-bearing rings into the cylinder head and overmolding of the upper half into the cam cover. While this modular approach required precise positioning of cover to engine — necessitating machining of both cylinder head and module to fit into the groove/notch located on the cam cover to hold the cam down during operation and prevent oil leaks — the composite module permits faster, easier installation, reducing assembly time and total system costs. Post-mold, during machining, the module was held in a stressed state to emulate loads from screw connections joining the module to the cylinder head in order to compensate for any machining-induced deformation.

Once the design was finalized, a single-cavity tool was cut, and the materials supplier molded physical parts on a press capable of delivering shot sizes of 600 cubic centimeters. After demolding, parts were heated to finish crosslinking and achieve higher material properties.

"In order to fit in a module with closed bearings, all existing bearing blocks (cups) in the cylinder head were machined down," continues Himstedt. "Also, in the area of the actual bearing points, where loads are greatest, and in the module's screw connection, geometry was shaped so valve train forces were transmitted in compression." Composites and their relatively high mechanical properties saved cost and weight by eliminating metallic inserts in areas where screws connected the module to the cylinder head and control-housing cover. Only where fine threads were used (e.g., screw-mount connections for ignition coils and the camshaft sensor), or where the module directly supported the camshaft, were metallic inserts molded into the cover.

Tight tolerance requirements in the cylinder head and cam roller finger followers — used to raise/lower intake and exhaust valves on overhead cam engines — required two-step, post-mold machining of the cover module. First, the sealing area, reference hole, slotted hole and positioning hole for the seal were machined and oil-feeder holes were finished. Second, the bearing seat was machined.

> The project showed composites can be used successfully in demanding ICE applications.

After that, the camshaft and the module were joined via the shrink-fit method to avoid the cover coming loose. Cams, trigger wheel and axial bearing were installed and aligned. Then the assembly was heated to permit the shaft to fit through the cams and be mechanically joined to the cover. The team was careful to prevent excessively heating the composite to avoid degradation. Once the camshaft cooled, bearings were oiled to ensure proper operation. The module installs as a single assembly, saving engine assembly steps and time.

Next, the team measured and documented key aspects of the camshaft to ensure it moved smoothly within the bearing seat. All measured torsional moments were less than 3 newton-meters, a requirement in the unscrewed condition. The cover was optically scanned to check for defects that could cause premature failure — none were found. Next, pull-out tests around exterior-threaded inserts and twist-out and push-out tests on overmolded camshaft bearings were conducted, all with satisfactory results. These tests validated earlier CAE predictions for bearing twist moments of 100 newton-meters, as well as axial push-out forces of ~10 kilo-newtons and mean-pullout forces on threaded inserts of ~5 kilo-newtons.

Subsequently, Mahle validated one prototype on a cylinder-head test bench with portions of the benchmark engine (minus piston train). Twist moments for the camshaft in the module were measured at less than 3 newton-meters in the installed state. After 100 hours, the module was removed and evaluated for defects. Since none were found, and the module was deemed to be operating properly, tests continued for another 500 hours. Deformation analysis via optical 3D measurement before and after showed positive results, as did disassembly of the camshaft from the module to examine wear on bearing points, camshaft contact points and cam/bearing surfaces.

Positive results

Overall, the project demonstrated mass reduction of 20%, noise/vibration/harshness (NVH) improvements, and potential cost savings during engine assembly by eliminating steps normally required to install components like the bearing shells, phaser gear and camshaft position sensor, which are now incorporated into the module. The team feels the project showed composites can be used successfully in demanding ICE applications. Although designed for passenger-car gasoline engines, the concept is translatable to cars or trucks with diesel or gas engines with camshafts and engines positioned similarly to that used in the study.

Further validation in a running engine is planned. Future work could quantify NVH improvements, reduction of greenhouse-gas emissions and optimize mold and manufacturing process to eliminate post-mold machining. CW

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ABOUT THE AUTHOR

Contributing writer Peggy Malnati covers the automotive and infrastructure beats for *CW* and provides communications services for plastics- and composites-industry clients.
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Large composite covers protect a lot of water

A massive concrete water storage facility in Bogotá, Colombia, gets a much-needed makeover with the resin transfer molding of 840 large composite domes that keep the water potable.

By Jeff Sloan / Editor-in-Chief

» Water storage and delivery in Bogotá, Colombia, like for any large urban area, is complicated. The challenge is not one of supply, for the city of some 9 million people receives 32 inches (824 millimeters) of rain each year, plus the Bogotá River flows through the city. The challenge is to capture that water, treat it and then store it so that it remains potable and available as needed by residents and businesses. To do this, Empresa de Acueductos y Alcantarillados (Company of Aqueducts and Sewers, EAAB, Bogotá) has, over the years, constructed a series of 59 tanks throughout the city to store treated water and ensure supply to customers.

Some of these tanks are actual tanks — fully enclosed to protect the water from the outside elements. Others, many of them older, are massive concrete basins protected from the elements with a series of removable covers. One such tank, called Casablanca and located in the Ciudad Bolivar neighborhood in the southern section of Bogotá, serves a population of about 3 million people. Casablanca, the largest water storage tank in the EAAB network, and the largest water storage tank in Colombia, measures 144 meters (472 feet) long x 110 meters (361 feet) wide x 9 meters deep (29.5 feet) and has capacity to store 143,000 cubic meters (38 million gallons) of water. The tank is bisected by a concrete divider running down its middle so that water is stored in two equal sections.

Maintaining the 66-year-old Casablanca is no easy task. In 2009, it was discovered that cracks in the concrete floor of the tank were allowing 360,000 liters (95,000 gallons) of water to escape each *hour*. Repairs to the concrete with a polyurea coating reduced

RTM'd composite covers

Workers install one of 840 composite covers manufactured via resin transfer molding (RTM) by composites fabricator Soling. The massive covers weigh 705 pounds each and protect the Casablanca water storage tank in Bogotá, Colombia, which holds up to 38 million gallons of water and is the largest water storage system in the country. Source | Soling

leakage to zero. Casablanca, however, still had a problem above the concrete. Water in the tank was protected by a series of covers that consisted of a mix of concrete and asbestos, which posed a significant threat to water quality and human health. The old covers were also prone to failure and were expensive to maintain. EAAB needed to replace the old covers with a safer, lighter, more durable alternative.

Casablanca tank

The 66-year-old Casablanca tank is bisected by a concrete divider that allowed EAAB, the Bogotá water and sewer agency, to empty one half of the tank so that covers could be installed. The old concrete and asbestos covers, on the right, were subject to breakage and costly to maintain. It's expected that the composite covers will have a longer life and require less maintenance. Source | Soling

Big covers, and a lot of them

EAAB decided to pursue a composites solution for the covers, but was challenged immediately by the scale of the project. Casablanca is crisscrossed by a series of concrete pillars that support a network of beams on which the covers rest. These beams are spaced about 7.2 meters (23.6 feet) apart, thus the new covers would have to be self-supporting and cover that span to make use of the existing infrastructure. EAAB, through a contractor, looked for someone capable of manufacturing the covers in composites, but guaranteeing a good finish on both sides. The challenge? Composite structures of this size required for this application had never been manufactured via closed molding in Colombia. Many fabricators simply were unable to take on the project.

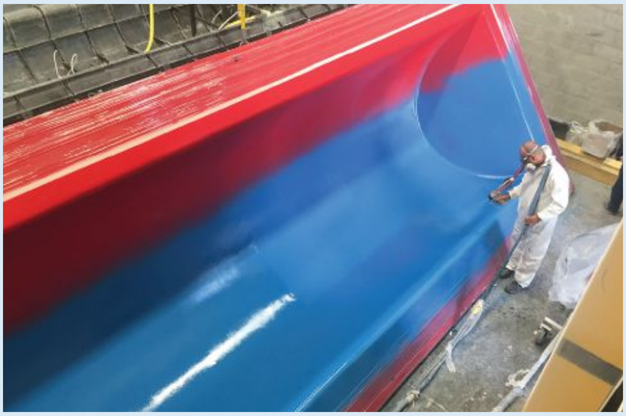
The exception was Innovative Engineering Solutions, or Soling, a composites fabricator located in La Estrella, Antioquia, Colombia, just south of Medellín, founded in 2014 by CEO Javier Moreno. Rodrigo Vergara, engineering coordinator at Soling, says the size of the covers was a non-starter for many fabricators: "Nobody had experience with this in Colombia because of the size of the part. It is the biggest composite part fabricated via LRTM in Colombia." For Moreno, however, the size of the covers was an interesting challenge. "For our CEO," says Vergara, "it was a dream come true. 'Impossible' is a word he doesn't understand. He said, 'We will do this!' I said, 'OK, let's do it!'"

> Soling completed production of all 840 covers over a period of 7-8 months, finishing in late 2020.

Soling proposed a specific solution for the Casablanca project: A series of *840* domed, rectangular composite structures, each measuring 7.6 meters long and 2.4 meters wide (24.9 x 7.9 feet). The semi-circular dome design was chosen, says Vergara, because "the geometric shape that has the most mechanical resistance is a circumference. This was the main factor to guarantee that the covers were self-supporting. On the other hand, we had to find the easiest way to ship them from the manufacturing site to the installation point, which was 260 miles away."

The covers would be manufactured via LRTM with, according to EAAB specification, a blue gel coat on the exterior surface and a white gel coat on the interior surface. Comprising glass fiber fabrics and a polyester resin, the cover, with a surface area of 28.5 square meters (207 square feet), would weigh 320 kilograms (705 pounds), »

1 Soling partnered with Magnum Venus Products (MVP) to develop the light resin transfer molding (LRTM) process used to fabricate the Casablanca covers. Shown here is the MVP Patriot Innovator high-volume injection unit that pumped 617 pounds of polyester resin for each cover. Source (all steps) | Soling



2 The female half of the mold used to fabricate the Casablanca covers is first sprayed with a blue gel coat, per EAAB's requirements.

3 The male half of the mold for the covers is sprayed with white gel coat. The white, or interior side of the covers, face the interior of the Casablanca tank.

4 After glass fiber fabrics, supplied by Jushi, are placed in the female half of the mold, the male half is lowered into place via crane and the two haves are bolted together.

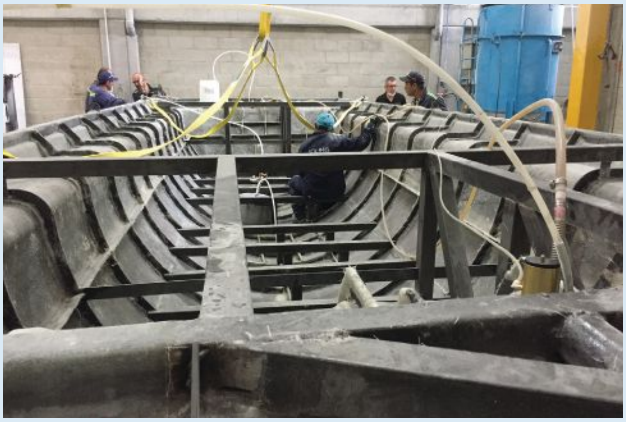
208 kilograms of which would be resin. With a design in hand and a commitment to deliver the covers, Soling went to work.

Building the perfect cover

Soling, of course, did not take on the Casablanca project without help. Working with the company was a supply network that included a distributor, a material supplier and an equipment manufacturer. The distributor, Minepro SAS (Medellín, Colombia), provided technical support and worked with equipment supplier Magnum Venus Products (MVP, Knoxville, Tenn., U.S.), which supplied pumps and auxiliary equipment for the LRTM fabrication process. The materials suppliers are Andercol (Medellín), which provided the polyester resin matrix, gel coats and technical support, and Jushi (Tongxiang City, China), which provided the E-glass fiber fabrics.

Manufacturing, naturally, begins with tooling. The question was how many molds the project required. To determine this, Vergara says Soling first had to establish the pace of manufacture to meet EAAB's delivery requirements. This, in turn, was affected by requirements at the installation site. To avoid potentially contaminating the water supply during installation of the new covers, EAAB agreed to empty the half of the Casablanca tank over which covers were being delivered and lowered into place. Reducing Casablanca's water storage capacity by half poses challenges, thus EAAB needed delivery and installation to happen as quickly as possible.

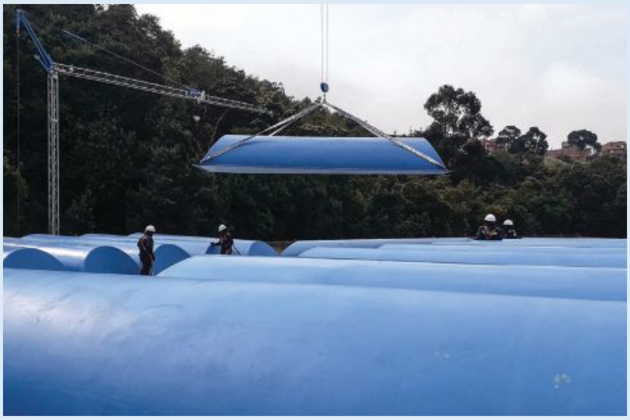
Soling, explains Vergara, settled on a production schedule that would deliver six covers each day. In a facility running



5 With the male half of the mold in place, Soling employees prepare to inject resin. This photo shows clearly the metallic structure that supports the tool, as well as the two resin injection ports (foreground and background) and the vacuum port in the middle of the tool.

6 Soling built two molds to fabricate the covers. Each mold is fed resin via two injection ports (one shown here), and uses one vacuum port. Injection of the polyester resin, supplied by Andercol, took about 40 minutes. Soling produced one cover per mold per shift.

7 A finished cover is pulled from the mold and then trimmed to final shape. Each cover is 7.6 meters long and 2.4 meters wide. It features a semi-circular dome so as to maximize mechanical strength given the area each cover must span.



8 Completed covers are delivered to the Casablanca tank and lowered into place with cranes. The covers are not designed to be removed after installation, except in case of emergency. It took Soling a little more than 7 months to fabricate all 840 covers at a rate of about six per day.

three eight-hour shifts per day, that necessitated two molds, each capable of fabricating one cover per shift. The molds, he says, were built in-house and comprised a glass fiber composite male/female design backed by a steel support structure.

With the cover design defined, Soling began the work of establishing how, specifically, the domes would be manufactured. The team decided that the best option was for each mold to be fed by two resin injection ports, with one vacuum port. Once these details were defined, the molds were manufactured. Subsequently, Minepro and MVP were involved in the selection of a suitable machine for the process and the necessary supplies for the construction and operation of the molds. For resin injection, MVP recommended its Patriot Innovator high-volume RTM pump unit, which is capable of delivering the large volume of resin required by each cover. MVP also provided its Turbo Autosprue valves, as well as universal couplers, seals and mold accessories.

To start production of a cover, says Vergara, the male half of the mold was sprayed with white gel coat and the female half of the mold was sprayed with blue gel coat. Next, the Jushi-supplied E-glass mats and fabrics were hand-laid into the female half of the mold. This was followed by lowering, via crane, the male half of the mold into the female half, with the two halves clamped together. After vacuum was pulled, resin injection began. Vergara says injection of each cover was completed in about 40 minutes, followed by room temperature cure. After each cover was demolded, it was trimmed to final dimensions.

Vergara says the sheer size of the covers, combined with strict weight and dimension requirements, posed the greatest » challenge to their manufacture. Determining injection port location and managing injection timing required validation of flow analysis and consultation with technical experts. Eventually, however, Vergara says Soling settled on a fabrication process that proved highly repeatable and dependable.

"The biggest challenge was the weight of the elements that we were going to install, because we could not exceed the load capacity of the existing structure," Vergara says. "This required that all the pieces have the same characteristics, both in geometry and weight. The only way to guarantee these conditions was to use a process that guaranteed repeatability."

LEARN MORE

Watch video | short.compositesworld.com/Soling

Finished covers were shipped the 418 kilometers (260 miles) from Soling's facility near Medellín to the Casablanca work site in Bogotá and then installed via crane, lowered onto the support structure and positioned by workers standing on the beams the covers would rest on. The covers are assembled to overlap each other, in turn resting on the rainwater collecting channels, also made of composites, that were previously installed in the concrete beams; this entire system is fixed by mechanical anchors. Vergara says the covers are not designed to be moved unless "something very serious happened."

Soling began design work on the covers in early 2019 and started fabrication of the first covers in the same year. The coronavirus pandemic and occasional mechanical challenges caused manufacturing to stop and start, but Vergara says Soling completed production of all 840 covers over a period of 7-8 months, finishing in 2020. It is expected that the new covers will last substantially longer and require much less maintenance than those they replaced.

The Casablanca project, Vergara says, has demonstrated Soling's capabilities as a fabricator of high-quality, high-performance, large composite structures and has opened doors to other opportunities: "This project was a challenge in which we had to break paradigms that said that parts of this magnitude could not be made using this manufacturing method, and still we did it. For the future of Soling, something is very clear: There is no project that we are not capable of doing. And most importantly, we have a CEO who is not afraid to take on these types of challenges." CW

ABOUT THE AUTHOR

Jeff Sloan is editor-in-chief of *CompositesWorld*, and has been engaged in plastics- and composites-industry journalism for 24 years. **jeff@compositesworld.com**

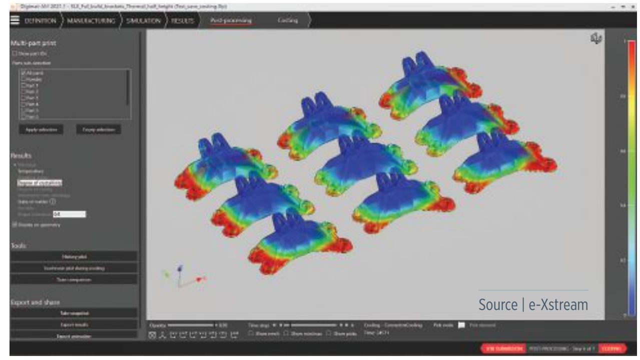
New Products

» 3D PRINTING SOFTWARE

Enhanced software offers improved composite 3D printing simulation capabilities

e-Xstream engineering, part of Hexagon's Manufacturing Intelligence (Luxembourg, U.K.) division, has introduced new simulation and virtual manufacturing capabilities within its Digimat software that enables users to analyze the production cost of polymer-based additive manufacturing (AM) parts against conventional processes, and to continuously improve their virtual engineering processes by validating the composite's microstructure with computerized tomography (CT) scans of manufactured parts.

The latest Digimat software enables businesses to simulate the 3D printing process and calculate the total cost of producing each part, including material and energy use, employee time and required post-processing steps. Using this new tool, an engineer can take a holistic view of part production and finishing processes to determine the best process chain for production. Crucially, the company adds, it can also be used to perform batch optimizations to print as many parts as possible in parallel, increasing production capacity and reducing lead time. It can also be used in production planning to consider the total cost of ownership of machines and amortize those costs over projected production volumes. This information is visualized for the user through plots and pie charts.



In order to troubleshoot quality issues and improve the accuracy of performance predictions — such as fiber orientation — Digimat now enables manufacturers to CT scan a part and import the 3D RAW image to build a finite element model (FEM) of its two-phase microstructure (e.g., carbon fiber-reinforced polymer) to perform analyses and model its behavior. Being able to account for variations within a manufactured part could potentially reduce material use or avoid points of failure, e-Xstream says.

Connecting physical measurement with virtual testing is also said to improve the accuracy of Integrated Computational Materials Engineering (ICME) processes when a new material system is introduced; the part performance can be compared to the simulated process to validate and certify the material model. CT scan validation also helps material professionals refine the microstructure models they have built manually to improve the accuracy of future simulations.

When refining new manufacturing processes, users can capture information about the part, material, 3D printer or process used and their physical tests as they work using material lifecycle management. e-Xstream engineering's MaterialCenter software — a separate feature from Digimat — captures a traceable, validated database of those trusted material properties so that they can be used in the design phase of a product. Using material lifecycle management, information can be easily documented within multi-disciplinary teams and shared throughout an organization, capturing valuable knowledge for re-use by authorized users.

Optimizing graphics processing units (GPUs) further ensure that some computational tasks, such as analyzing behavior of a CT-scanned microstructure, can now be performed interactively by the engineer with results produced in minutes. Benchmarks show the time required to analyze the stiffness of a material, for example, is reduced by 98%. This rapid solve time, combined with the introduction of a command line interface, also enables the use of Digimat FEMs within automated cloud-based optimization workflows on high-performance computing platforms.

Finally, when producing high-performance structures, the progressive failure analysis (PFA) model makes it possible to define safety margins for a structure and is said to optimize the use of potentially expensive materials and processes. The latest version of Digimat performs these complex Camanho model analyses twice as fast, making it possible to perform a parametric study to define defect tolerances and maximize production yields. e-xstream.com

» OX-OX CMC COMPONENT SURFACE FILM

Surface film targets improved high-temperature ox-ox CMC surface finish

Source | Axiom Materials Inc.

Axiom Materials Inc. (Santa Ana, Calif., U.S.), one of Kordsa's (Istanbul, Turkey) U.S.-based subsidiaries in the advanced composites materials segment, has launched its latest oxide-oxide ceramic matrix composite (ox-ox CMC) surfacing films product line, CerFace. The centerpiece of the product line is CerFace AX-8810, which is designed to co-cure with Axiom's ox-ox prepregs to reduce surface porosity and improve outer surface finish in high-temperature CMC components for industrial and aerospace markets.

Non-toxic and environmentally benign, the CerFace AX-8810 oxide matrix is applied to an oxide carrier using advanced solution coating techniques, protecting exposed fibers and minimizing surface roughness of CMC components for operating temperatures of up to 1,093°C. Application of the film is a single-step process, eliminating the need for traditional coatings and secondary processes.

CerFace AX- 8810 is currently being offered in rolls of 61-cm widths, and 23-m lengths. Wider widths will be available in the future.

Typical industrial applications include combustors, shrouds, gas filters for power generation and furnace hardware. Typical aerospace applications may include lightweight aeroengine components such as the mixer, center body and cone sections; hot sections of the aircraft structures near the engine; and radomes.

Application of CerFace also enhances the precision of machining and drilling of the CMC component. Axiom says it plans to introduce additional CerFace films for modifying the surface properties of ox-ox CMC components in the future.

axiommaterials.com

» SURFACE FINISH MATERIALS

Wind blade shell film removes surface finish limitations

Source | Hexcel

Hexcel's (Stamford, Conn., U.S.) HexPly XF surface technology is said to significantly reduce shell manufacturing time during the wind blade surface finishing process. Overall blade manufacturing efficiency is increased by reducing time in the mold by up to two hours and by banishing surface defects that require rework before painting.

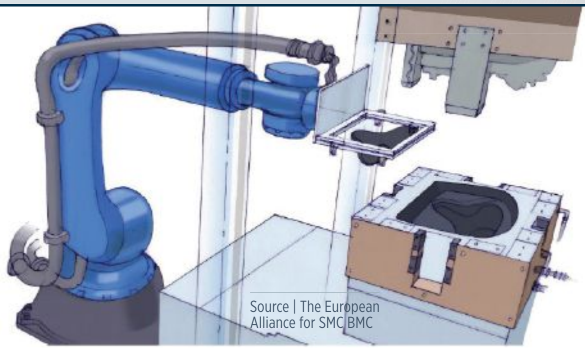
According to the company, HexPly XF is formulated to address the limitations of current blade shell surfacing techniques in the wind industry, where pinholes and other surface defects have to be repaired by hand to achieve the smooth surface required for painting.

To satisfy the most challenging surface quality, HexPly XF introduces a new material format as the surface finishing layer, eliminating the need for a traditional in-mold gel coating process. HexPly XF for infused rotor blades, is a lightweight, nonwoven semipreg construction, comprising an epoxy resin matrix that co-cures with standard epoxy infusion systems.

Easy to handle and supplied in a ready-to-use roll form, HexPly XF can be quickly applied by hand or with semi-automated layup equipment. It features one self-adhesive, surface finishing side, which is indicated by a removable protective foil. This side of the prepreg is placed against a release agent-treated mold surface. Once the material has been positioned, layup of the blade shell structure can begin, and the laminate can be infused. After curing, the blade is demolded.

HexPly XF is said to be less than half the weight of a typical gel coat per square meter, reducing the overall weight of the blade. Additionally, the consistent areal weight and thickness of the prepreg film is said to provide a uniform surface coating, ensuring blade weight distribution and balance are maintained. With no need to handle or mix liquid chemicals as in the gel coat process, HexPly XF reportedly improves the health and safety working conditions on the shop floor.

The material has a shelf life of six weeks at ambient temperature, minimizing cold storage requirements and reducing scrap. **hexcel.com**



Source | The European Alliance for SMC BMC

» BMC, SMC DESIGN GUIDE

Design guide series addresses SMC, BMC material use and manufacture

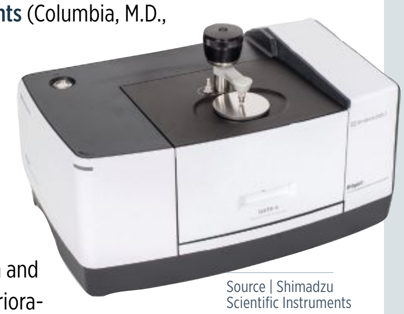
As sheet molding compounds (SMC) and bulk molding compounds (BMC) are being increasingly used in a broad range of end-use applications and markets, the European Alliance for SMC BMC, a European association operating under the umbrella of EuCIA (Brussels, Belgium), is launching a series of design guides that explain to designers how these versatile materials can be used and manufactured in larger production series.

The design guides will reportedly address a number of frequently asked questions concerning design and manufacture of SMC/BMC components and offer some practical tips to ensure their successful deployment. According to the European Alliance for SMC BMC, the first design guide will discuss the design process, potential design pitfalls, tool design considerations, the cost of an SMC mold and pose the question of whether to source production in-house or externally.

Copies can be found online. **smcbmc-europe.org**

» PLASTIC ANALYSIS SYSTEM

FTIR system facilitates highly accurate polymer qualification



Source | Shimadzu Scientific Instruments

Shimadzu Scientific Instruments (Columbia, M.D., U.S.) has introduced its new Fourier Transform Infrared (FTIR) Spectrophotometer plastic analysis system that includes proprietary UV- and thermal-damaged plastics libraries to facilitate accurate qualification and to determine the state of deterioration when analyzing foreign substances, contaminants and microplastics. The system features Shimadzu's IRSpirit FTIR spectrophotometer, QATR-S single-reflection ATR attachment and the Plastic Analyzer Method Package. This package includes FTIR spectral libraries for plastics degraded by UV rays and heat. These libraries help investigators analyze unknown samples that are difficult to identify with standard libraries. The UV-damaged plastics library includes more than 200 spectra from the UV degradation of 14 types of plastics, unirradiated and UV irradiated for 1-550 hours. The thermal-damaged plastics library includes more than 100 spectra from the degradation of 13 types of plastic heated to between 200°C and 400°C. **ssi.shimadzu.com**

Source | Teijin Ltd.

» CARBON FIBER

Carbon fiber intermediate materials target sport applications

Teijin Ltd. (Tokyo, Japan) has launched its novel *Tenax* PW (power series) and *Tenax* BM (beam series) brands of carbon fiber intermediate materials for sports applications.

Tenax PW, made of high-tenacity, high tensile modulus resin, is an advanced aircraft-quality material that, as a result of exceptional durability and toughness, maximizes power and speed. *Tenax* PW also reportedly suppresses and absorbs impact forces to minimize and localize damage after impact and retains a compressive strength superior to that of Teijin's standard carbon fiber prepregs.

Tenax BM is another highly advanced material. High rigidity, straightness, operability and stability make it ideal for applications requiring flexibility and resistance to thermal expansion. *Tenax* BM also offers superior vibration damping (suppression and absorption), achieving damping effects four times greater than that of Teijin's standard carbon fiber prepregs. Sporting goods made with *Tenax* BM are said to be highly resistant to impact deformation and shakes. **teijin.com**

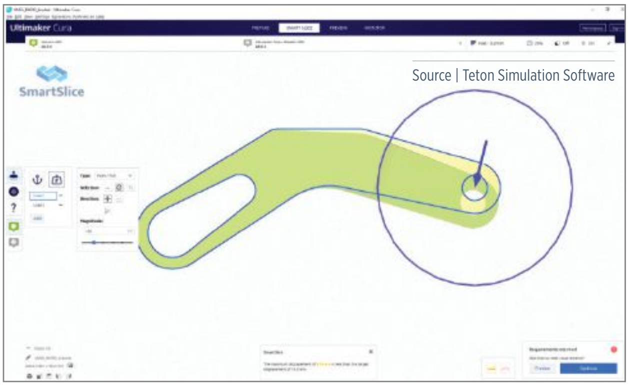
» FDM THERMOPLASTIC MATERIAL

ABS-based thermoplastic for improved functionality, versatility and light weight

Source | Business Wire

Stratasys Ltd. (Eden Prairie, Minn., U.S. and Rehovot, Israel) has introduced a new ABS-based carbon fiber material, FDM ABS-CF10, for its F123 Series 3D printer line, the first composite material for the platform. Formulated for applications such as manufacturing tools, jigs and fixtures, the material is said to make carbon fiber more accessible to the engineering and manufacturing community with high-performance F170, F270 and F370 3D printers. FDM ABS-CF10's material properties feature 10% chopped carbon fiber, offering an alternative that is 15% stronger and 50% stiffer compared to standard ABS, without the weight of metal. The carbon fiber material can also be printed with a high degree of accuracy. Further, the QSR Support water-soluble material makes 3D printing intricate and complex parts without time-consuming manual support removal possible.

With FDM ABS-CF10, Stratasys says it is particularly focused on addressing applications in the aerospace, automotive, industrial and recreational manufacturing industries. Parts applications include end effectors used with industrial robots, ergonomic aids such as lift assists and hand tools and alignment fixtures on assembly lines. **stratasys.com**



» AM PART PARAMETER SOFTWARE

3D printer simulation software offers improved user functionalities

Teton Simulation Software (Layramie, Wyo., U.S.) has released version 20.2 of its SmartSlice software, a simulation tool for optimizing 3D printer performance. New functionalities for this version include view displacements, tooltips, 10 new materials and the ability to sort optimized results by cost and identify regions of the part that may require modification.

Via the "view displacement" feature, users are now able to view how a part deflects under the prescribed use case, ensuring a problem is set up correctly.

Teton also has implemented the ability to inform users after a validation, or after an unsuccessful optimization, as to next steps if the as-printed geometry with the specified material and slice settings does not meet stiffness or strength requirements, including:

- Optimizing slice parameters using SmartSlice to meet the requirements
- Manually modifying the slice parameters to meet the requirements
- Changing the material to a stronger (or) stiffer material
- Highlighting regions of the geometry which could be modified to meet requirements.

For the last option, SmartSlice will now show the user where the part is either (a) the weakest or (b) the softest. The user can then take appropriate action to ensure their part will perform as expected.

Similarly, if SmartSlice cannot find a set of slicing parameters to meet the desired requirements, the user will be shown the areas of the geometry that need modification, and suggest the user either change the material to a stronger or stiffer material or modify the geometry at the indicated regions to meet the requirements.

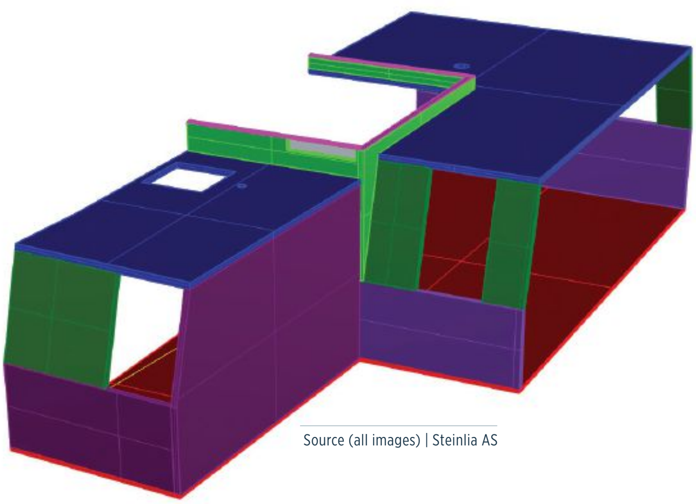
An additional feature, tooltips, are now available on all buttons within SmartSlice to inform users what the buttons do, and are available for all optimized results, enabling users to understand which slice parameters are being modified for the optimized result. Further, links to help and tutorials are now embedded directly within the toolbar on the left of the screen.

Teton's Cura feature makes sorting and filtering results by print time, mass, factor of safety, maximum displacement and cost possible.

Finally, to continually add to its materials database from a variety of material suppliers, Teton has built on Fiberthree PA-CF Pro, Fiberthree PA-GF Pro, igus GmbH iglidur I150, igus GmbH iglidur I180, Jabil PA 4535 CF, Jabil PETg 0800 ESD, MatterHackers NylonG, MatterHackers NylonX, Polymaker PolyMide PA6-CF and Polymaker PolyMide PA6-GF. Currently the software holds 40 material options. **tetonsim.com**

Composite panels aid design of prefabricated apartment addition

Glass fiber/epoxy sandwich panels achieved structural requirements, complex geometries and challenging installation needs for London apartment renovation.



Source (all images) | Steinlia AS

›When architecture firm Steinlia AS (Oslo, Norway) was commissioned to design a second-floor addition to an existing apartment complex in a historic district in London, U.K., architect Matthew Anderson explains that there were a number of challenges involved. The structure not only needed to meet building codes and structural requirements, he says, but also needed to be lightweight to meet weight requirements for crane installation, constructed and installed quickly at a site with restricted access and match the complex geometry of the existing house.

To meet these requirements, Anderson designed a prefabricated, two-pod concept largely comprising lightweight composite sandwich panels engineered by vdL Composites (Wesel, Germany), a joint venture formed in 2012 by ATL Composites (Molendinar, Australia) and MuH von der Linden (Wesel, Germany) to produce DuFLEX composite panels for the European market.

DuFLEX panels are used for the main structure of the extension, including the 70-millimeter-thick external walls and roof and 40-millimeter-thick floor. As the panels also offer appropriate insulation, they also serve as the finished internal surfaces for the walls, ceiling and floor.

The structures are constructed from 600-gsm biaxial E-glass/epoxy skins from ATL Composites, cored with PET foam. “We chose DuFLEX due to its high specific strength [strength/weight ratio], insulating properties, aesthetic qualities and flexible application,” Anderson says. The PET foam was chosen for its recyclability, smoke and toxicity properties, good mechanical performance, chemical stability and its tendency not to absorb water.

DuFLEX composite panels are said to offer a range of benefits, including structural stiffness and light weight — a 90% weight saving over a comparable steel design, according to vdL Composites. They are characterized as durable and low maintenance, and will not rust, rot or corrode. DuFLEX is also reported to provide excellent thermal insulation with vastly improved properties compared to steel, with a significant reduction in the size and weight demands on support structures and foundations; this is also said to translate to a reduced cost for installation and handling. With diverse applications ranging from building facades and doors, gates and window frames, to long-span roofing, composite decks, bridges and pre-fabricated housing, DuFLEX can be engineered into a majority of architectural projects to meet design loadings and regulatory requirements.

For this specific project, the pod sections were built and CNC routed at vdL Composites’ Germany facility, and then glued together and packed at Bootswerft Baumgart, a shipyard in Dortmund, Germany. From there, they were transported by Glogau International Yachttransporte (Neumünster, Germany) to the London site.

The project began in September 2019 and was completed in July 2020, including a two-month delay due to COVID-19 restrictions. The pods themselves were installed in only two hours, according to Anderson. “We are satisfied with both the speed and precision of constructing with DuFLEX, the structural performance of DuFLEX and the beautiful rooms that we created together,” he adds. CW

Composites Events

Editor's note: **Events listed here are current as of March 9, 2021. Visit short.compositesworld.com/events for up-to-date information.**

April 12-14, 2021 — ONLINE
North American Pultrusion Conference
web.cvent.com/event/822b0342-d26d-4212-afef-466ba0d2203a

April 13-15, 2021 — Detroit, Mich., U.S.
WCX World Congress Experience
sae.org/attend/wcx

April 13-15, 2021 — ONLINE
World Pultrusion Conference (WPC)
pultruders.org

April 14-15, 2021 — Silverstone, U.K.
MotorsportAM
motorsportam.com

April 22, 2021 — ONLINE
Clean Sky Spring event
cleansky.eu/news/clean-sky-spring-event-brussels-21-22-april-2020

April 27-28, 2021 — ONLINE
GOCarbonFibre 2021
gocarbonfibre.com/home

May 4-6, 2021 — ONLINE
Composites Industrial Revolution Conference
acma.today/CIRC2021

May 31, 2021 — ONLINE
SE Summit 21
sampe-europe.org/conferences/se-summit-21-paris

June 1-3, 2021 — CANCELLED
JEC World 2021
jec-world.events

June 7-10, 2021 — ONLINE
AWEA CLEANPOWER Conference 2021
cleanpowerexpo.org

June 15-16, 2021 — ONLINE
ACMA International Composites Supply Chain
acmanet.org

June 23-25, 2021 — Beijing, China
SAMPE China
sampechina.org

June 21-24, 2021 — Rockville, M.D.
NSMMS and CRASTE 2021
usasymposium.com/space

June 29-July 1, 2021 — Mexico City, Mexico
UTECH Las Américas
utechlasamericas.com

July 6-7 2021 — Southampton, U.K.
MarineAM
marineam.com

July 15-16, 2021 — Bali, Indonesia
International Conference on Composites in Civil Infrastructure (ICCCI)
waset.org/composites-in-civil-infrastructure-conference-in-july-2021-in-bali

July 28-30, 2021 — Shanghai, China
PU China/UTECH Asia
www.puchina.eu

August 1-6, 2021 — Belfast, Northern Ireland
International Conference on Composites Materials (ICCM 23)
iccm23.org/about-the-conference/

August 10-12, 2021 — São Paulo, Brazil
Feiplar Composites and Feipur — International Fair and Congress of Composites, Polyurethane and Thermoplastic Composites
feiplar.com.br

August 16-19, 2021 — Houston, Texas, U.S.
OTC – Offshore Technology Conference
otcnet.org

August 23-25, 2021 — Stockholm, Sweden
AAC Epoxy and Resins Technology Conference
advancedmaterialscongress.org/eamc/pages/epoxy-&-resins-technology

August 23-25, 2021 — Raleigh, N.C., U.S.
Techtextil North America
techtextil-north-america.us.messefrankfurt.com

August 23-26, 2021 — Colorado Springs, Colo., U.S.
Space Symposium 365
spacesymposium365.org

August 30-Sept. 1, 2021 — Cleveland, Ohio, U.S.
Ceramics Expo
ceramicsexpousa.com

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ADVERTISING INDEX

Composites protect subsea cables for offshore wind power

Balmoral uses FRP to improve installation, performance and service life while reducing cable failures in rough seas.

By **Ginger Gardiner** / Senior Editor

» Offshore wind has grown from 1% of global wind turbine installations in 2009 to more than 10% in 2019 with 6.1 gigawatts (GW) of capacity installed, according to a 2020 report by the Global Wind Energy Council. That percentage is estimated to double by 2025 when annual installations will reach 21.5 GW. By 2030, projected installations will surpass 31 GW, which translates into an annual total of more than 2,060 to almost 2,600 turbine installations, based on the 12-15-megawatt (MW) models set for serial production by 2024.

Offshore wind turbines provide carbon-free, utility-scale power generation that is increasingly cost-competitive with coal and natural gas. The levelized cost of electricity (LCOE) for offshore wind has dropped 67.5% since 2012 to US $84 per MW-hour and is expected to reach US $58 per MW-hour by 2025, thanks to larger turbines and GW-scale projects.

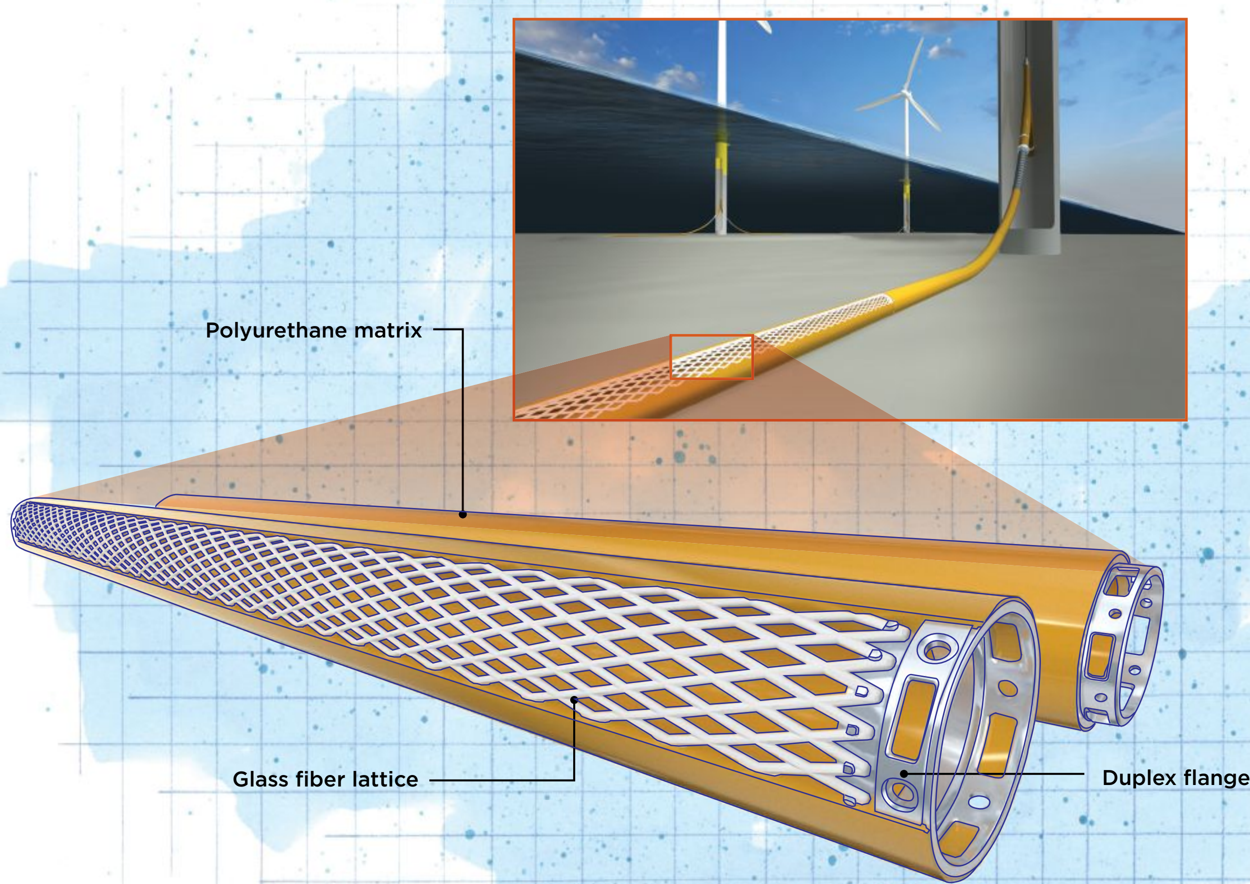
However, building and installing such behemoths is only one part of the challenge. Each turbine must also be connected via high-voltage (33- or 66-kilovolt) cables to an offshore substation,

Reliability for life of field in extreme environments

Balmoral's patented fiber-reinforced polyurethane FibreFlex cable protection system — shown above being tested on the company's test rig — improves stiffness and fatigue to better protect subsea cables carrying power from offshore wind turbines, especially in rough weather. Source (for all images) | Balmoral

and then to an onshore power grid. These subsea power cables must be protected as they exit the wind turbine monopile foundation and bend to the ocean floor where they are typically covered. Moreover, the cable protection systems must resist saltwater and subsea pressures, excessive bending from ocean currents and storms, and abrasion from rock piles around the monopile foundations to ensure that the electric power in the cable is not interrupted. Also, damage to cables would be difficult and time-consuming to repair, thus maintenance must be kept to a minimum.

Balmoral (Aberdeen, Scotland) is a pioneering product design and manufacturing company, established in 1980. Though well



DESIGN RESULTS **Balmoral FibreFlex cable protection system (CPS)**

- FRP mechanically locks to end connectors instead of relying on unpredictable PU bonding.
- 200% increase in axial tension and 150% increase in bending stiffness improves control in rough seas.
- Reduced creep improves fatigue life, guaranteeing performance for the life of the wind field.
- Improvements achieved without having to requalify new PU materials.

Susan Kraus / Illustration

known for meeting the extreme demands of the oil and gas industry, the company has a long history in both glass fiber-reinforced polymer (GFRP) and advanced composite products for a range of industries, including water tanks, wind turbine blades, wave and tidal energy components, subsea tree components and protection covers, guides and centralizers for offshore tubulars and specialized high-volume moldings.

Balmoral FibreFlex is the company's new high-performance protection system for subsea power cables in the offshore wind sector. Its innovative glass fiber lattice, produced by a robotic winder, reinforces an elastomeric polyurethane matrix and mechanically locks into each segment's end connectors. This design achieves a 200% increase in tensile strength and 150% increase in bending stiffness versus unreinforced polyurethane systems, as well as substantially improved fatigue and creep resistance, ensuring 20 or more years of service in sea conditions that are increasingly unpredictable. Equally important is the ability of this composite design to meet thermal requirements for maximum electrical power delivery and wind industry cost requirements through an automated production process.

Just adding fiber is not enough

"We do a lot of cable protection for oil and gas and saw a growing need in the renewable energy sector," says Fraser Milne, engineering and projects director at Balmoral. "The FibreFlex product came through acquisition of a company that had developed the product but couldn't get the technology to work properly. The thought was to just add fiber and that will make it stronger, which equals better." However, as explained by Dr. Aneel Gill, product R&D manager at Balmoral, "their use of fiber actually made the product quite brittle in terms of its strength profile. Thus, we had to put the product through its paces in lab work and testing to understand its performance and limitations."

"We looked at fatigue properties and at stiffness, which are absolutely critical as design parameters," Gill continues. "How the fiber affects the stiffness of the polyurethane is very important. We »

Subsea solutions

Finished Balmoral FibreFlex cable protection system segments with integrated stainless steel male and female flange end fittings.

had to understand the product behavior in terms of fatigue performance and long-term aging characteristics including UV, temperature, hydrolysis and hydrothermal aging." He notes that fatigue affects the stiffness profile of the fiber/polyurethane composite. "We also had to understand how the production process affects the properties — for example, wetting out the fibers with polyurethane, which is key," says Gill.

In the end, Balmoral completely characterized the glass fiber/polyurethane composite. Such fiber, polymer and composites testing is done at the company's own test labs onsite. "There are no datasheets for this kind of composite," notes Gill. "Although the polyurethane we use is a thermoset, it is at the other end of the flexure profile spectrum from what they use in composite leaf springs, for example. Most composites test houses don't normally work with such elastomers, while elastomer test houses don't work with fiber-reinforced composites. So, we are combining two worlds, each completely different in how to design with the material and failure modes, but also in how to handle in manufacturing. We're combining these to create something which is better than the sum of its two constituent parts, which is a good thing." But that also requires a significant amount of work up front, and then more work to understand how to use this superior performance to optimize the design.

Redesigning FibreFlex to perform

Once Balmoral understood the composite material, it then had to rework the design for the performance it wanted to achieve. "Storms, waves and currents move these undersea cables," says Gill. "Our job is to protect the cable from overbends which exceed the ULS (ultimate limit state), for example, in a 100-year storm. Increasing stiffness in the cable protection system makes it harder for the cable to move. This also increases control of its curvature, prevents kinking and flexing and improves its fatigue life.

"Thus, we want a design that provides good axial properties and torsional stiffness," he continues. "For this reason, we use a kind of fiber lattice, similar to how hoses are braided." This fiber lattice, Milne explains, is produced using a robot that Balmoral had developed with MF Tech (Argentan, France) to wind the fiber in the ±45° direction.

"This delivers the buckling resistance and stiffness we want but at a very thin wall thickness," Gill emphasizes. Why is this important? "Because the cable protection system is effectively placing a large insulator onto a power cable, which generates heat. The thicker the protection, the more heat it traps, which can then limit its power-carrying capacity. So that's where knowing how to design the fiber technology allows us to protect the cable while maintaining its performance. Our design also allows operators to apply ballast on our lines, when necessary, and not have issues such as long-term creep rupture," says Gill. "The fiber reinforcement limits the effect of creep rupture, which is a known failure mode for unreinforced polyurethane protection systems."

The robot-wound fiber lattice Balmoral devised adds another key design advantage. FibreFlex cable protection is produced in 4- or 5-meter-long segments and then joined to form a continuous hose into which the subsea power cable is threaded. The connections are male-to-female flanges made from Duplex (austenitic and ferritic) stainless steel, guaranteed to provide decades of subsea performance. These are integrated into each hose segment via the fiber lattice. "Each flange has 40 to 50 fingers," explains Milne. "Our robot will run the fiber from one end of the pipe to the other, catching each of these fingers to create the lattice. Thus, the flanges are mechanically attached to the fibers and not bonded."

This, explains Gill, creates a very robust product with reduced risk. "Conventional protection systems often bond the end fittings into the unreinforced polyurethane," he notes. "So, you have a piece of malleable plastic that may exhibit 100% or 200% elongation to break, and you must bond that to a stainless steel substrate. This introduces a number of issues, including very tight control over surface preparation, making sure that all primers are compatible with the type of polyurethane you're using and then testing to write off for my customer that this bond will endure for 30 years in a subsea environment. If we eliminate sole reliance on that bonding, we take all of that risk away."

Gill concedes one alternative would be mechanical attachment to the stainless steel flanges. "There are methods for doing that, but you cause other issues like large stress raisers, where the polyurethane is now on a fixed anchor point," he says. "This can create high stress concentrations, and therefore you need larger cross-sections to deal with those, but then you jeopardize the necessary thermal performance."

Precision manufacturing for commodity cost

"Even though Balmoral is mostly a bespoke product manufacturer, we understand the cost target required for the wind industry, which is much more challenging than oil and gas," says Milne. "FibreFlex is expensive technology that we have had to commoditize via a smart design and automated manufacturing." He points out that the robotic winder is not a radial braiding machine. "It is direct fiber placement. Once we have the lattice with the two end flanges connected, we place this into a matched metal mold, close the mold and inject the polyurethane so that the lattice is embedded in the polymer." The finished composite laminate is 30 millimeters thick, while the diameter is chosen from a standard range to accommodate various cables used in the offshore wind market.

"This process demands high precision control in the mold," Milne emphasizes. "We heat the mold to 100°C and that temperature must be controlled to get the polyurethane viscosity right for impregnation of the fiber." With regard to production cycle time, Gill explains, "we infuse, cure and demold in minutes." He notes this is indeed very short compared to the process times used with the elastomeric fluoropolymers in the early days of oil and gas subsea umbilicals. "Our process speeds depend on maintaining tight process control," says Milne. "We've invested a huge amount of money in our plant and equipment, and we work with all the polyurethane and fiber manufacturers to make sure that we're within the correct operating envelope."

Pioneering quality, standards and new products

FibreFlex products are qualified to each customer's specifications. "There are standard specs for polymer products in oil and gas," says Gill, "but this product is for offshore wind, not oil and gas, and it is a fiber-reinforced composite, not an unreinforced polymer. So, we base product qualification on first principle, risk-based testing, and then test per the client's specification. For example, a client will come to us and give the design and service envelope. We have a lot of experience and understanding in how to translate this into product requirements in order to validate the performance against their specification.

"All of the fatigue and creep testing is actually done onsite to our specifications," he continues. "For steel, it's easy; go to the library and pick your material properties and test standards. For S-N curves to qualify fatigue performance for our particular composite, for example, that just doesn't exist. We have to create those. There are composite testing standards, but not for renewable energy cable protection systems specifically. The industry is still emerging and is just not there yet. You have to have the experience to pick standards which are valid and then we do risk-based testing, validating fatigue, flexing, hydrolysis, etc."

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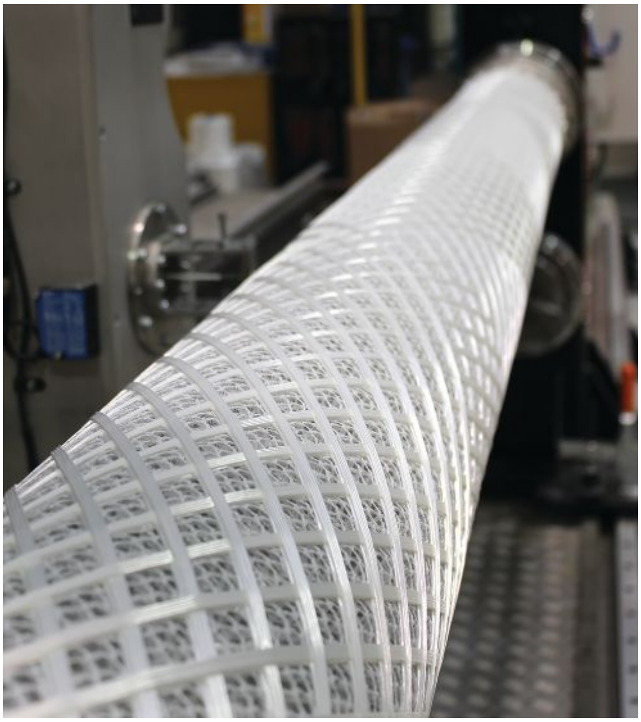
"We're not a one-trick pony with composites," notes Milne. "We've long made standard GFRP covers using vacuum infusion for protection of subsea wellheads and other equipment. These are more than 100 millimeters thick and can be 12 meters by 8 meters or larger. We also make composite tank covers using an ergonomic shape where the loads are all transferred laterally into the flanges to reduce thickness. So, again, we look at how to use the fiber and good design to cut weight by 30% in these tank lids, which can be up to 36 meters in diameter."

He says that although FibreFlex is Balmoral's first commercial series product for renewable energy, "we are also working heavily on wave energy, tidal energy and other wind energy applications. We have done a lot of development processes with various suppliers and for us, all of the work is in composites." He points out that a lot of these new renewables technologies started with components in steel, "but we're seeing a big movement now toward composites. We understand what composites can do for them and how to develop designs that will deliver the performance and cost required." CW



Smart design, automated manufacturing

Balmoral has designed FibreFlex to provide the necessary axial and torsional stiffness at a slim cross-section but also automated manufacturing using a robotic winder, to meet the challenging requirements for process control and low cost demanded by the offshore wind industry.

ABOUT THE AUTHOR

CW senior editor Ginger Gardiner has an engineering/materials background and more than 20 years of experience in the composites industry.
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Post Cure

Highlighting the behind-the-scenes of composites manufacturing


Source | Fraunhofer IPT

Show us what you have!

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

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

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Automated production of CFRTP blades

Fraunhofer IPT (Aachen, Germany) has demonstrated fully automated layup and thermoforming combined with CNC milling of 16-millimeter-thick carbon fiber fabric PA12 organosheets into aeroengine fan blades. The goal is to replace autoclave-cured thermoset epoxy prepregs with materials that provide faster and less costly manufacturing and have already shown high performance and durability in flying structures such as rudders and leading edges of wings. Fraunhofer IPT's next tests will include carbon fiber/PEEK tapes and sensors embedded into the laminates for improved 4.0 processing and potential for structural health monitoring (SHM) while in service.


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