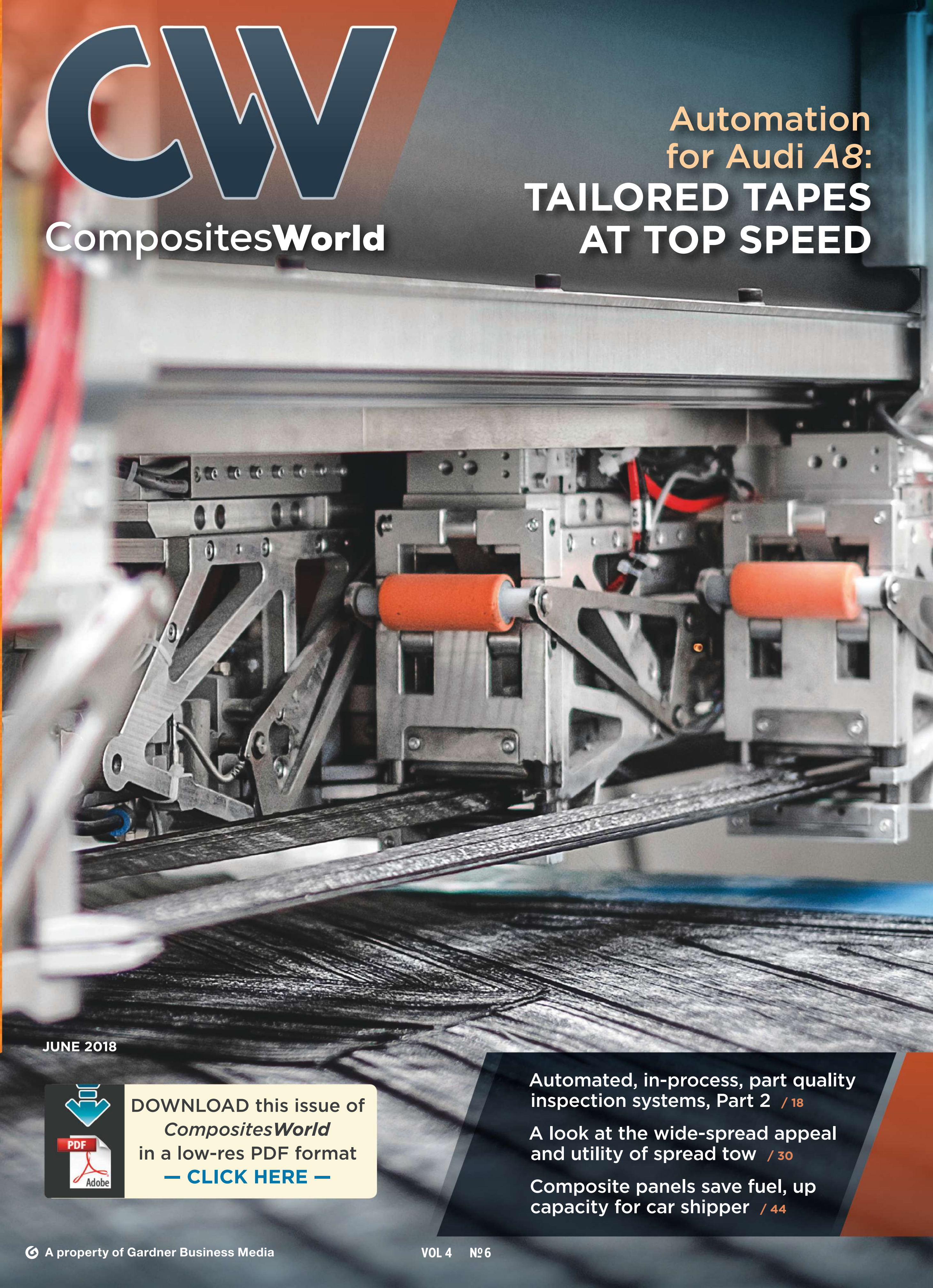

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Automation for Audi *A8*: TAILORED TAPES AT TOP SPEED

JUNE 2018

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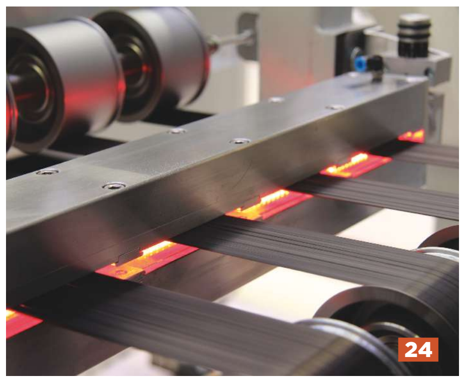
COLUMNS



DEPARTMENTS

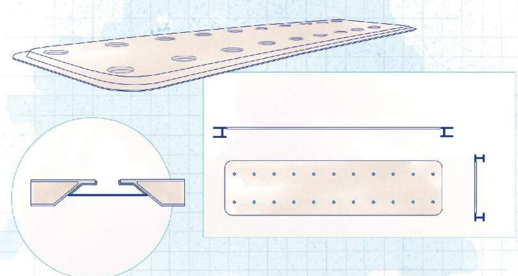
FEATURES

ON THE COVER

Cut tapes are placed, up to four at a time, onto a rotary table, tailoring both tape length and orientation angle within the laminate stack (e.g., 45°/90°/30°), inside Voith Composites' (Garching, Germany) Voith Roving Applicator, a fully automated system that, in a single line, spreads carbon fiber tow into bindered unidirectional tape, then cuts and stacks it to form tailored blanks. See it and read about it on p. 24.

Source / Voith Composites

FOCUS ON DESIGN



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I was a journalism major in college. I took classes on news reporting, news writing, feature writing, publication management, journalism ethics, magazine publishing, news editing and public relations. I learned how to ask questions, conduct interviews, take notes and write clearly and concisely. I learned about the journalism profession, in which there is a certain nobility attached to writing and publishing for an audience. I learned that journalism has, theoretically, a built-in objectivity that confers to it a much-coveted authority, reliability and trust that must be closely guarded and protected.

Serving the advertiser best by serving the reader first.

I also learned about the publishing business. I learned that a successful publication — newspaper or magazine — typically depends on advertiser support for its financial survival. I learned that advertisers seek potential customers, and that a good publication provides advertisers such customers by cultivating and serving a well-defined audience. In short, I learned that the journalism *profession* needs the publishing *business*, and the publishing business needs the journalism profession.

Despite this symbiotic relationship, I also was taught that an upstanding journalist should never be influenced — or even appear to be influenced — to write or not write, or publish or not publish, in the service of business or monetary interest. I was told that there is a high, wide, impenetrable wall separating journalistic pursuits from financial pursuits. Never the twain shall meet.

Then I graduated.

I chose to go into business-to-business trade publishing, which is more specialized and niche-oriented than business-to-consumer publishing. I discovered — to my horror, at first — that that high, wide wall separating journalistic pursuits from financial pursuits was more like a short, narrow, friendly hedgerow — a suggestion of a separation of interests, but not a real separation of interests.

So, there I was, 23 years old, fresh out of college, in a new job, working with new people, full of untainted journalistic aspirations. I was being asked by sales representatives much older and more experienced than myself to do them favors. To publish a new product for a customer, or prospective customer, or to place an ad on the same page as the company reference in a story. I did not learn how to handle such requests in college, but fortunately I had editors above me who could provide the guidance I needed.

The truth is that business-to-business publications, in particular, usually operate in industries too small and too relationship-focused to be neatly segregated the way the theoretical college version of journalism demands. I discovered that I could not and cannot, as an editor, simply ignore the interests of the advertisers who support us. Conversely, I could not and cannot turn editorial content into a marketing vehicle for advertisers. What to do?

Eventually, I developed my own philosophy, and it came down to this: We serve our advertisers best when we serve our readers first. That is, our primary job as editors here at *CW* is to serve the needs of our audience, and we do that by exploring the tools, materials and processes they use to do their jobs as they fabricate composite parts and structures. If we do that well, which I think we do, we create an editorial environment that is trusted, respected and useful — an environment that advertisers want to be a part of, because you, our readers, want to be a part of it.

This is not a trivial or idealistic notion, because *CW* relies *exclusively* on advertiser support to serve its audience. We do not charge you a subscription or any other fee for the content we produce. If you, as a reader, are deemed “qualified” — that is, you are a designer, engineer, manager or OEM involved in composites manufacturing — then you can receive *CW* for free. In turn, our advertisers get access to you, a prospective customer, who works in the industry our advertisers serve.

So, maybe that hedgerow is not so easy to breach. Maybe it’s a little taller and a little thornier, and we have to be careful and thoughtful reaching over it. In the meantime, we will continue here at *CW* serving your needs first, and hope to do so for many more years to come.

JEFF SLOAN — Editor-In-Chief

Looking back — and ahead

» In March 2013, I was invited to dinner in Paris by Jeff Sloan and Sara Black of *CompositesWorld*. Over traditional cuisine in a small bistro, they asked me to consider writing a monthly column in what were then their two magazines, *Composites Technology* and *High-Performance Composites*. What topics did they want me to cover? What restrictions would I have? Write about whatever you want, they told me. No restrictions, so long as there is some tie to composites. Reveal your observations, discuss your experience, predict the future, challenge assumptions. The options were wide open. It was managing editor Mike Musselman who so aptly captured all of this in the tagline "Perspectives & Provocations."

As the adage goes, time flies. At the beginning of 2015, those two magazines became one, *CompositesWorld*. This is my 61st column. I had no expectation I would still be doing this five years later.

What I've come to realize is the importance of focusing on the long game. Success takes perseverance ....

After approximately 45,000 words (which could have been many more if not for column length restrictions), I've covered a number of topics across the composites universe. In preparation for this look back, I went through all my previous columns, looking for several things: What were the things that surprised me? What did I think would happen that did not? What got me the most excited? What did I overlook? How has my thinking evolved over these five years?

In my initial "provocation," I asked whether any automaker would follow BMW's lead (none have done so, yet, to that degree). At the time of that writing, I had not yet visited BMW, but have since visited multiple times and held multiple discussions, each time increasing my appreciation for what the automaker has achieved. And I have mentioned BMW in 14 additional columns. Although it may *seem* that BMW has pulled back a bit and is relatively quiet, I know it has focused its R&D on those levers that will get the cost of carbon fiber composites where it needs to be for widespread deployment. One result has been an evolution in my own thinking: Rather than BMW's composite-intensive *i Series* approach, I see a more practical path to growing the carbon fiber market via adoption of minor levels of composites across millions of vehicles via the "intelligent lightweighting" practiced in the BMW *7 Series*.

On the aerospace side, I have mentioned Boeing 17 times and Airbus 15 times these past five years, sometimes to speculate if either would launch a single-aisle replacement with extensive carbon fiber content, at least in the wings. I have been disappointed that such announcements have yet to materialize, and that out-of-autoclave technology for carbon fiber composite aerostructures remains mostly in the realm of exploration rather than production.

During these 60 months, several technical advancements have proven truly eye-opening. 3D printing evolved from building shoebox-sized components, using CAD-derived extruded layers over several days, to building structures weighing tons in a matter of hours, opening all kinds of potential, including low-cost tooling. Digital simulation of manufacturing processes is virtually on par with that of performance prediction; the two are related as the process variables of manufacturing define the real performance of the part. A related topic, the Industrial Internet of Things (IIoT), is starting to provide real-time feedback that validates our simulations and will eventually enable intelligent control of processes. Finally, the number of companies (and respective approaches) involved in recycling of composites has grown explosively these five years. This is very encouraging and addresses a key market need.

My favorite columns include March 2015 (promoting thinking out of the box), January 2016 (musing about what if composites had preceded steel), and October 2017 (my eclipse experience and space exploration).

I've been intimately involved with composites since 1984, and what is now clear about those days is "we didn't know what we didn't know." We naively expected widespread adoption would "just happen." Clearly, enormous progress was made in composites between 1984 and 2013, the most obvious outcomes being the Boeing 787 and Airbus A350, the explosion of the wind industry, and all the processing technology created during those years. What I've come to realize is the importance of focusing on the long game. Success takes perseverance — and patience.

As I noted in November 2016, innovation in composites is moving more quickly than ever. Anyone visiting JEC World or CAMX is exposed to numerous technical advances, year after year. There are plenty of hurdles we will overcome as composites earn their way onto future cars, planes, turbines, boats, bridges and spacecraft. Assuming *CompositesWorld* continues to abide my prose, my plan is to be right here — provoking, observing and crediting those future advancements, wherever they occur. CW

ABOUT THE AUTHOR

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


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Fiber-optic sensors shed light on the toughest composite design challenges

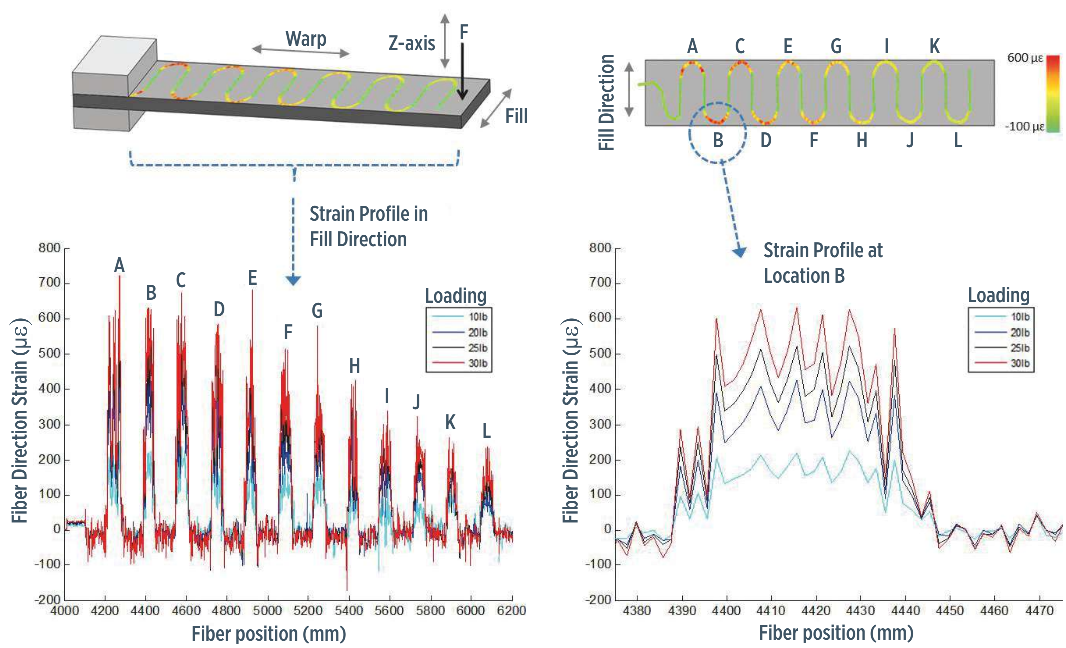


FIG. 1 High-definition fiber-optic sensors embedded into this composite cantilever beam provide continuous strain data with resolution less than 1 mm in all three dimensions and interior to the part.

Source | Luna Innovations

» Designers of composites are learning that if they are to be able to guarantee component and system performance, repeatability and reliability, it is critical that they have access to more sensor and test data. Whether they are striving to certify a complex structural component, validate the structural integrity of a part over its entire lifecycle or simply assess the performance of an adhesive bond, designers now have a new measurement tool that provides unprecedented visibility into the structural behavior of composite components.

For decades, the go-to device for materials engineers and stress analysts was the metal foil strain gage. Invented in the 1950s, the foil strain gage quickly became the standard tool for spot measurement of strain levels in metals. However, due to the cost and complexity of applying foil gages (gage size, attachment and bonding, wiring, etc.), stress analysts were forced to focus on the most critical locations and select only a handful of key stress points to instrument with gages. In an era dominated by standardized isotropic materials, such as metal, with well-understood properties and knowledge of how stress propagates through the material, this approach of using relatively sparse test data was an efficient and effective way to test materials and validate the accuracy of high-fidelity models.

> The gap between reality and simulation can be greatly reduced with fiber-optic sensors.

The current state of composite materials and systems, however, is another story. In addition to their orthotropic properties, composites encompass a vast and growing range of material types and manufacturing. Although the models and simulation software available for composite materials are advancing at an impressive rate, the number of variables and complexity inherent in composite materials and systems remains a significant challenge for the designer looking to guarantee the performance and reliability of a new design. As carbon fiber composites are more frequently used in structural applications, requiring higher levels of verification and certification, spot checking with strain gages leads to problematic blind spots.

Fortunately, the gap between reality and simulation can be greatly reduced with fiber-optic sensors. Pioneered in the 1990s for monitoring civil structures, fiber-optic sensing has developed, evolved and matured to a level of capability and robustness useful in the composites industry, enabling much more complete and accurate testing and verification. In fact, the technology promises to move beyond the test lab because it is proving useful in building smart parts that incorporate thousands of integrated sensors.

High-definition fiber-optic sensing

These developments are a direct result of the advent of high-definition fiber-optic sensing (HD-FOS). HD-FOS can use a standard optical fiber as a very sensitive, continuous sensor of strain or temperature. By exploiting the minute effects that strain and temperature have on how light travels through that optical fiber, HD-FOS systems are able to detect and measure more than *1,000* discrete points of strain or temperature per meter of the fiber length, with accuracy and sensitivity on par with legacy sensors, including strain gages.

Moreover, optical fibers are physically compatible with composite materials. Extremely lightweight, small and flexible, optical fiber sensors can easily be installed on composite parts regardless of geometry. They even can be embedded within a part and measure internal or interlaminar strain — loads that are invisible to strain-gage or vision-based systems. Multiple studies have shown that embedding fiber-optic sensors into a composite structure has no detrimental effect on the structure's performance. Additionally, unlike metal-foil strain gages, fiber-optic sensors are passive, immune to electrical fields, chemically inert, and exhibit excellent fatigue performance.

For example, Fig. 1 (p. 6) illustrates a composite cantilever beam with three-dimensional carbon fiber reinforcement. A 125-μm optical fiber was integrated into the preform fabric along the x (warp), y (fill) and z axes. These HD-FOS sensors are, therefore, able to capture thousands of discrete strain locations in all three dimensions. The figure includes a sample of the measured strain data along the y-axis, which is transverse to the applied strain. However, the labeled points where the fiber makes a turn (A, B, C, etc.) experienced tensile strain that increased with load; those data are also mapped onto the beam for easier visualization.

Multi-material joints and adhesive bonds

One particularly challenging area where this type of high-density measurement data can make a difference is the use of adhesively bonded interfaces, particularly for mixed materials. Although adhesive bonds have many significant advantages, mechanical fasteners remain a requirement in many applications because it is a challenge to certify adhesive bonds due to their unpredictable performance and durability.

Conventional nondestructive evaluation or test (NDE/NDT) methods can be used to inspect bonds, and to some extent, quantify damage or disbonding. But HD-FOS is proving to be a valuable tool to measure residual strain directly, along or within the bond lines, to verify the integrity of the bond and to provide detailed insight into disbond growth. Fig. 2, above, shows measurement data from an HD-FOS bonded to both sides of a Center Cut Plies (CCP) test specimen, which is about 30 cm long. After a fatigue test, the CCP was ultrasonically scanned, and the C-scan was compared to the HD-FOS data. The HD-FOS data are able to more precisely pinpoint the locations of the disbond tips, allowing the calculation of disbond growth rate. Continuous strain along identified sections 1, 2 and 3, at a single moment in time, is displayed along with the C-scan inspection. »

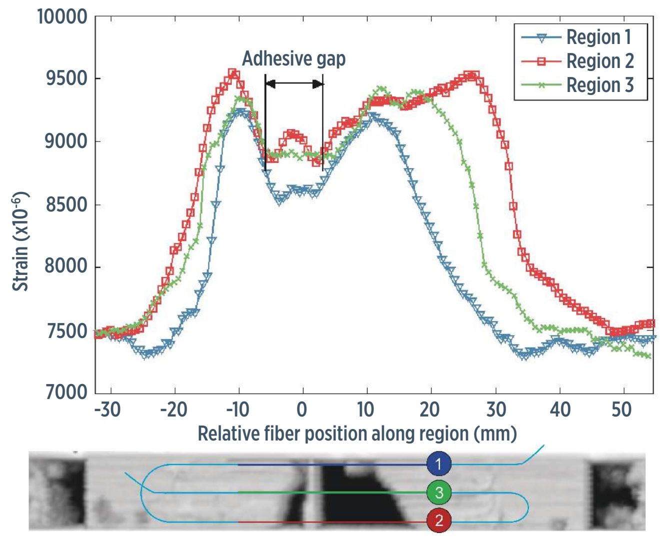


FIG. 2 Data from an HD-FOS used on a Center Cut Plies (CCP) adhesive joint is able to precisely locate disbond tips. The C-scan of the CCP test specimen is included at the bottom of the figure. Source | Ribeiro, F.N., Martinez, M., Rans, C., *The Journal of Adhesion* (2018), https://doi.org/10.1080/00218464.2018.1433039.

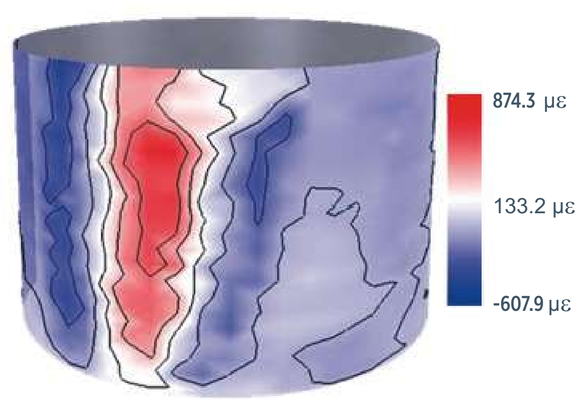


FIG. 3 Embedded fiber-optic sensors provide invaluable data on the integrity of a component or system. The red area identifies internal damage sustained in a drop test. Source | Luna Innovations

Smart parts for damage detection

Although gaining insight into these complex material systems and building more accurate damage and fatigue models are important, the holy grail may be the ability to monitor the performance of the material, bond or system *during* operation. Currently, a variety of NDE/NDT methods are typically used to detect flaws or damage. However, these methods are time-consuming and require significant downtime and labor costs. The ability to use onboard sensors to provide in-situ health monitoring or instant detection of structural issues is the promise of structural health monitoring (SHM) and damage detection technologies.

Consider a composite structure that has lightweight and unobtrusive fiber-optic sensors embedded throughout its geometry during fabrication. At any time, a snapshot of the stress and strains throughout the structure can be taken to provide an assessment of residual strain, which research has shown to be a reliable indicator of fatigue damage, impact damage, crack growth, disbonding, delamination or general damage.

Fig. 3 (p. 7), for example, shows a composite overwrapped pressure vessel (COPV) with multiple meters of fiber-optic sensors woven into its overwrapping. A quick interrogation of the embedded HD-FOS sensors generates thousands of residual strain measurements over the entire surface, which is mapped onto the 3D model of the COPV. This vessel had previously been drop tested and the 3D data map easily identifies areas of sustained internal damage, indicated by the red areas.

The ability to embed these HD-FOS sensors into materials, components, bonds and systems can potentially change the way composite parts and structures are designed and managed through their lifecycles. HD-FOS sensors are starting to enable truly smart parts and smart structures that are enhanced with a "nervous system" of sensors able to detect and analyze internal stresses, deformation and movement while in operation. In the meantime, the same sensor technology is already providing unprecedented visibility into the performance of new materials, processes and designs. CW

ABOUT THE AUTHOR

David Potter is director of marketing for Luna Innovations (Blacksburg, VA, US), a manufacturer of fiber-optic sensing systems. He holds a BSEE from Vanderbilt University and an MSEE from M.I.T. He has more than 25 years of experience in the testing and measurement industry, developing and managing products and solutions for data acquisition, industrial measurements and control. He is responsible for product management and strategic marketing at Luna.

Composites Index starts second quarter with a surge

April 2018 – 61.4

» The GBI: Composites Fabricating Index closed April at 61.4. It was the highest number reached since the Index was first recorded in November 2011, and broke its previous all-time high reached just one month earlier. Compared to the same month one year ago, the Index has increased 13.6%.

Of the six components used to calculate the overall Index, three also set record highs during the month: Exports, Backlogs and Employment. Although the Production and Supplier Deliveries sub-indices did not post record-setting numbers in April, they were within a fraction of a point of their all-time high readings. Only New Orders, which registered its all-time high in March, did not break or come very near its record-high number.

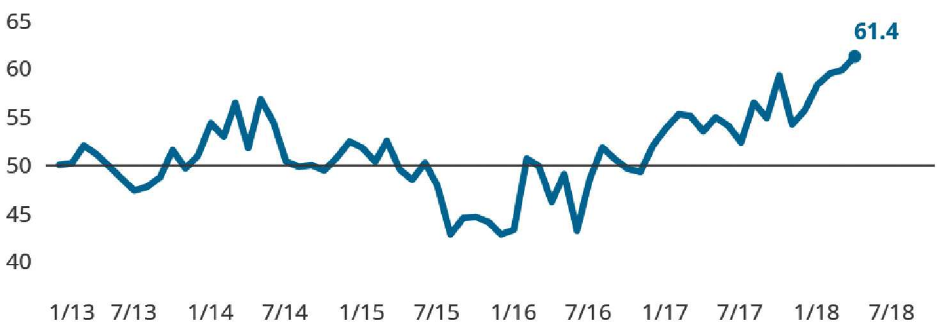
The Gardner Intelligence team's review of the month's underlying data indicates that the Index — an averages-based calculation — was lifted higher by Production, Backlogs, Supplier Deliveries and Employment, while New Orders came in just slightly below the overall Index. Exports was the only subcomponent to significantly pull the Index lower, while simultaneously attaining a multi-year high reading. That said, all Index components registered expansion (>50.0) during April.

Despite reported greater expansion in Production compared to New Orders, Backlogs grew at their fastest rate since 2012. The expansion in Production appears to have had a significant impact on Supplier Deliveries, which in March and April registered its two highest readings in more than 6 years. CW

ABOUT THE AUTHOR

Michael Guckes is the chief economist for Gardner Intelligence, a division of Gardner Business Media (Cincinnati, OH US). 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**

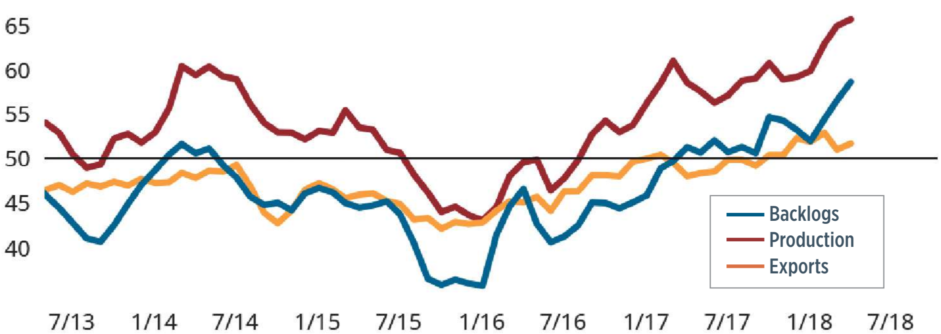
GBI: Composites Fabricating



CFI at record high expansion

The Composites Fabricating Index has now established three consecutive record-high readings. With the exception of New Orders, all components of the Index are at or near all-time high levels.

GBI: Composites Fabricating — Backlogs, Production and Exports (3-month moving average)



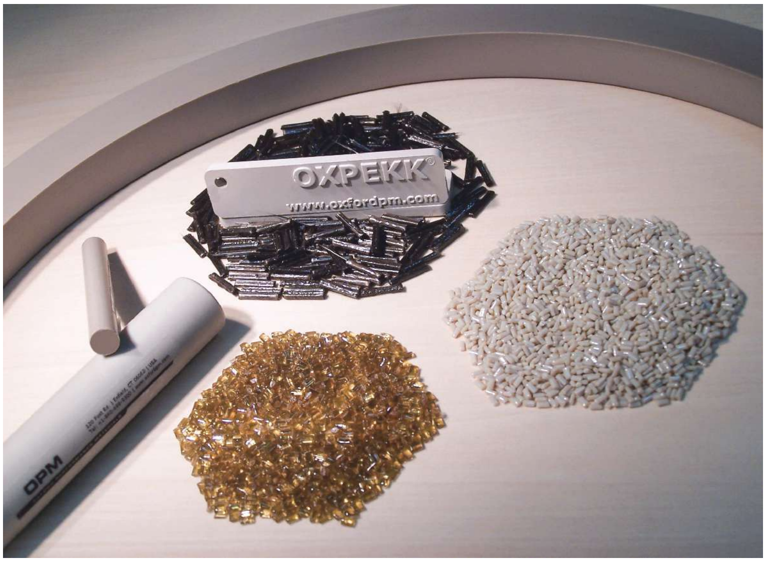
Backlogs up despite New Orders slowdown

Despite record-setting Production growth and a slowing in the growth of New Orders, survey data indicate that Backlogs increased at their fastest rate in CFI history. Further, a growing segment of the New Order demand in 2018 is that from foreign customers.

Newsworthy developments in thermoplastic composites research have impact in the aerospace and medical sectors while the US House of Representatives and a five-country European study group look at composites in civil infrastructure.

AEROSPACE

Aerospace TPCs: "Cold-process" PEKK holds promise for prepregs



As The Boeing Co. (Chicago, IL, US) and Airbus (Toulouse, France) debate how thermoplastics will play a part in near-term and future aircraft, both are evaluating the price, processability and performance of two high-performance engineered polymers: PEEK (polyetheretherketone) and PEKK (polyetherketoneketone). Members of the broader polyaryletherketone (PAEK) family, they have similar crystallinity, a characteristic that affects both the polymer's mechanical properties in a finished part and the speed at which it can be processed as composite parts are molded. Although PEEK has been the predominant choice in aerospace for two decades, its processing temperature is higher (385-390°C). Alternatively, PEKK offers a wider, lower-temperature process window (355-375°C). The two are currently cost-competitive, but that could change as the market scrambles to address capacity and quality concerns when suppliers compete for work packages announced by Boeing and future aircraft fuselage and wing development programs in Europe.

Against this backdrop, Oxford Performance Materials (OPM, South Windsor, CT, US) has introduced a new PEKK product, OXPEKK-LTS, which it claims offers some interesting advantages. OPM CEO Scott DeFelice notes all PEKK products on the market today are made using a method originally developed by DuPont (Wilmington, DE, US), which uses high-temperature synthesis (HTS). DeFelice notes that this HTS process runs fairly fast, which keeps cost down, but points out there was another process, developed by Raychem, which was sold to BASF (Wyandotte, MI, US), but the latter abandoned PAEK materials. "Raychem's technology was for *low*-temperature synthesis (LTS)," says DeFelice.

The HTS process produces PEKK polymer *flake* which must then be ground before being mixed with solvent, etc., for prepreg and 3D printing applications. LTS technology, however, enables production of a *powder* with a spherical shape that is possible to control. DeFelice asserts that because LTS is a "cold" process, it is also much more controllable in terms of the finished polymer's molecular weight and molecular structure. Although the LTS process is slower and, thus, a little more costly "it is also possible to go directly to powder with no grinding step," says DeFelice, "which helps to offset the slower processing."

This patented LTS process is the basis for OPM's new OXPEKK-LTS product. DeFelice claims it offers the best of both worlds: a controllable process that produces a product with a spherical polymer powder. "With grinding, you end up with jagged 'rocks' of polymer which are difficult to stack uniformly when coating and impregnating a tape," he explains. "The round shape of OXPEKK-LTS allows more precision during tape making." So now we can improve the tape and enable true out-of-autoclave (OOA) processing via in-situ consolidation, which is hampered by current tape dimensional fidelity." The result is a lighter structure with greater strength-to-weight and fatigue than can be achieved with a PEEK-based part, produced in one step instead of two. (Read more online about in-situ consolidation in *CW*'s two-part series | **short.compositesworld.com/ISC-Part1** | **short.compositesworld.com/ISC-Part2**.)

"The physics of round polymer particles in prepregging is well-established," says DeFelice. "We believe we offer control of these particles which then gives more levers to achieve the balance needed for producing large OOA primary structures that meet cost and performance targets. We have very powerful tools to get this technology where Airbus and others want it to be." OXPEKK LTS will be introduced for developmental purposes by the end of 2018 and commercially available in early 2019.

AUTOMOTIVE

Zoltek carbon fiber to form Uniti *One* electric car bodies

Zoltek Companies Inc. (St. Louis, MO, US), a global leader in the production of low-cost industrial grade carbon fiber, and electric vehicle manufacturer Uniti (Landskrona, Sweden), announced April 17 that the two companies have signed a Memorandum of Understanding (MoU).

The agreement, which took effect immediately, outlines a partnership between Zoltek and Uniti in which Zoltek will be the preferred supplier of carbon fiber for Uniti's line of electric cars. Uniti says it has received thousands of pre-orders for its Uniti *One* vehicle, which made its debut in early December 2017. It will feature an all carbon fiber composite body,

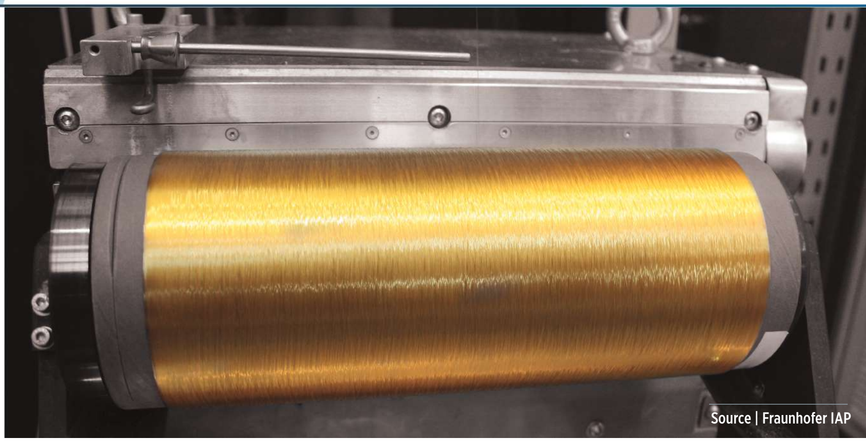
Source | Uniti

made with ~20 kg of Zoltek PX35, 50K carbon fiber. The MoU secures the carbon fiber supply for Uniti as demand for the *One* increases.

"It was important for us to develop a partnership with a carbon fiber supplier with the proven ability to increase production to help us grow our business," says Anton Franzén, CTO, Uniti.

Use of Zoltek PX35 has resulted in a lightweight vehicle that still maintains superior mechanical properties, without the high price typically associated with the use of advanced materials.

"We … are happy that they recognized Zoltek as the logical choice for a carbon fiber partner as they scale up," says David Purcell, Zoltek's executive VP of composite intermediates and oxidized fiber. "This further validates Zoltek's business model of stable, predictable pricing and guaranteed supply, and should alleviate any concerns in the supply of carbon fiber as Uniti plans for significant growth in the coming years."


Source | Fraunhofer IAP

Fraunhofer melt-spinning technology to reduce PAN precursor cost

The Fraunhofer Institute for Applied Polymer Research (IAP, Potsdam-Golm, Germany) presented its ComCarbon technology, an alternative method for producing the polyacrylonitrile (PAN) fiber precursor from which carbon fibers are manufactured, at the aerospace trade fair ILA Berlin 2018 in Germany, April 25-29. The new technology will reportedly make it possible to produce PAN carbon fiber at relatively low cost, making it more accessible to the mass market.

About half the cost of producing conventional carbon fibers is incurred in producing the PAN precursor. The PAN fiber that has been available to carbon fiber manufacturers, however, could not be melted and was and is, therefore, produced using an expensive solution-spinning process.

"We have developed an alternative PAN-based precursor technology that saves around 60% of the precursor costs," claims Prof. Johannes Ganster, who heads the Biopolymers research division at Fraunhofer IAP. "It is based on an inexpensive melt-spin process, using special, meltable PAN co-polymers that we developed especially for this purpose."

When they are used to produce carbon fibers, the precursor fibers must undergo stabilization and carbonization processes. To permit this, IAP's melt-spun precursor fibers are converted to an unmeltable state after they are spun. Once this pre-stabilization is complete, the multifilament yarn can be continuously fed into conventional stabilizing furnaces and carbonized at temperatures of up to 1600°C.

Melt spinning has economic *and* ecological advantages over solution spinning. For one, it does not use environmentally harmful solvents that must be recycled at great expense. Eliminating solvents means that 100% of the melted material can be spun, which enables reportedly significantly higher spinning speeds.

MARINE

Titan prepares for *Titanic* expedition

CW first reported on OceanGate (Everett, WA, US) a year ago, describing the company's composites-intensive *Cyclops 2,* a five-person, deep-sea submersible vehicle (see our July 2017 report online at **short.compositesworld.com/Cyclops2**). *Cyclops 2*, at the time, was in the final stages of production. Today, *Cyclops 2*, renamed *Titan*, is water-ready and undergoing testing ahead of its expected first expedition in early 2019, when marine explorers will descend in it to the 4,000m depths in the northern Atlantic Ocean to study the wreckage of the *RMS Titanic*.

Titan comprises two major components, a five-person submersible and an integrated launch and recovery platform. This tandem was scheduled to undergo sea trials in Puget Sound (WA, US) through March of this year, with deep-sea certification to follow in the Bahamas during April. The *Titan* team was to move late in April to St. John's, Newfoundland, Canada, to prepare for the first manned expedition to the *RMS Titanic* since 2005.

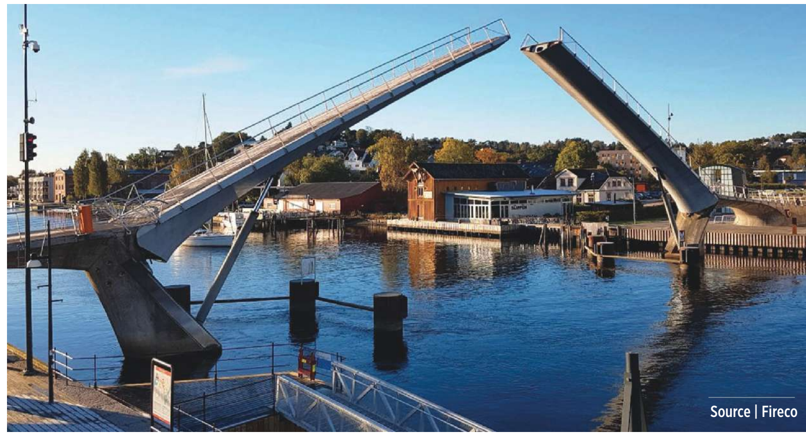
As detailed in the *CW* report, *Titan* features a filament wound carbon fiber hull (the largest yet built for a manned submersible), two titanium hemispheres (with the forward dome hinged to serve as the access hatch), the largest viewport of any deep-sea manned submersible, and a fiberglass hull insert to prevent condensation from dripping on the crew and to eliminate electrical ground faults.

One of the most significant innovations is *Titan's* real-time structural health monitoring system. Nine acoustic sensors and 18 strain gauges throughout the pressure vessel boundary analyze the effects of changing pressure on the vessel as the submersible dives deeper. This onboard health analysis system provides early warning for the pilot with enough time to arrest the descent and safely return to surface. "Safety is our number one priority," says Stockton Rush, OceanGate CEO. "We believe real-time health monitoring should be standard safety equipment on all manned submersibles." During the deep-sea certification dives in the Bahamas, Rush is expected to become the second person in history to dive solo to 4,000m. These dives will validate the design depth; *Titan*'s maximum dive depth will be certified by an independent certification organization.

Titan will be equipped with multiple 4K cameras, multi-beam sonar for navigation, data tablets with a wireless connection to onboard computers, 50,000 lumens of external light, a laser scanner and four electric thrusters for maximum maneuverability.

INFRASTRUCTURE

Euro study seeks optimally damage-tolerant infrastructure composites


Source | Fireco

It is a familiar scenario: An old concrete bridge with narrow lanes has to be overhauled to accommodate heavier traffic, widened to accommodate pedestrian walkways *and* upgraded to meet new standards. It turns out, of course, that the existing bridge cannot support the weight of the wider concrete superstructure without additional support. The result is a costly reinforcement of bridge pillars and piers or, often, an entirely new bridge design/build process.

Under the direction of the European Union Horizon 2020, groups from five countries are now conducting materials research into enabling the production of, among other items, deck extensions and other bridge elements made of fiber-reinforced plastic that could avoid such costly scenarios, says project leader Jens Kjær Jørgensen of SINTEF Industry (Trondheim, Norway). The research project, which began in January 2018 and will run through December 2021, is called DACOMAT, for Damage Controlled Composite Materials.

The overall objective of DACOMAT is to develop more damage-tolerant and damage-predictable, low-cost composite materials, in particular those used in large load-carrying constructions that include not only bridges, but also buildings, wind turbine blades and offshore structures. The developed materials and condition-monitoring solutions will provide a high tolerance for manufacturing imperfections and high capacity to sustain damage. This effort is expected to enable large composite structures to be manufactured and maintained at low cost. Project outcomes include the development of guidelines and modeling tools for reliable design of critical load-carrying composite structures; guidelines for materials qualification; structural health monitoring (SHM) and damage assessment solutions; and lifecycle analysis (LCA) methodology for large composite constructions.

The project, coordinated by SINTEF, includes the following participating companies — Polynt Composites (Carpentersville, IL, US), Hexcel (Stamford, CT, US), Carbures (Cadiz, Spain), 3B Fiberglass (Battice, Belgium), LM Windpower (Lunderskov, Denmark) and DNV GL (Oslo, Norway) — as well as several universities. All intend to work together to ensure that any development of fractures has minimal likelihood of compromising the strength of composite bridge elements and wind turbine blades. Specifically, the aim is FRP materials with properties that will make fracture propagation more difficult than it is now in existing alternatives. "The objective is to develop composites that will give bridges a longer lifetime than conventional structures, while reducing lifespan costs by 30%. In the case of wind turbine blades, the aim is a 30% increase in lifespan and a 50% reduction in costs," says Jørgensen.

To acquire more knowledge about material properties over time, the project also aims to develop technology that will enable program researchers to monitor fracture development, using optical and acoustical sensors. The project's findings also will be applicable to offshore installations and other structures that have to withstand harsh environmental conditions.

BIZ BRIEF

Royal DSM (Geleen, The Netherlands) announced on May 14 that strong demand for its products has prompted an increase in production capacity for its Dyneema ultrahigh molecular weight polyethylene (UHMWPE) fiber, unidirectional (UD) reinforcements and fabric. The company reports that it is installing additional new UD technology at its plant in Heerlen, The Netherlands, and its plant in Greenville, NC, US, and will also make improvements to existing production lines to expand Dyneema UD and Dyneema fiber manufacturing capacity. The global production capacity of Dyneema UD will be increased by more than 20%. The additional capacity will become available during the course of 2018 and be fully on stream by first-quarter 2019.

INFRASTRUCTURE

House Subcommittee on R&T: Can composites help rebuild US infrastructure?

The US House Subcommittee on Research and Technology held a hearing on April 18 to discuss the role of composites in rebuilding US infrastructure. The goal of the hearing was to review a report from the National Institute of Standards and Technology (NIST, Gaithersburg, MD, US) on overcoming obstacles to adopting composites for infrastructure projects, to discuss the value of developing standards for composites in infrastructure applications, and to examine composites as an alternative or supplement to conventional materials.

The subcommittee heard testimony from Dr. Joannie Chin, deputy director, Engineering Laboratory, NIST; Dr. Hota GangaRao, Wadsworth Distinguished Professor, Statler College of Engineering, West Virginia University; Dr. David Lange, professor, department of civil and environmental engineering, University of Illinois at Urbana-Champaign; and Mr. Shane Weyant, president and CEO, Creative Pultrusions Inc. (Alum Bank, PA, US).

Dr. Joannie Chin of NIST; Dr. Hota GangaRao of Statler College of Engineering, West Virginia University; Dr. David Lange of University of Illinois; and Shane Weyant of Creative Pultrusions Inc.

Collectively the witnesses built a case for investing in the renovation of existing infrastructure with composites, citing examples of composite bridges, fiber-reinforced polymer (FRP) rebar and composite utility poles and crossarms.

"Currently, composites account for less than 1% of the structural materials by volume in spite of their many advantages, such as high strength, corrosion-resistance, lighter weight and better performance per unit weight," said Dr. GangaRao.

The witnesses were careful to state that composite materials should not be viewed as a replacement for conventional materials, such as steel and concrete, but should be used in harmony with existing materials. Evidence was presented to illustrate the reduction of maintenance costs that could be seen during the long lifecycle composite structures enjoy.

"In the utility industry, we have seen probably 30% lifecycle cost savings when using composites," stated Weyant.

The witness spoke about the need to educate the engineering community about composites and to take advantage of research centers that offer partnerships between academic institutions and industry, as well as the need for standards to help engineers fully understand the properties and capabilities of composite materials.

Rep. Elizabeth Esty (D-CT) said that she and subcommittee chairwoman Rep. Barbara Comstock (R-VA) will introduce a bill concerning composites, a part of which is the IMAGINE Act (Innovative Materials in American Grid and Infrastructure Newly Expanded). The latter calls for the creation of an interagency innovative-materials task force to assess existing standards and test methods and compare them against composite materials. The initiative would identify key barriers in the current standards that inhibit market adaptation and adoption of composites. Chaired by NIST, it would bring together regulatory agencies, including the US Federal Highway Admin., the US Army Corp of Engineers, the US Environmental Protection Agency (EPA) and others.

BIZ BRIEF

FACC (Innkreis, Austria) announced on May 9 its subsidiary, **FACC Solutions Inc.** (Wichita, KS, US), will expand its location. The latter provides maintenance for aircraft components in the US and offers aftermarket services with a focus on the modification and repair of components and systems for aircraft. The company offers a portfolio of support services in the aircraft maintenance, repair and overhaul (MRO) business sector, with emphasis on maintenance and repair of composite systems.

Citing 200% growth in MRO at its US site in Wichita, FACC says major investments are being made in response at the location to expand the serviceable surface area to 60,000 ft^2 (5,575m^2). The new service area, which is situated close to the present factory, was expected at *CW* press time to be in use by early June.

"We see great potential in the repair and maintenance business," says Robert Machtlinger, CEO of FACC. "This additional space enables us to further drive our growth in the field of aftermarket services."

FACC offers its MRO services to commercial airlines, other MRO stations, spare parts and service providers, and aircraft OEMs in North, Central and South America.

CW MONTH IN REVIEW

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

UPS to deploy fleet of composite EVs in London, Paris
UPS is working with UK firm ARRIVAL to develop a pilot fleet of 35 composites-intensive electric delivery vehicles that will be trialed in London and Paris.
05/14/18 | short.compositesworld.com/UPS-EVs

SKAPS completes Matrix Composites acquisition
The US-based geosynthetic and nonwoven drainage products source adds woven and nonwoven fiberglass products with Texas- and Kentucky-based Matrix.
05/14/18 | short.compositesworld.com/SKAPtrix

SGL and Automotive Management Consulting to codevelop "xFK in 3D"
SGL SIGRAPREG TowPreg, patented 3D winding process to produce lightweight, optimized composite structures with efficiency, speed and reduced waste.
05/14/18 | short.compositesworld.com/xFKin3D

M. Holland Co. to distribute Owens Corning filaments for 3D printing
The Northbrook, IL, US, company will manage a network of sub-distributors and directly sell and deliver Owens Corning's XSTRAND filaments to clients.
05/11/18 | short.compositesworld.com/SumiOandG

Update on CTC Global's ACCC Conductor
The carbon fiber-cored powerline is now used in South Carolina, India and Spain.
05/10/18 | short.compositesworld.com/CTC-ACCC

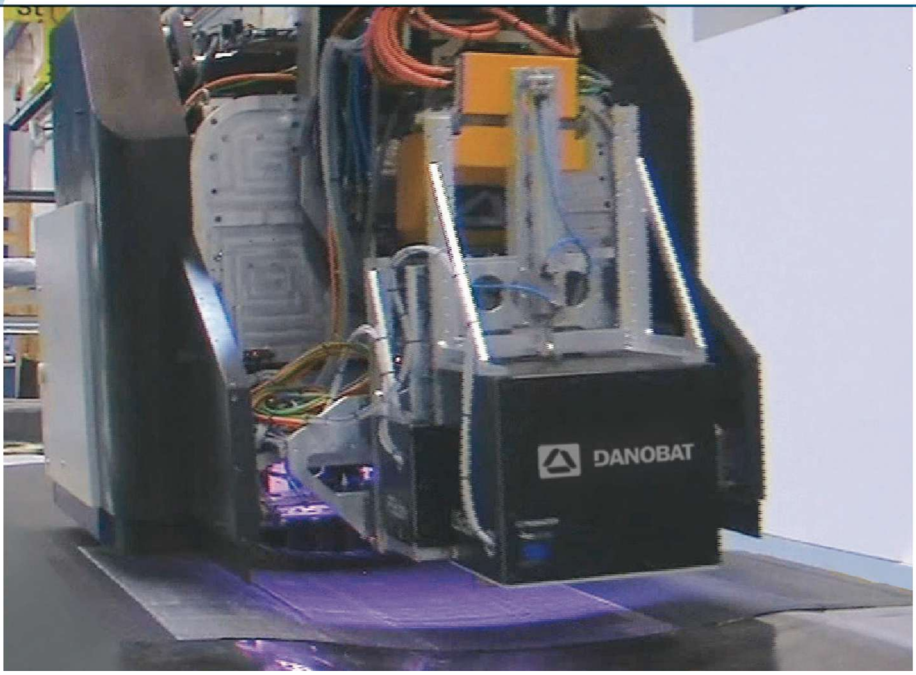
TPI Composites and Vestas add two wind blade manufacturing lines in Mexico
TPI Composites will produce blades for Vestas' 4-MW wind turbine platform at TPI's new facility in Matamoros, Mexico.
05/09/18 | short.compositesworld.com/TPIMexico

HK Research and Scott Bader form strategic alliance
They plan to explore mutual interests in markets and technologies to strengthen their respective positions in the European and American gel coat markets.
05/09/18 | short.compositesworld.com/HKBader

Orbital ATK supports Mars *InSight* mission
The company provided advanced hardware for both the ULA-built *Atlas V* launch vehicle and the *InSight* lander.
05/08/18 | short.compositesworld.com/ATKInsight

Premium Aerotec presents thermoplastic CFRP A320 pressure bulkhead
Showing the potential that CFRP with a thermoplastic matrix holds for the future with the world's first demonstrator for an Airbus A320 pressure bulkhead.
05/04/18 | short.compositesworld.com/PAdemoBH

ACMA launches online composites education resource
New online resource educates end-users about FRP possibilities.
05/03/18 | short.compositesworld.com/ACMAed



Inspection of dry fabric placement

Danobat's (Elgoibar, Spain) high-speed ADMP (Automated Dry Material Placement) head, which places dry fabrics, is shown here, equipped with the company's automated inspection system, an outgrowth of the European ZAero Project.

Source | Danobat

Improving composites processing with automated inspection, Part II

Three additional inspection equipment providers describe their development of inline production quality-control systems.

By Sara Black / Senior Editor

» To ensure that the speed of composites fabrication keeps pace with customer demand, the ability to inspect and monitor composite part quality must become an integral part of high-rate part manufacturing. *CW* follows up its coverage of automated, in-process inspection and verification, begun in February (see Learn More, p. 21), with news about three providers and their approaches to addressing the growing need for inline inspection.

One is Danobat Composites (Elgoibar, Spain), a cooperative company owned by Mondragon Corp. (Mondragon, Spain). A specialist in automated manufacturing solutions, including those for composites fabrication, its high-speed Automated Dry Material Placement (ADMP) technology is well-known in the wind industry as well as aerospace (see Learn More) for its ability to rapidly lay down wide multiaxial and broadgoods preforms for infusion. Danobat is developing technology and software systems to support automated process inspection for its ADMP machines.

The second group is Fives Cincinnati (Hebron, KY, US), a provider of familiar automated composites manufacturing equipment: Viper automated fiber placement (AFP) machines, Gemini dual AFP/automated tape laying (ATL) machines, Charger ATL machines and, through its Forest-Liné division (Granby, QC, Canada), ATLAS tape layers. Together with Fives Lund (formerly Lund Engineering, Seattle, WA, US), a custom manufacturing design firm, Fives Cincinnati has developed a real-time, in-process inspection system for AFP/ATL that, it claims, puts a new and improved twist on inline inspection methods now in commercial use.

The third is Apodius (Aachen, Germany). This subsidiary of Hexagon Manufacturing Intelligence (Cobham, Surrey, UK) has developed successive iterations of its Apodius Vision System, an automated quality control system for low- and high-rate composites production, including automotive parts, that is still economical for smaller facilities.

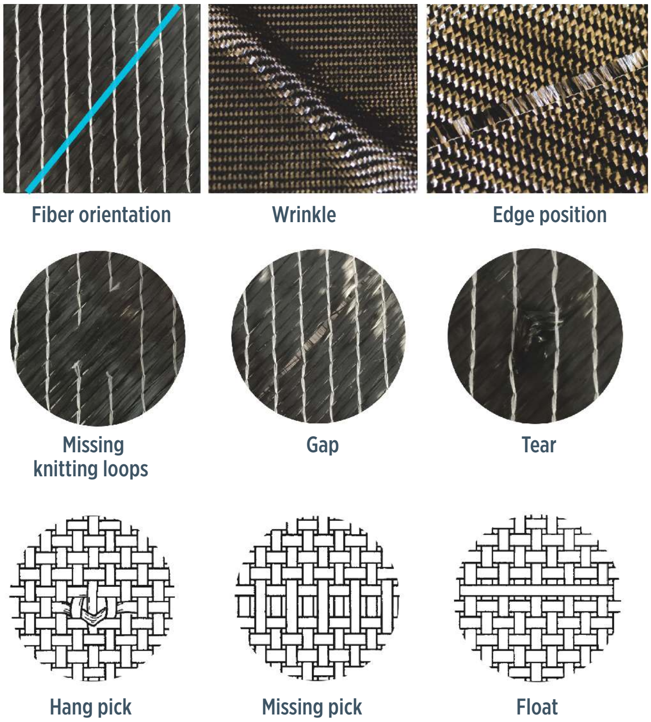
Dry control, rapid defect detection

"With dry fabric, placement defects and any defects that stem from the fabric's structure must be rapidly detected," says Asier Gandarias, business development manager of Danobat's composites division. "We are currently focusing our efforts on two types of inspection systems for our ADMP technology." The first uses a laser profilometer, or LLT (laser line triangulation) sensor, to map the edges of the dry materials during lay down and detect whether fabric positions are within the specified tolerances. The company has developed algorithms in-house for measuring and comparing the edges to specifications. Gandarias notes that the system is being developed to function in two ways: 1) lay a first course of fabric and measure the edges in a second pass; and 2) carry out the inspection as the material is placed in real time. Challenges of LLT include process speed and ensuring that data collection and processing keep up with the machine; perfecting the filtering algorithms based on complex mathematics; and being able to inspect any fabric type, without loss of performance.

The second method involves a combination of LLT sensing and photometric scans with camera sensors. This work is an outgrowth of the European ZAero Project, which *CW* has reported on (see Learn More), involving Airbus and several machine equipment suppliers, with the goal of "zero-defect manufacturing." Danobat has worked extensively with machine vision specialist Profactor (Steyr, Austria) to develop a robust automated inspection system with integrated sensors within the ZAero project. The system goals are more ambitious: Beyond what the first method does, it detects fiber distortions, foreign objects and missing stitches in the dry multiaxial fabrics laid down during part manufacturing, using the two types of sensors.

"For inspection of dry material placement, a special variant of a laser triangulation sensor is used," explains Gandarias. "The idea is to extract the 3D shape of the surface right after placement of the ply. Because we work with very wide widths of fabric, the sensor's field of view has to be large, but at the same time, produce high-resolution images," he points out. The sensor system, thus, includes multiple lasers and cameras to enable the calculation of the height profiles. To ensure accuracy, Danobat uses a high-precision calibration method that ensures correct orientation of the sensors with respect to the ADMP machine's coordinate system.

In terms of software, Danobat has developed its Advanced Relationship Model (ADRM) to process the collected inspection data. For the first method (with a single LLT sensor), the collected points are saved and displayed in the human machine interface (HMI) screen display. In the second method, with multiple sensors, an image of the entire ply is shown with all required information. Gandarias notes that the system is employed in wind blade manufacturing, where the LLT sensor detects wrinkles during laydown and the multi-camera system detects gaps or overlaps between plies, enabling real-time corrections of material placement. Now, with the ZAero project, Danobat is focused on the aerospace sector, and is manufacturing test samples and parts for OEMs as part of private collaborations and publicly funded research projects.



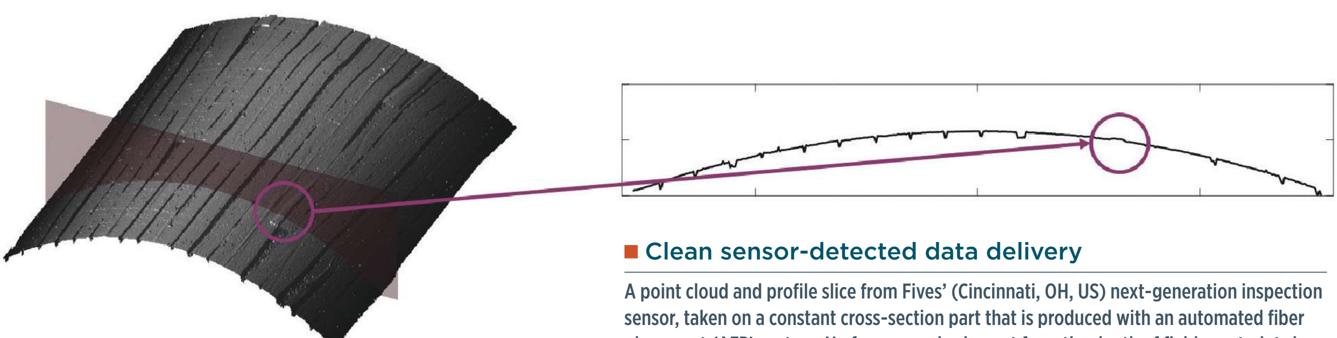
Common defects rapidly detected

Because Danobat's ADMP technology uses dry fabric, placement defects as well as any defects that stem from the fabric's structure itself must be rapidly detected. These are common examples of fabric defects that can occur. Source | Danobat

Automated inspection for contoured AFP

"We have a lot of experience with LLT sensors inspecting medium-contour applications and have been evaluating commercial offerings and designing our own LLT sensors for more than 5 years now," says Erik Lund, CEO and chief technology officer at Fives Lund. "We've taken a large amount of data and made hundreds of large parts, utilizing an automated, in-process inspection system with LLT sensors."

The outcome of the company's experience and research is a new industrial sensor, targeted to inspection of highly contoured components. The sensor, says Lund, enables highly accurate »



Clean sensor-detected data delivery

A point cloud and profile slice from Fives' (Cincinnati, OH, US) next-generation inspection sensor, taken on a constant cross-section part that is produced with an automated fiber placement (AFP) system. No focus or noise impact from the depth of field constraints is apparent, says the company. Source | Fives

■ **Vision-based sensing via robot**

This Apodius (Aachen, Germany) HP-C-V3D Vision System is mounted on a Romer arm for collection of three-dimensional image data. Source | Apodius

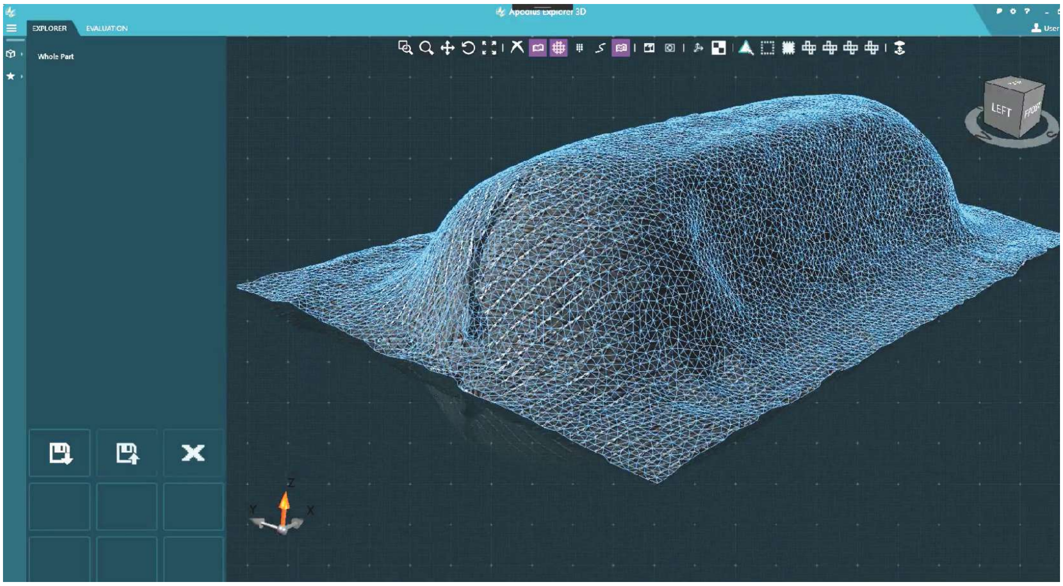
measurements when mounted on a machine head in a position that does not impede the machine path.

Gil Lund, senior project engineer at Fives Lund, explains that his team has performed extensive testing and benchmarking of inspection solutions for several years, which has helped prioritize development of its inspection solution: "Surface profilometry describes many different techniques for noncontact measurement of surfaces, including surface finish — gloss, texture — and shape (for example, flatness, curvature, waviness), of which laser line triangulation is but one subset." Because the physics of LLTs requires a triangle-shaped sensing configuration, he says, it can make taking measurements tough during fiber placement applications on parts with features difficult for the LLT machine to negotiate, such as tight corners and curved recesses. "So, we've moved away from LLT technology and designed a system compact enough to fit on the head, with plenty of mold clearance and without impacting the head's functionality." Further, the sensor is close enough to the part to ensure accuracy of the scan and produce high-resolution images as the head moves.

Gil Lund explains that because typical off-the-shelf LLT sensors operate optimally when orthogonal, or perpendicular, to the part surface, it is almost impossible to use them on a highly curved tool surface — for example, a fuselage barrel or inlet duct part. If the angle is excessive, the laser light gets reflected away, or too much reflection is generated, a condition termed "blooming." Both conditions make it difficult to achieve consistent, clear images.

Fives Lund's system involves a custom sensor attached to the machine head/end effector, pointing at the part surface just a few millimeters behind the compaction roller. Gil Lund says that company has developed part program analysis software that evaluates the inspection system's coverage, identifying any blind spots caused by AFP head path and/or part geometry constraints, *without* the use of overhead line templates (OLTs or laser line projectors): "Our solution," says Lund, "has more mounting flexibility because of the increased depth of focus and reduced sensitivity to incident angle."

Although specific public details are few, a proprietary and unique imager (not an optical camera) captures frames of the tape or fiber course as it is laid, processes that data immediately with what Fives Lund refers to as a "highly parallelized data streaming architecture" to form composite point cloud images of the part surface: "We're using familiar concepts of processing surface profilometry data, but we have



■ **Building digital models as comparative tools**

A mesh is generated by the Apodius Explorer software package to form a digital model of the part, which is used to document fiber orientation and detect possible defects. Source | Apodius a very different way of sensing the surface, such that it doesn't have the physical constraints of an LLT sensor," says Gil Lund. "The way we collect and transfer the data and stitch the images together with our software, it's happening on the fly, in real time, with fewer data, so there's no lag. In other words, we can provide process feedback immediately, as the head lays material."

He notes that the software works together with the AFP machine's path-generation programming: "Not only does this system accomplish process inspection, it's also going to improve machine cycle time. Every machine runs into problem areas, where it needs to slow down, like a tight curve, or a surface contour that is troublesome — we can analyze that now and improve cycle-time performance because the inspection sensor is giving you constant feedback so that you can adjust the CNC path in those problem areas."

Fives Cincinnati's director of technical sales Robert Harper says, "There are many inspection systems out there, but ours, mounted on the head, truly provides real-time information on whether the course is good or bad, during operation, so we can stop the machine and adjust or re-lay the course, rather than laying a 50-ft [15.2m] course and finding out, after the fact, that it's bad, and has to be pulled off and discarded."

This next-generation inspection system is being evaluated first for retrofitting to existing Fives Viper machines. "It also will be installed natively on new Fives AFP and ATL equipment," says Harper.

LEARN MORE

Read this article online | short.compositesworld.com/AutoInsp2

Read February's Work in Progress article titled "Improving composites processing with automated inspection" online | short.compositesworld.com/AutoInspEI

Read more about ZAero online:

In the *CW Blog* titled "Zero-defect manufacturing of composite parts" | short.compositesworld.com/ZAero

At the ZAero Web site | zaero-project.eu

Read about inline aircraft inspection in the *CW Blog* titled "Real-time automated ply inspection (RTAPI) system: *CW*'s series on automated inspection methods" | short.compositesworld.com/MaassBlog

Learn more about Danobat technology at the following links | https://vimeo.com/205175344 | danobatcomposites.com

Multi-application inspection

At Apodius, inspection technology revolves around its first-generation Vision System 2D, an optical system for fiber orientation measurement and defect detection, qualified for fully automated inline and stationary offline inspections. In a manufacturing workcell, for example, in which fabrics or tapes are cut, then shaped into a preform, the system can capture the preform's surface texture with a high-resolution, camera-based system. Up to » three fiber orientations can be automatically detected, measured and analyzed by the Apodius Explorer software. Fiber orientation can be measured to 0.1° resolution by evaluating the recorded raw image data of the surface texture compared to the textile's actual design, including woven, noncrimp and braided fabrics. The system enables statistical process control (SPC) for release of preforms into production, and it is in use in several large-scale production lines.

The Apodius Vision System 2D system also can be used to repair finished carbon fiber composite parts. Because it can detect fiber orientation on the surface of consolidated parts, it can, in combination with a laser ablation cell, provide self-regulating, layer-by-layer repair preparation. As the laser ablates or removes each composite layer in the repair area, the image processor provides a record of the position and fiber orientation of the repair area. Use of the 2D data can enable economical repairs of small or partial defects in components and thus and avoid replacement of entire components.

With the addition of a ROMER Absolute Arm (also made by Hexagon Manufacturing Intelligence, and fabricated from carbon fiber composites), the HP-C-V3D Apodius Vision System can collect three-dimensional image data. The ROMER Arm serves as a global reference system and determines the positional relation between part, arm and sensor head. The ROMER Arm scans the part with a laser scanner to generate a point cloud and determine the surface geometry, then the camera vision sensor configured with LED lighting captures images of the surface. Position data from the sensor plane and part surface enable the allocation of image information to a position on the part's surface, and the image and geometric information are assembled, or stitched together, by the software program to form a digital model of the part, to document fiber orientation and detect possible defects, enabling cost reduction for composite production lines.

Evaluation of measured results is performed by Apodius Explorer software, which visualizes the measuring process in real time and analyzes results. Tools available to the user enable defect detection and part analysis as well as an actual-to-target value comparison with previously digitized master parts. Further, measurement results can be exported for iterative simulation and design purposes. For example, Apodius can verify draping simulations using as-measured fiber orientation data. Fiber and geometry data are exported directly into Digimat software from MSC Software (Santa Ana, CA, US, also a Hexagon company) for finite element analysis, to predict the part's mechanical performance. CW

ABOUT THE AUTHOR

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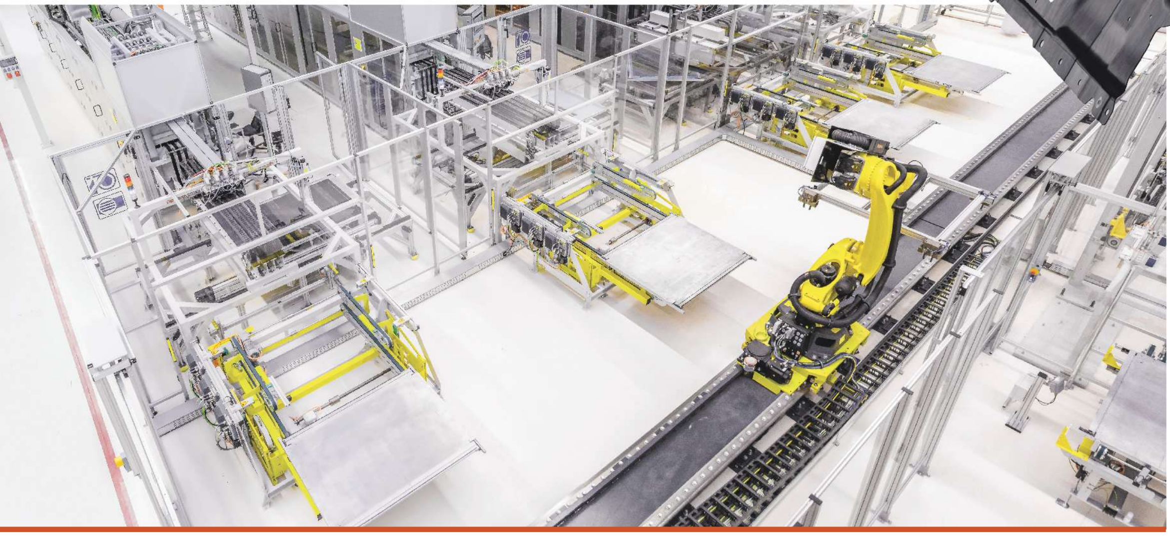
Rear wall reboot: One-stop, tow to tape to CFRP part

Audi and Voith Composites iterate the CFRP rear wall from *R8* sports car to *A8* luxury sedan via an automated production line able to output hundreds of parts per day.

By Ginger Gardiner / Senior Editor



High-volume autocomposites production for the Audi *A8*

The highly automated processes envisioned by Voith Composites and Audi when they first partnered in 2011 has been realized. Four Voith Roving Applicator lines (left/top) and a suite of fully automated forming, molding and assembly cells can produce hundreds of the rear wall modules per day. Source | Voith Composites

» At the onset of carbon fiber composites' current advance into automotive applications, manufacturer BMW Group (Munich, Germany) seemed to stand apart. Initial work to accelerate resin transfer molding (RTM) for production of its *M* sport model's roof led to establishment of a complete supply chain for carbon fiber-reinforced plastic (CFRP) parts on its *i3* and *i8* vehicles and then to all-new fabrication and assembly workcells for the multi-material Carbon Core body-in-white (BIW) on its *7 Series*.

BMW committed to the *i3* in 2009 to great fanfare, but that same year, Audi AG (Ingolstadt, Germany) established a technical center devoted to fiber-reinforced plastics. In 2011, Audi announced a partnership with Voith Composites (Garching, Germany) to develop and produce CFRP parts at high volume. The following year, it publicized the development of a CFRP-reinforced steel B-pillar, made using resin transfer molding (RTM), *and* its partnership with SOGEFI (Guyancourt, France) to commercialize composite coil suspension springs. In 2012, Audi also served as a founding partner for the MAI Carbon leading-edge cluster, which included BMW, Voith Composites, SGL Group (Wiesbaden, Germany) and others.

Most notably, Audi's own narrative of CFRP development begins with its first-generation *R8* sports car, released in 2006. It featured compartment covers for the convertible top as well as sideblades made by resin transfer molding (RTM). The company progressed from aesthetic exteriors and smaller structures to the Modular Sportscar System (MSS) in the Audi *R8 e-tron*. Although that electric supercar's main structure comprised extruded aluminum beams joined by aluminum castings, all of the panels and in-fills were CFRP, including a trunk insert with corrugated crash structures that enabled the rear module to absorb five times as much energy as the metal frame.

The backbone of the MSS is its *rear wall*, which evolved from an initial concept in 2011 to the module that is currently produced for the non-electric *R8* by SGL Technologies (previously BENTELER-SGL, Ort im Innkreis, Austria; see Learn More, p. 29). But Audi was already planning its next step: iterating the rear wall for use in its higher-volume *A8* luxury sedan, with Voith Composites as its manufacturing partner.

Voith Composites is a 10-year old subsidiary of the multinational Voith GmbH & Co. KGaA, established in 1867. The parent company now fields 19,000 employees, has annual revenues of €4.2 billion (US$5.2 billion) and provides manufacturing equipment and technologies through four divisions: Voith Digital Solutions, Voith Hydro, Voith Paper and Voith Turbo. Voith Composites evolved from production of CFRP rolls used in papermaking to manufacturing automotive and industrial CFRP driveshafts/cardan shafts and flat laminates.

In 2011, Voith Composites began work on a highly automated CFRP process chain, aimed at producing the *A8* rear wall. At its core was the Voith Roving Applicator (VRA), which, in a single line, spreads 35K carbon fiber tow from Zoltek (St. Louis, MO, US) into bindered unidirectional (UD) tape, which is then cut and stacked to form a tailored blank. The VRA was recognized with a JEC Innovation Award in 2017. It also established a robust base for subsequent preforming and molding operations. Auto category top honors were captured again for Voith Composites and Audi at JEC World 2018 for the completed VRA-based digital 4.0 production line used to manufacture the Audi *A8* rear wall module. Working with resin supplier Dow Automotive (Auburn Hills, MI, US) and Zoltek, these partners not only developed the materials, process and integrated inline inspection systems necessary to manufacture high-performance CFRP parts at high-volume rates, but also created the full suite of essential computer-aided design/manufacturing (CAD/CAM) and simulation tools which are already being applied to develop future parts.

Efficiency-driven design evolution

"We began working with Audi early on," says Dr. Jaromir Ufer, Voith Composites' head of business development. The first priority was to develop the new *A8* rear wall design, which would direct how the part should be manufactured.

"When we began the engineering for this production, we could not find off-the-shelf [software] products which had everything we needed," explains Ufer. "So we brought together design tools like ABAQUS, but built our own material cards and developed our own simulation methods." Audi had already identified reduced BIW weight and increased torsional stiffness as key objectives for the *R8* rear wall design (see Learn More). For the *A8* module, an integral design was put forth to reduce the multi-component *MSS* assembly to a single, shaped CFRP panel with a small number of bonded and riveted attachments. This design drove development of a highly anisotropic laminate with localized load paths, which enables the finished part to provide 33% of the drive cell's torsional stiffness at 50% of the weight vs. an assembly of three to five welded aluminum parts.

"The composite preform for the Audi *A8* rear wall panel varies from a base of 6 plies up to 19 plies where local reinforcement is added — for example, where there are cut-outs or point loads, such as the child carrier restraint attachments," explains Ufer (Fig 2).

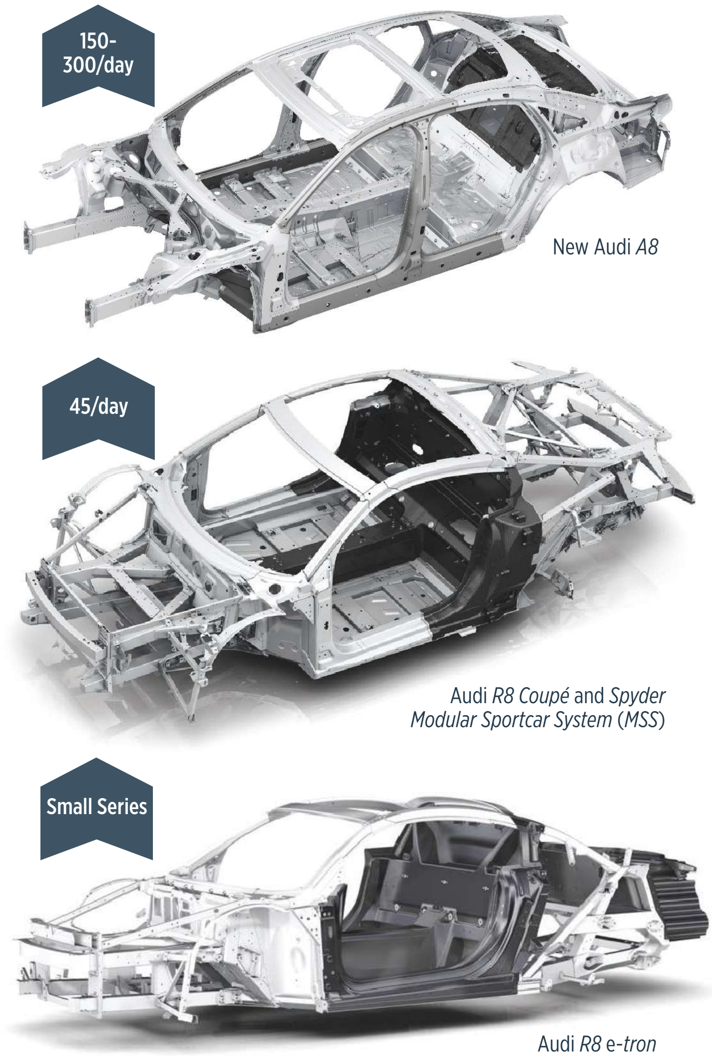


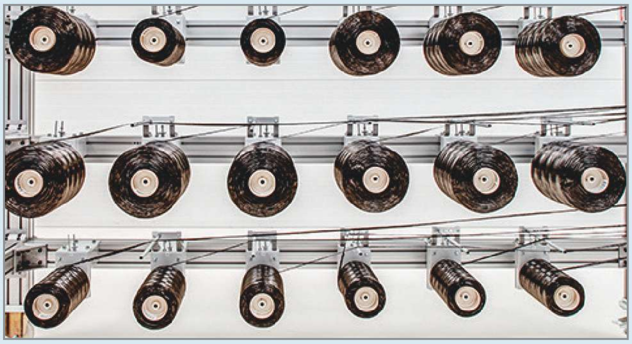
FIG. 1 From small series to high volume

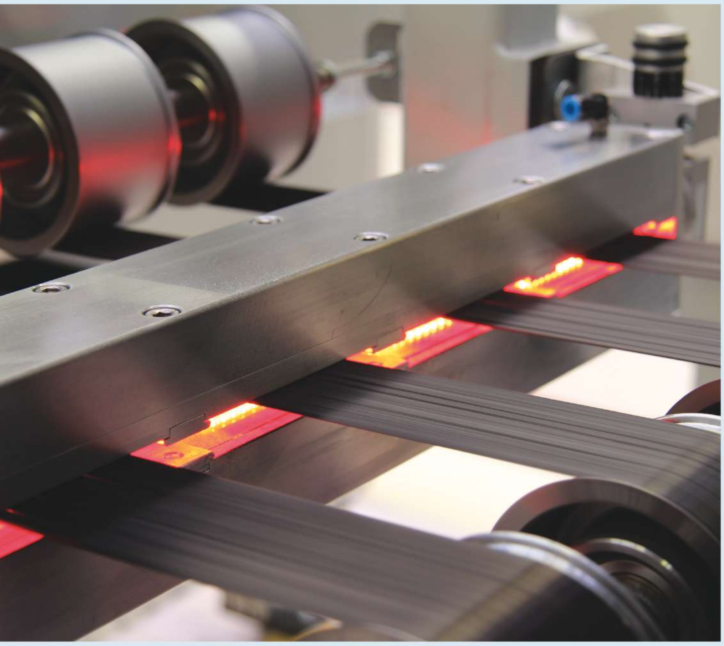
Audi has optimized the production efficiency, cost and integral design of its CFRP rear wall as it evolved from the *R8 e-tron*, where the goal was maximized lightweighting, to the *R8 MSS*, the first step toward higher volumes in production, to the new *A8*, which demanded another level of industrialization. Source | Audi AG

Voith Roving Applicator

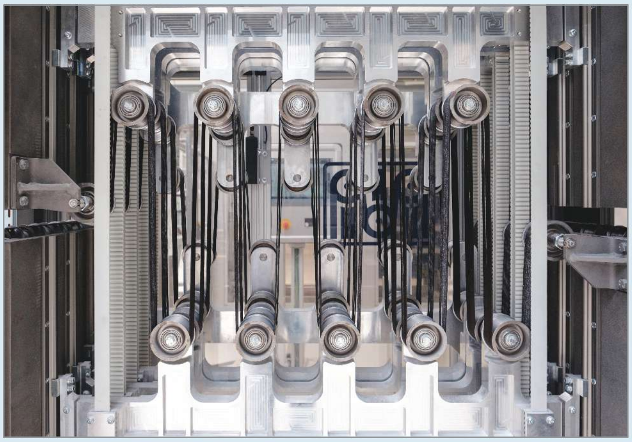
Ufer notes that development of this design and the VRA proceeded in tandem. "Only by having the design freedom that the VRA offers was the performance of the new *A8* rear wall possible." Also important was the fact that fiber supplier Zoltek made a 7-year price commitment to the program.

The VRA's process begins with a creel of Zoltek's PX 35 carbon fiber. Multiple bobbins of 50K tow are fed into each VRA line and spread to produce 50-mm wide tapes. Next, an epoxy-based binder is applied that will later react with the Dow VORAFORCE snap-cure epoxy matrix resin during resin transfer molding (RTM) of the composite part. A small amount of infrared (IR) heat is applied to melt the binder enough to hold the tape together »

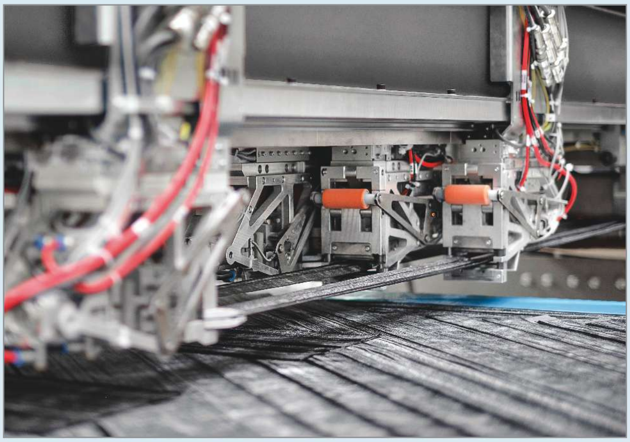




1 Zoltek 50K carbon fiber tow is fed into the Voith Roving Applicator (VRA), where it is first spread, then coated with epoxy-based binder and afterward IR-heated to partially melt the binder.



2 The spread-tow tape is then consolidated as it proceeds through multiple rollers under tension.



3 The VRA then cuts the tape and places up to four pieces at a time onto a rotary table, tailoring both tape length and orientation angle within the laminate stack (e.g., 45°/90°/30°).

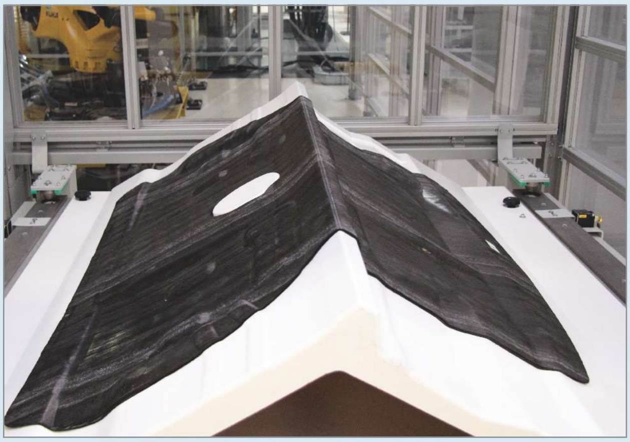
through subsequent consolidation, cutting and stacking steps (Step 1, above).

"This is a continuous process that is completely automated," says Ufer. "If for some reason it is necessary to stop the line, the equipment reacts automatically. For example, the IR heater is immediately switched off and retracted to prevent damaging the tape from overheating. There are hundreds of such details in the equipment, and digital control enabling this technology."

After binder application, tape consolidation is achieved as it passes through multiple rollers under tension (Step 2). Ufer explains this also builds in a buffer for the line. "We have a unit that interrupts the continuous pull flow of the fiber, providing a transition to the pulse format of the tape cut-and-place mechanism." This gantry-based mechanism cuts the tapes to tailored lengths and places them at specified angles from 0-360° onto a rotary table (Step 3). Each tailored stack, comprising 6 to 19 layers of tape, ranges in thickness from 1.5 to 3.7 mm, respectively.

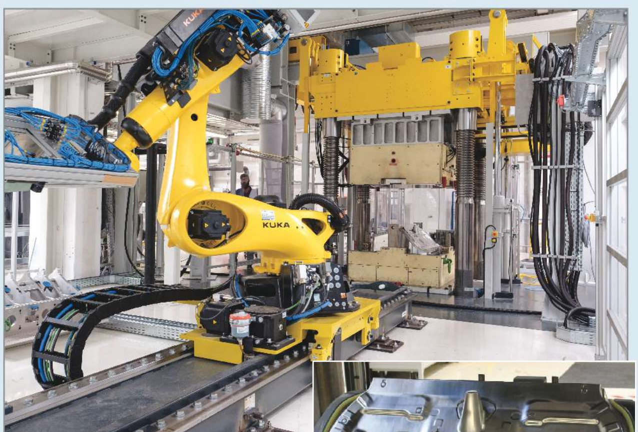
Voith has installed four VRA lines (see opening photo, p. 24), and although each applies up to four 50-mm wide tapes at a time, Ufer points out, "the lines have a modular approach, so they could apply 10 or more tapes at a time. It depends on the part size and production rate."

Automation includes quality inspection. Scans of the tapes and preforms are compared with a rejection algorithm. "The VRA's 100% scanning of the tape ensures the right fiber distribution for the whole production line," Ufer explains. "We also use thermography and laser sensors to check the preforms at designated areas." The VRA then can react to any issues it detects. "If one tape is not correct," he points out, "the VRA will cut out the deficient length and produce another to replace it." A QR code is placed on



4 The tape stack is shuttled into a press, where it is formed into the final 3D part shape.

6 BETAFORCE polyurethane adhesive is robotically applied for bonded attachments and then cured in a short oven cycle.



5 The shaped preform is placed into a 350-kN press and molded, using ultra-RTM.

7 The finished part is then prepared for shipment to the Audi *A8* final assembly line.

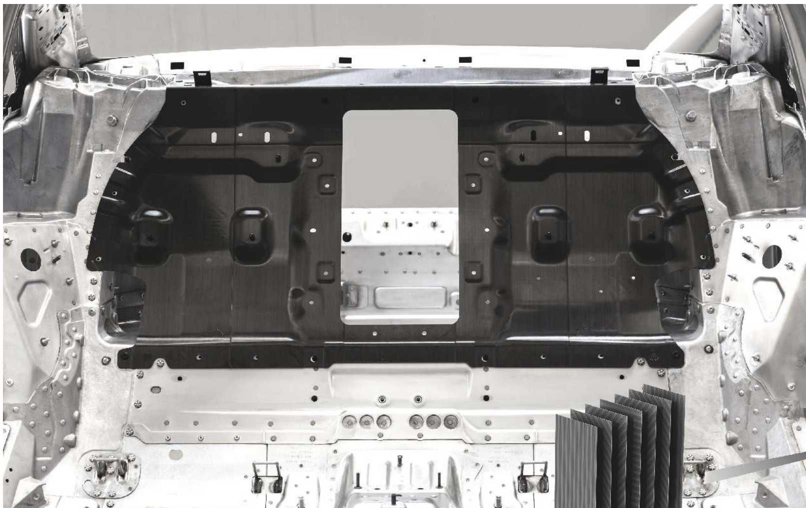
the finished preform for traceability. (QR codes are preferred to radio frequency identification (RFID) tags because they reportedly better withstand the resin injection process.)

Forming, molding and assembly

The 2D stack exits the VRA and is shuttled into the production line's forming, molding and assembly section. The first press into which it is placed, supplied by composites automation specialist FILL (Gurten, Austria), uses heat and pressure to shape the 2D tape stack into a 3D preform (Step 4, p. 27). Ufer explains that because the preform varies in thickness and shape, the press can adapt the pressure applied as it stamp-forms separate regions of the preform clamped in the forming tool. ALPEX Technologies (Mils bei Hall, Austria) made the matched-steel RTM molds, based on a design provided by Voith Composites. "We developed the tooling and press process virtually," says Ufer. "Although no actual test loop was required, we did validate and verify the simulation models on other shapes and parts prior to machining the *A8* rear wall production tools. This simulation of the molding process ran right into real production, and helped to speed optimization."

The press holds for a few seconds to react the powder binder and set the shape, resulting in a stable preform that can resist fiber wash during resin injection. "The binder particles also function to hold the fibers apart for improved resin flow during RTM," notes Ufer. "This is helpful because there is no stitching in the preform to aid in resin flow, so these binder particles act as micro flow channels."

The shaped preform is next transferred by robot into an EiMa Maschinenbau GmbH (Frickenhausen, Germany) CNC cell, where an ultrasonic knife trims the outer final contour. It is then »



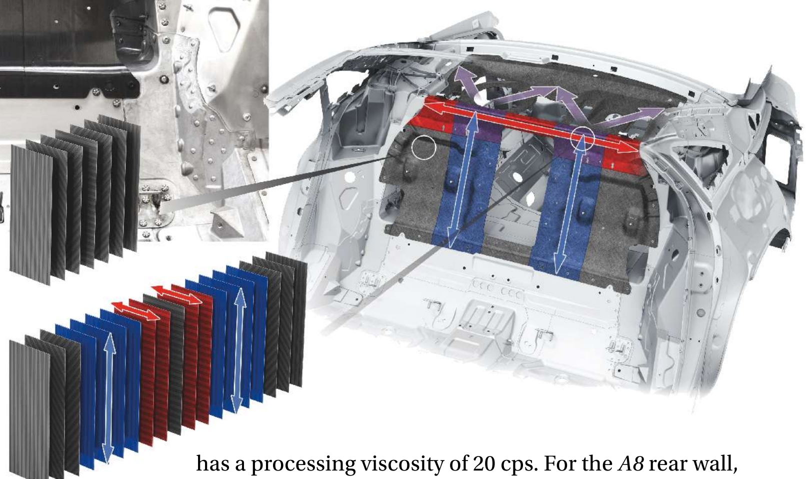


FIG. 2 UD tape provides design freedom and performance

The high performance of the Audi *A8* CFRP rear wall was made possible by the design freedom of tailoring the orientation and placement of unidirectional tapes, realized in production by the Voith Roving Applicator. The composite laminate varies from six plies as a base to as many as 19 plies where additional reinforcement is needed. Source | Audi AG

robotically placed into an RTM press (Step 5, p. 27) supplied by ENGEL (Schwertberg, Austria). All robots in the line are supplied by KUKA Robotics (Augsburg, Germany).

The RTM process used to mold the *A8* rear wall is the same developed at the Audi Lightweight Center for the previous *R8* rear wall, referred to as ultra-RTM. It enables molding of large parts using fast injection but low pressure. Compared to the 140 bar typical of HP-RTM, the in-mold resin-injection pressure during ultra-RTM of the Audi *A8* rear wall is <15 bar, even less than that for the *R8*. As a result, instead of 2,500 kN of press force, only 350 kN is required. Therefore, a smaller, less-expensive press can be used to produce high-quality, high fiber-volume parts.

The VORAFORCE 5300 epoxy resin, a three-component system that includes mold release, cures in 90-120 seconds at 120°C and has a processing viscosity of 20 cps. For the *A8* rear wall, a 1.3-kg resin shot is injected into the preform, followed by a 120-second cure.

The cured part is robotically demolded and loaded into a closed CNC milling cell for machining of cutouts. Next, the milled part is placed into an automated washing machine to clean off residual CFRP dust.

The washed rear wall is transferred into an assembly cell equipped with two robots. The first robot places the molded part into an automated riveting machine, which documents force applied during rivet installation. This is part of the manufacturing intelligence built into the overall process and is added to each part's digital processing record (i.e., digital thread). The part is then moved into the bonding area and a second robot prepares areas for bonding, using an automated solvent wipe. The same robot then applies the fast-curing, two-component Dow BETAFORCE 9050M polyurethane structural adhesive (Step 6, p. 27), which is compatible with the three-part epoxy. The part is next placed in an oven for a short adhesive cure cycle.

This production line maintains a 5-minute cycle time for the completed part and current demand for parts can be met in one or two 8-hr shifts. A 3D laser scanning device is used periodically to check the part's 3D shape and measurements. Finished parts are then prepared for shipment to the Audi *A8* final assembly line in Neckersalm, Germany, about 3 hours away by road (Step 7, p. 27).

FIG. 3 The Voith Roving Applicator

Each automated Voith Roving Applicator line feeds fiber in from 12 bobbins of Zoltek P35 carbon fiber, spreads the 50K tow into four tapes, applies binder, consolidates the resulting tapes and then cuts, orients and stacks these tapes into tailored preforms for subsequent RTM processing. Source | Voith Composites

Direct fiber placement = future flexibility

With all of the investment that has been made, it is surprising to learn that Voith Composites was not assured of this business, but indeed the company completed development and then participated in a competitive bid process to win production. "We were able to meet the target part cost defined by Audi, as well as quality and part performance requirements," says Ufer. This was no small feat, considering that quite a few companies vied for the program.

Voith Composites has patented multiple parts of its process.

LEARN MORE

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

Read more online about SGL Technologies' (previously BENTELER-SGL) production of the MSS rear wall in "Plant Tour: BENTELER SGL, Ort im Innkreis, Austria" | short.compositesworld.com/BentelerSG

Read more online about the Audi *R8* rear wall design process in "Audi *R8* seat wall: A prelude to production" | short.compositesworld.com/AudiR8Wall

Read online about the BMW *7 Series* production in "BMW *7 Series* Plant: Dingolfing, Germany" | short.compositesworld.com/BMW7Ser

Read online about the development of smart, flexible composite parts production lines in "Airborne, Siemens and SABIC partner to mass produce thermoplastic composites" | short.compositesworld.com/MassTPCs

"The VRA has demonstrated industrialization using direct fiber placement [DFP] of tapes, which reduces scrap as well as material used via a highly optimized layup," says Ufer. It also uses the most cost-effective materials — untreated heavy-tow fiber and powder binder. Its second-generation process replaces powder binder with direct application of resin, eliminating more process steps. However, the company has developed other DFP processes, including the Voith Longfiber Preformer and Voith Prepreg Winding.

"We are setting new standards for carbon fiber parts for high-volume automotive serial production," says Voith Composites managing director Dr. Lars Herbeck. "The smart factory we have established brings the automated production of CFRP components to a new level of efficiency and flexibility, including almost any shape as well as individual lot sizes." This is, indeed, where the industry is headed. CW

ABOUT THE AUTHOR

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The spread of spread tow

Advancing from "lighter and thinner" to boosting strength, stiffness, impact resistance and productivity, spread tow unlocks new applications and markets.

By Ginger Gardiner / Senior Editor

» "Spread tow" refers to the practice of spreading a fiber into a thinner, flatter reinforcement. For example a 5-mm wide, 12K, high-strength (HS) carbon fiber tow is commonly spread to a 25-mm-wide tape. This unidirectional tape then can be used in automated tape laying (ATL) and automated fiber placement (AFP) processes. It also can be used to produce thin woven fabrics or multilayered noncrimp fabrics. Although it's possible to spread glass, aramid and polymer fibers, carbon fiber is the reinforcement driving growth in spread-tow technology, as industries from sporting goods to aerospace seek lighter, thinner composites. Spread-tow reinforcements can weigh as little as 15 g/m^2 with a thickness of only 0.02 mm.

According to sources at a global carbon fiber producer, 80% of carbon fiber now used worldwide is spread before further processing. This includes most 50K, 24K and some portion of 12K carbon fibers, which are less expensive than smaller 1K, 3K and 6K tow, yet can be spread to produce

Myriad forms and applications

Clockwise from top left: Hexel PrimeTex fabric in CORIMA bike wheel, TeXtreme CF/Innegra hybrid fabric in Swift canoes, NTPT discontinuous fiber prepreg tubes, TeXtreme spread-tow CF twill fabric, NTPT 400-ply block.

Sources | (top left) | Hexcel / (top right) | Oxeon / (bottom left & right) | NTPT / bottom center | Oxeon high-quality reinforcements that weigh less than 300 g/m^2. For example, Toray's (Tokyo, Japan) epoxy prepreg made with T700S 12K plain-weave fabric has the same areal weight as a fabric made from 3K tow and is now ubiquitous in rockets and space structures (see Learn More, p. 36).

Spreading also enables the tailoring of areal weight as well as other properties, such as resistance to crack propagation for improved damage tolerance. The flatness of spread tow means filaments are straighter than those bundled in normal fibers. This results in more efficient load-carrying capability, by weight, and improved surface finish, as well as an aesthetic appeal.

It's no mistake that spread tow is the starting point for an iconic "woven look" seen increasingly in sporting goods, small airplanes and motorsports applications.

Spread tow also has proven useful in the design of laminates that withstand significantly greater stress before first-ply failure and last-ply failure (see Fig. 1, p. 32), according to Dr. Stephen Tsai, professor emeritus at Stanford University (Palo Alto, CA, US) and co-developer of the Tsai-Wu failure criterion for anisotropic materials. His idea for bi-angle CF multiaxial fabric, launched as C-PLY by Chomarat (Le Cheylard, France and Williamston, SC, US), combines one thin fiber layer at 0°, with a second at a shallow angle, such as 20°, to achieve autoclave-cured unitape prepreg performance in resin-infused laminates made without the time or cost of an autoclave (see Learn More).

Spreading and weaving: Parallel developments

Today, there are a number of companies that can supply the equipment necessary to spread tow for tapemaking as well as tape-capable fabric-weaving equipment. But the suppliers mentioned here are those credited with significant developments that often represent spread-tow technology's innovative turning points.

Tape weaving — weaving a fabric with tapes instead of tows — was invented in 1995 by Dr. Nandan Khokar at Chalmers University of Technology (Gothenburg, Sweden). He presented his work in 2002, where students Andreas Martsman and Henrik Blycker saw the potential value to composite parts manufacturers and founded Oxeon (Borås, Sweden) in 2003, becoming VP of marketing and sales and CEO, respectively.

"There was nothing called spread tow when we started Oxeon," says Martsman. Oxeon introduced its TeXtreme spread-tow fabrics in 2005. TeXtreme spread-tow fabrics have been widely adopted in motorsports and sporting goods — Bauer, Bell, Cobra and Giro, to name a few — as well as industrial and aerospace applications. The latter include *BlackWing* sport aircraft (Blackwing Sweden AB, Eslöv, Sweden) and a new commercial aircraft seat developed with HAECO Cabin Solutions (Greensboro, NC, US) that reduces its previous composite seat's weight by 20%.

Although Oxeon was first to market, there was ongoing development elsewhere. In a 2001 patent application, heavy-tow carbon fiber producer Zoltek (St. Louis, MO, US) detailed a carbon fiber splitter device, which used a spreader bar and two or more eccentric splitter bars. That same year, founders of what »

80% of carbon fiber is spread before further processing

Spread tow is used in woven fabric, noncrimp multiaxial fabric and thermoset and thermoplastic prepreg tape. From the top down: C-PLY fabric manufacture at CHOMARAT, DORNIER flat tape-weaving machine, NTPT's 15 g/m^2 prepreg tape and steel fiber/carbon fiber hybrid tape in spreading zone of Karl Mayer TC54 online creel as part of FUTURE project with Airbus and Quickstep.

Sources | (top) | Chomarat /(upper middle) | DORNIER / (lower middle) | NTPT / (bottom) | Karl Mayer

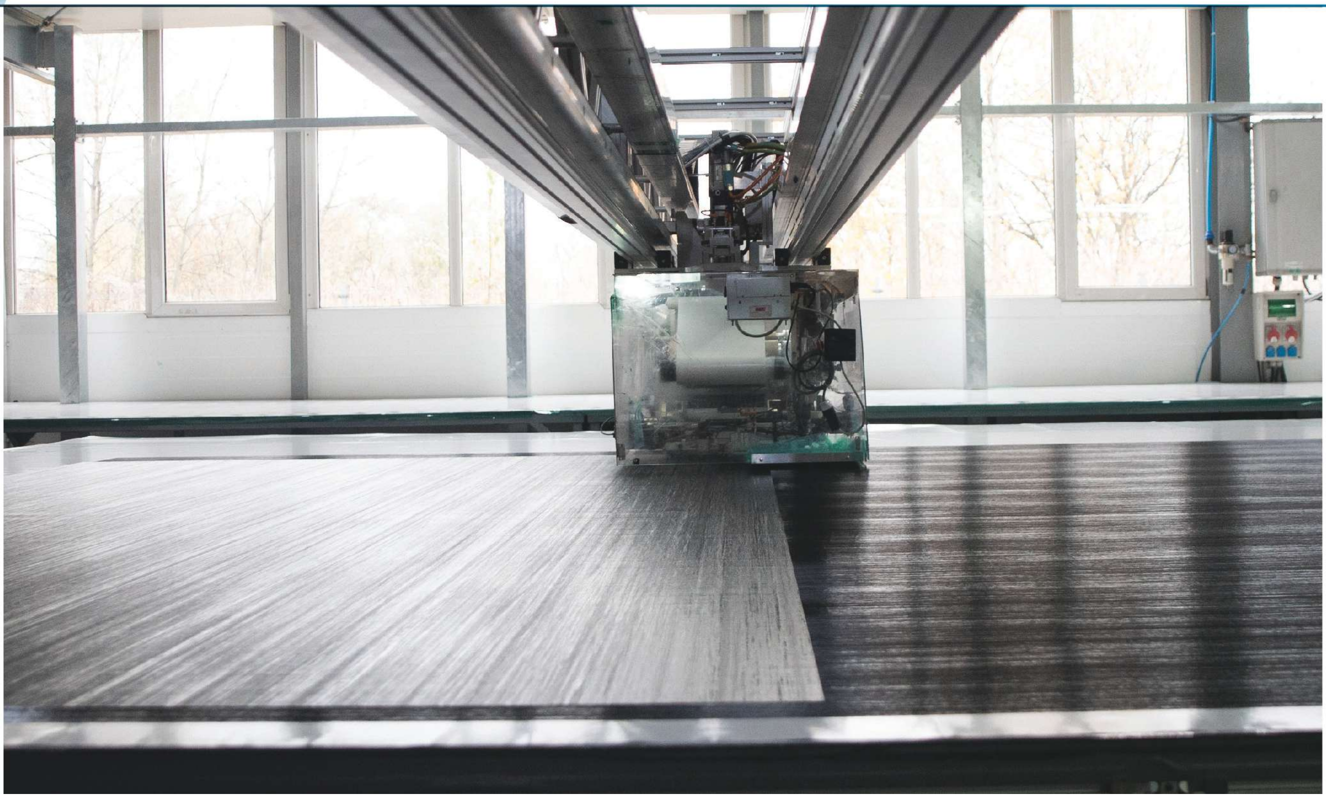
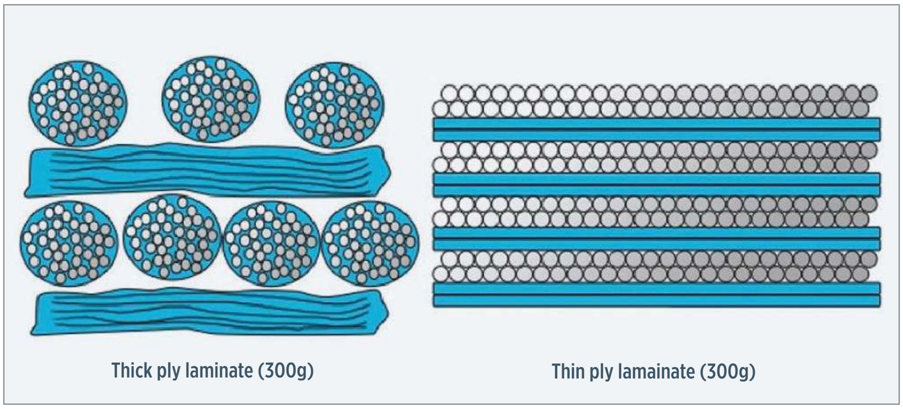


FIG. 1 Delayed ply failure for higher-performance composite structures

Results from testing completed by EPFL and NTPT confirm Dr. Stephen Tsai's claims that spread tow, thin ply laminates can withstand significantly greater stress vs. conventional thick-ply laminates before first-ply and last-ply failure, as well as improved damage tolerance after impact. NTPT offsets the labor of applying the great number of thinner plies required by using unique in-house developed ATL equipment (shown above), which it also sells to others.

Source (both images) | NTPT



would become North Thin Ply Technology (NTPT, Renens, Switzerland) began developing thin-ply materials aimed at improving CF sails. This thin-ply technology was used in 2005 by the Alinghi America's Cup yachts and branded as 3Di by NTPT sister company North Sails (Milford, CT, US). NTPT now sells thin-ply *prepreg* as well as composite tubes and blocks (see opening photo collage, p. 30) made with thin-ply materials into the aerospace, marine, automotive, sporting-goods and consumer-goods markets.

Also in 2005, Boeing Aerostructures Australia (Melbourne, VIC) produced >9m long trailing-edge skins for The Boeing Co.'s (Chicago, IL, US) 787 *Dreamliner*, using resin infusion and PrimeTex spread-tow fabrics developed by carbon fiber manufacturer Hexcel (Stamford, CT, US). Notably, PrimeTex fabrics are unique in construction: "We do not spread tows into tapes and weave," says Guillaume Coustaud, Hexcel's composites marketing manager for reinforcements in Europe. "We weave the fabric and then spread it, using proprietary technology, resulting in a flatter fabric, without having to spread the input fibers." (Fig. 2, p. 35.) Hexcel PrimeTex fabrics have expanded: They are used in CORIMA bike wheels (opening collage) and Fischer skis, for example, as well as space, defense, automotive and marine applications.

In parallel, LIBA (Naila, Germany) launched its MAX 5 weft insertion machine for producing CF multiaxial fabrics in 2002, developed spread-tow technology in 2004, launched its UD 500 offline spreading machine in 2007 and then used that technology to revise its MAX 5 machines, enabling weft insertion of carbon fiber UD tapes. The machine also offered the ability to place discrete layers at angles from -45° to 45°, adjustable in 1° increments. The UD tapes could be spread online up to 227 mm wide or offline up to 254 mm wide. The offline system could spread 50K or 60K fiber, with the possibility to add a second level for spreading 12K or 24K tow. The online system, however, offered only the latter. LIBA was acquired in 2014 by Karl Mayer (Obertshausen, Germany). »

Sigmatex installed MAX 5 machines in both its Benicia, CA, US and Norton, UK sites. MAX 5 machines also were purchased by SGL Kümpers (Lathen, Germany), FORMAX (Leicester, UK, acquired by Hexcel in 2016) and Vectorply (Phenix City, AL, US). Chomarat used MAX 5 machines to produce C-PLY multiaxials in France in 2010 and in its new US facility in 2014. MAX 5s also produce Chomarat's C-WEAVE line of woven spread-tow fabrics.

Chomarat North America president Brian Laufenberg also notes that "we have been quite successful in spreading the very large and low-cost 457K carbon fiber tow developed at Oak Ridge National Laboratory (ORNL, Oak Ridge, TN, US)." He is referencing ORNL's 400K-600K tow made from low-cost, textile-grade precursor, converted into a carbon fiber that offers 400 ksi tensile strength and 40 Msi modulus (see Learn More). "This is spread into 120-g/m² plies and converted into ±45° biaxial carbon noncrimp fabric," Laufenberg adds. "We don't just buy a machine from the manufacturer and use it, but instead adapt it quite a bit, and we are continuing to develop the technology." For example, the 457K tow was also spread to make a 600-g/m² highly permeable wind blade spar cap reinforcement that was subsequently pultruded and used in a 9m thermoplastic blade fabricated by the Institute for Advanced Composites Manufacturing Innovation (IACMI, Knoxville, TN, US) and nominated for a 2018 JEC Innovation award.

Another major player is DORNIER Composite Systems (Lindau, Germany). "We produce machines and full production lines, not materials or parts," explains DORNIER Composite Systems product manager Mario Krupka. "However, we offer our customers the ability to make trials in our technology center, where we have all our machines, including spread-tow lines, tape-production lines and machines for weaving tapes/spread tow, as well as standard and 3D weaving equipment." Like Oxeon, DORNIER first entered the market by weaving tapes. "There was customer demand seven years ago, so we developed a special tape-weaving machine," says Krupka. "The customers came back and wanted to make the tapes themselves." Thus, DORNIER also makes fully impregnated thermoset *and* thermoplastic prepreg tape production lines. The latter, he notes, may use spread-tow glass fiber just as often as CF tapes.

One key to spread tow's reach is the extent to which it has been adapted for mass production.

Industrialization and cost

One key to spread tow's reach in the market is the extent to which it has been adapted for mass production. NTPT makes spread-tow products, "but we are also an automation company," says company president James Austin, noting that it sells specialized ATL equipment, developed in-house. "Because the layers are so thin — for example 0.03 mm for a 30-g/m² prepreg — we could be laying 10 to 100 plies, which hindered material sales in the beginning. But as we have automated both lamination and kitting, this has changed. Now, we see more opportunity to help other companies develop these types of unique solutions for various market niches."

When Austin says automated lamination, what he means in this case is digitally controlled application of 10 or 16 layers on a 10m-by-4m working area.

"If you're making a 1m-by-1m part, then we can cut that large area into 40 tiles," he explains. "At 10 layers each, you can generate a 400-layer stack on one machine that has been running in the background, laminating and kitting the materials for this part in a cost-effective manner."

SIDE STORY

How is tow spread?

A great deal has been made of late about spread-tow, particularly with regard to products made from carbon fiber composites. Thus, the occasion for *CW's* feature article, for which this short note serves as a Side Story. Conspicuously missing from *CW's* feature coverage is a discussion of the ways and means by which spread-tow suppliers *actually spread* the bundled, typically large-tow fibers to accomplish their ends.

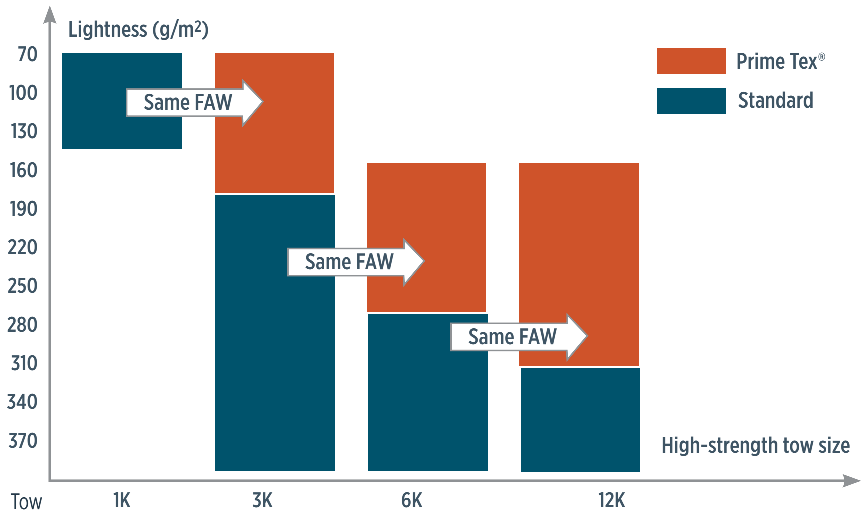
How is fiber spread? We really don't know much about how it's done. Much like the fiber sizings and treatments that are the fiber manufacturers' primary means of setting their products apart from their competitors', and about which, therefore, they have been historically so secretive, spread-tow providers don't surrender much detail about their spreading processes. Methods are patented, and suppliers make frequent use of the word *proprietary* in reference to their technologies.

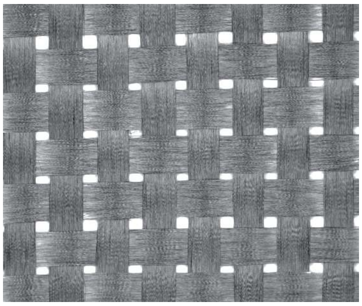
That said, there was some light shed in a paper titled, "Spreading of heavy tow carbon fibers for use in aircraft structures," presented at the 17th European Conference on Composite Materials (ECCM 17, Jun 26-30, 2016 in Munich, Germany). In it, authors from aerospace manufacturer Airbus (Toulouse, France) and two German universities, citing various patents and studies, claimed that spreading methods can be classed, generally, as *active*, *passive* or a *combination*.

Active methods are explained as those using some type of energy to spread the fiber. One example is the application of airflow (either pressure or suction) to the fiber within a small gap. Other active methods use the transfer of ultrasonic waves or vibrations into the bundled filaments.

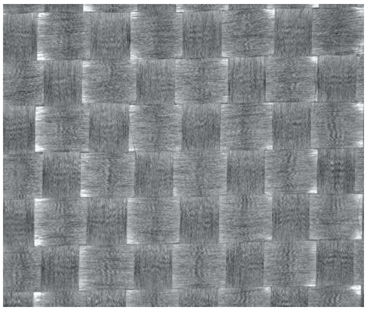
Passive methods, on the other hand, use only tension and constant movement, drawing the fibers over spreading bars or other geometrical elements.

Of note, *CW* has interviewed sources who have tried active vibration vs. passive methods and found no significant difference, so that no vibration was chosen in the final process.





Conventional woven fabric



Equivalent PrimeTex fabric

FIG. 2 Closing the gap at equal areal weight, using less expensive, larger tow

PrimeTex carbon fabrics use spreading technology to close gaps in the weave for reduced porosity, which results in higher mechanical performance and surface quality. PrimeTex 98 g/m² fabric made from 3K tow is 12% thinner than conventional 1K carbon fabrics at the same fiber areal weight (FAW). Similarly, 6K tow PrimeTex can be used to match the FAW of conventional 3K woven fabrics and 12K PrimeTex can match the FAW of 6K conventional fabrics. Source | Hexcel

Oxeon's Martsman, looking back, notes, "Our products are much more industrialized than when we first introduced them, and the technology has developed substantially. We have worked with these materials for 15 years, in many different types of parts and have learned what works, where." He sees Oxeon as more of a development partner than a material supplier. "With the flexibility that our technology provides, we can enable manufacturers to try many more options." How? "With traditional weaving technologies you need 500 bobbins, even if the trial amount needed is only 5m²," he explains. "But we can easily set up a few bobbins and produce 10m² of product with 10 variations. So the customer can have a more efficient development."

Does this higher performance product command a price premium? "Not necessarily," says Hexcel's Coustaud. "If PrimeTex was so much more expensive, then it would not have been used as much as it has. It has won its way due to performance at the right cost per application."

Krupka at DORNIER comes back to scale: "You can spread 50K tow to 100 g/m², cut the tapes to 25-mm width and weave them to a 200-g/m² fabric. A weaving speed of 50 picks per minute allows making 1.25 linear meters of fabric, or 2.25m² of 180-cm wide fabric. This is very economical vs. using a more expensive, lighter CF tow to make the same areal weight."

Controlling areal weight and crack propagation

Although automation and cost control have certainly helped remove barriers to spread tow's acceptance, it is the technology's tailorability that is now aiding its expansion in the marketplace. "I think it is hard for people to understand the flexibility in our technology," says Martsman. "We spread tow to whatever width we prefer. Thus, a 10-mm wide spread tow is one areal weight and an 11-mm wide tow is a different areal weight. We can also use a wide array of input tows — from 1K to 60K and even 320K from SGL. We can also take multiple input tows. So you really can tailor precisely the fiber areal weight that you want."

According to Krupka at DORNIER, spreading a single tow vs. multiple tows is performed on the same machine, but uses a different setup. Single-tow spreading makes sense for smaller 12K or 24K tow, but requires a larger number of spools. Alternatively, multiples tows are often used to make wider tape that is then slit into the desired widths. "Multiple tow spreading makes you independent from the tow size with respect to areal weight," he adds. However, the exact spreading ratio depends on the customer and application requirements.

As areal weight is tailored, so is thickness. The benefit? "Impact performance improves with thinner plies," says Oxeon's Martsman. Bob Skillen, founder and chief engineer at VX Aerospace (Morganton, NC, US), who has used Chomarat's C-PLY in multiple aircraft projects, agrees: "A greater number of thinner plies makes a stronger and tougher part than fewer, thicker plies." He notes that thin-ply, bi-angle laminates outperform conventional quasi-isotropic laminates (i.e., 0°, 90°, +45°, -45°).

"We go *super* quasi-isotropic," says Austin at NTPT, "using eight fiber orientations instead of four, and we can even go to »

16 in extreme cases. Because the layers are so thin, this achieves a kind of homogeneity, with very good resin-to-fiber distribution, which improves filament-to-filament load transfer for higher performance."

Using spread-tow vs. normal fiber bundles in woven fabrics also offers an impact improvement. "Woven fabrics distribute impact energy to more fibers because they are interlaced instead of simply placed on top of each other, as in multiaxial fabrics," Martsman explains. "However, weaving crimps the fibers, which limits how much energy they can absorb because it lowers their load-carrying maximum. *Spread-tow* fabrics have much less crimp, providing the best of both worlds."

Martsman also notes that large aircraft OEMs are combining thin plies with traditional thick plies. "For example, five thin plies with 10 standard thick plies gives an interesting crack propagation behavior that allows them to tailor the damage tolerance performance in the aircraft structures."

There is one caveat to all the performance benefits. "You have to adapt your computer models and simulation for thin materials because the mechanics are different," says Martsman, noting that Oxeon invested heavily for this purpose in finite element analysis (FEA) capability three years ago. "We can combine our materials with other materials and model variations in the laminates and structural performance. We model new designs for customers and compare to what they have today, including evaluation of different options, such as change in fiber type, areal weight or putting more fiber in one direction vs. another. It's important to be able to compare all of these options quickly and easily."

+ LEARN MORE

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

Read "A technological brake for the carbon supply roller coaster?," a 2005 spread-tow summary article written by Oxeon co-founder Henrik Olofsson online | short.compositesworld.com/HO-2005

Read more online about Dr. Stephen Tsai's development of spread-tow-based bi-angle fabric and the subsequent development of Chomarat C-PLY in "Bi-angle fabrics find first commercial application" | short.compositesworld.com/TsaiBiFab

Read online about Oak Ridge National Laboratory's low-cost, 457K carbon fiber tow technology and its availability for licensing in the *CW* news article titled, "ORNL seeks licensees for its low-cost carbon fiber technology" | short.compositesworld.com/ORNL475K

Read more about NTPT's work with spread tow in marine and golf-shaft developments in the online Side Story titled, "Spread tow brings new life to legacy markets" | short.gardnerweb.com/spreadnew

Future products, processes and applications

What does the future hold for spread tow? "We see growth not only for aesthetics, but parts can be up to 20% stiffer," claims Krupka at DORNIER. "This is due to less crimp. For example, using 20 layers of spread-tow fabric instead of 10 layers of 3K fabric achieves a higher stiffness for the same wall thickness," he says. Greater stiffness per unit of thickness has proven attractive. " We are seeing more interest in using tapes and tape-woven fabrics for structural reinforcement because of this."

Another driver is the use of fully-impregnated thermoplastic tapes. "The high impact resistance of these materials is very attractive for automotive parts like doors and bumpers," Krupka notes. "Composites from glass fiber/polypropylene tapes are price-competitive to lightweight metals like aluminum or magnesium, and the forming process is fast with a high degree of design freedom." He cites applications in high-end car models in Asia and Europe that are now migrating into mass-produced models.

Austin at NTPT discusses new opportunities in legacy markets, such as marine and golf shafts. For marine, NTPT's prepreg automation has enabled sandwich panels for bulkheads and other interiors that offer lower cost, delivery time and weight vs. resin-infused panels. In golf shafts, discontinuous prepreg achieves improved performance, which Austin believes may provide benefits in other tubulars like driveshafts (see Learn More).

He also sees opportunity in new markets, such as urban mobility, where a growing number of programs are developing unconventional aerospace vehicles, including electric vertical takeoff and landing (EVTOL) aircraft (e.g., the Airbus *Vahana*). "These are all very weight-dependent and natural applications for thin-ply materials," he contends. "We are actively working on multiple programs, pursuing ultra-lightweight aerostructures. There are also a lot of electric motor applications for CFRP with tremendous opportunities for us. I think there is a lot more going on here than people appreciate. We think electric vehicles will have a significant impact on the future of our company."

Oxeon's Martsman also is optimistic about aerospace, for which his company's new ±45° Spread Tow Grid is made. He says scrap reduction is driving increased demand. "For a 1m part made from a 1m-wide 0°/90° fabric, you produce your bias plies by cutting this at an angle, but that results in 50% scrap. Another case is larger parts, like a 1.5m-wide wingskin, where you can only get 1.6m wide 0°/90° fabric. Again, you cut bias plies at an angle, which produces triangles that are thrown away. The scrap rates are amazingly high when you make large parts, such as tanks and floor panels."

DORNIER is developing products for increased productivity, including machines to make thicker tapes and wider fabric, increasing widths from 150 cm to 266 cm. "We are also looking at weaving wider tapes, moving from 40-mm warp and 45-mm weft to 50 mm. Higher speed is also a priority, but the faster you go, the lower the quality. Customers want 50 m/min and perfect tape quality. While this is not possible, we do continue to develop improvements."

Hexcel sees a continuing market for spread tow in woven fabrics and multiaxials, producing the latter in Leicester, UK. "We are still working on developments across all markets," says Coustaud. "This is a key technology, and we will keep pushing it." CW

ABOUT THE AUTHOR

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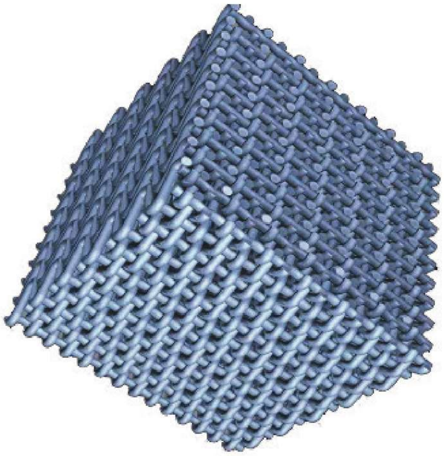
New Products



» THERMOSET RESINS & ADHESIVE SYSTEMS

Renewed version of legacy epoxy vinyl ester

Ashland (Dublin, OH, US) has launched Derakane Signia epoxy vinyl ester resins, a new take on the company's legacy corrosion-resistant thermoset line that design engineers and end-users have specified for FRP piping and tanks in safety-critical markets, such as chemical processing, air pollution control, mineral processing and water treatment. The new formula has a detection system that enables post-production verification of the product's use, in cases where the design integrity of contract-specified corrosion-resistant fiberglass-reinforced plastic (FRP) pipes and tanks is questioned.

Ashland says Signia is the first resin that enables an engineer who specs it for the integrity of a project to easily test and verify that the resin actually has been used in completion of the project.

The new resins are built on the same backbone as the legacy Derakane line and continue to offer the same corrosion-resistance and mechanical properties, improve manufacturing efficiency and reduce emissions with an styrene-suppressant technology. The resins are formulated to provide a no-prep surface, increased secondary bonding and reduced gassing for faster consolidation and less processing time and labor. Further, less odor and dust are said to provide a better overall work environment for employees, and its longer shelf life allows Derakane Signia resins to maintain workability for an extended timeframe. **ashland.com**

» TESTING, MEASUREMENT & INSPECTION SYSTEMS

Versatile industrial computed tomography system

YXLON International (Hamburg, Germany) has introduced the FF85 CT, a new computed tomography (CT) system. Broadly applicable, the CT system is capable to test both small and large parts as well as materials of varying densities. Features include a dual X-ray tube configuration and a high-precision granite manipulator that provides up to 7 axes. The FF85 CT also runs on the Geminy software platform already in use with the more compact YXLON FF20 CT and FF35 CT systems. Equipped with an open micro-focus tube capable of up to 225 kV as well as a mini-focus tube that operates at up to 450 kV and a choice of flat panel detectors, the FF85 CT is suitable for use not only with composites, but also aluminum, steel, additively manufactured components, mechatronic modules and geological and biological samples. Its applicability reportedly spans a myriad of industries, academic fields, research and development projects, and industrial processes and production control. The system's ScanExtend feature allows for horizontal measuring circle extension and is said to be ideal for scanning larger components or maximizing magnification on smaller components. **yxlon.com**

» CAD/CAM/CAE/FEA SOFTWARE/HARDWARE

Composites analysis/simulation platform

MultiMechanics' (Omaha, NE, US) MultiMech 18.0 simulation platform release contains several new features designed to improve its accuracy, speed and ease of use, including the following:

- *A data compression algorithm,* developed to speed analysis time by 1,000x. This proprietary tool allows computations that previously required days in HPC systems to be solved in minutes, on a laptop.
- *Optimization capability,* which can be used for both design optimization and microstructural model setup. Engineers simply need to provide MultiMech with a target mechanical response under different scenarios and the software will automatically find the microstructural design that best fits the desired response. This reduces the amount of time required to build microstructural models.
- *Native ABAQUS integration*, allowing ABAQUS users to convert their models to multiscale without learning a new software tool. ABAQUS users now can analyze behavior at the microstructural level and test the robustness of their designs by evaluating the effect of manufacturing-induced microstructural defects, thus enhancing their structural analysis and allowing them to get more accurate results.

The company says the speed increases are so dramatic that a very complex 3D multi-scale FE model with progressive damage that previously might require almost 30 days to run can, with MultiMech 18.0, be solved in about 30 minutes.

mulitmechanics.com | ansys.com | 3ds.com/products-services

» THERMOPLASTIC TAPE & SHEET MATERIALS

Continuous carbon fiber-reinforced PVDF

Solvay (Alpharetta, GA, US) has announced the launch of Evolite F1050, a market-first, high-performance thermoplastic composite with continuous carbon fiber reinforcement, intended for demanding offshore oil and gas applications. Evolite F1050 is a unidirectional tape that combines the chemical- and temperature-resistance of Solvay's Solef PVDF (polyvinylidene difluoride) with the inherent high-strength performance of carbon fiber reinforcement.

Typical oil and gas applications for Evolite F1050 include offshore hybrid flexible pipes and thermoplastic composite pipes (TCPs).

Solvay introduced Evolite F1050 at the Offshore Technology Conference (OTC), April 30-May 3, Houston, TX, US.
solvay.com

» FIBER/RESIN COMPOUNDS & PREPREGS

Natural fiber-based bulk molding compound

Lorenz Kunststofftechnik (Wallenhorst-Hollage, Germany) has developed a bulk molding compound (BMC) that combines a polyester resin matrix with jute, cotton or sisal fiber that the company says exhibits, depending on the composition, properties similar to conventional inorganic fiber-reinforced polymers (FRPs). The BMC's fiber length is selectable and the material can be processed via either compression or injection molding. The new BMC is based on Lorenz's existing BMC 0204, which already contains two eco-friendly materials: calcium-carbonate (as a bulking agent) and aluminum trihydrate (ATH, as a flame retardant). Fiber densities in this product range from 1.65 to 1.7 g/cm^3. In UL94 flammability tests, a 1.5-mm-thick test coupon extinguished within 10 seconds, which corresponds to a V0 classification. Target applications include automotive interiors and electronic components. Lorenz says all of its natural fiber thermosets can be recycled. The company also is working on an organic resin matrix to replace the currently used polyester resin. **lomix.de**

» COATINGS & COATING TECHNOLOGIES

SWNT-based conductive gel coat

A new line of conductive gel coats from **BÜFA Composite Systems** (Rastede, Germany) feature colored and glossy surfaces but also achieve surface resistivities as low as 10^3 Ω/sq in polyester-based gel coats. The achievement of both colorful appearance and conductivity is credited to the use of TUBALL single-wall carbon nanotubes (SWNTs).

Application of carbon black or graphite to resin formulas as a conductive additive negatively affects the natural fiber color, resulting in a black component surface, or dark grey at best. The outcome has been the stereotypical association of conductivity with black color.

"Switching to TUBALL nanotubes, produced by OCSiAl [Columbus, OH, US], has enabled us to overcome this drawback," says Elmar Greiff, project leader of Nanocomposites, BÜFA Composite Systems. "We now make conductive gel coats with previously unachievable color shades, including almost white."

Reportedly, the TUBALL single-wall carbon nanotubes' properties are such that even ultra-low loadings are sufficient to achieve the required permanent and stable conductivity. This provides a smooth and homogeneous fiber surface, without the negative influence on weathering that is usually associated with carbon black or graphite. Further, the nanotubes are supplied in the form of a paste that allows customers to handle them with standard application methods, without the need for any additional equipment.

There are some particular applications where nanotube-based gel coats can almost completely replace standard gel coats. An example is tooling gel coats. Due to the tribo-electric effect, a static discharge can occur when a GRP part is demolded. Even a minor flash can cause an explosion at a facility if there are any flammable materials nearby. BÜFA Composite Systems has made a breakthrough in industrial safety protection by developing a tooling gel coat with TUBALL nanotubes. Its surface resistivity of 10^6 Ω/sq is low enough to prevent any accumulation of electric charge. Another big advantage of such anti-static coatings is that they stop the surface from attracting the dust that would otherwise result in shorter working cycles and longer mold preparation times.

With their high performance and protective characteristics, conductive gel coats with TUBALL single wall carbon nanotubes are reportedly proving attractive in particular markets. Pipes and tanks for chemicals, ventilation systems, printing rollers, control boxes for electronics, floor coatings at industrial production plants, tooling gel coats and resins for composites, are just a few examples. In comparison with conventional coatings, says BÜFA, they have, thus far, demonstrated much better chemical resistance, with no reactivity drift, and their low contamination makes for an exceptionally clean production process.
buefa.de | ocsial.com

» SPRAYABLE ADHESIVES & SPRAY EQUIPMENT

Spray adhesive for infusion applications

3M (St. Paul, MN, US) has launched Hi Tack Composite Spray Adhesive 71 for composites fabricating applications that involve resin infusion processes, particularly in the industrial, marine and transportation markets. Product features include quick-to-tack capability, visual control and minimal intrusion during the resin infusion process. The adhesive also features a high solids content, so the product reportedly lasts longer and less is required for proper adhesion. 3M notes that infusion requires specific adhesive attributes, including compatibility between the resin and adhesive. Hi Tack Composite Spray Adhesive 71, in addition to clear, is available in green, allowing operators to visually ensure that the appropriate amount has been applied. The formula works with polyester, vinyl ester and epoxy resin systems. It also bonds fiber, fabric, wood, laminates and metals. 3m.com

» FIBER/RESIN COMPOUNDS & PREPREGS

New prepreg targets automotive leaf springs

Hexcel (Stamford, CT, US) has developed HexPly M901, a new prepreg formulated for use in molding composite automotive leaf springs. It is said to offer a cure time of less than 15 minutes, and produces a finished part with 15% higher overall mechanical performance compared to competitive prepregs, and enhanced fatigue properties. HexPly M901 provides a T_g of up to 200°C, following postcure. The unidirectional glass fiber-reinforced materials are available in a number of areal weights up to 1,600 g/m². hexcel.com

» FIBERS & FIBER REINFORCEMENT FORMS

New ±45° spread-tow fabric

TeXtreme by **Oxeon AB** (Boras, Sweden) has launched a new ±45° spread tow-based fabric called Spread Tow Grid. It can be tailored to meet specific needs, such as increasing torsional stiffness with minimum weight increase, or enabling radio transmittance through the fabric's openings. This material can be used in monolithic structures as well as for sandwich skins, in either prepregged form or dry form, for infusion. Because of its relatively low 21-g/m² areal weight, this version of the dry grid material can be wet out by capturing excess resin from neighboring prepreg plies. TeXtreme notes that even though the Grid fabric has designed gaps that resemble a lattice, its characteristics are similar to other TeXtreme Spread Tow reinforcements. When the Grid fabric is used by itself or in combination with other products in the TeXtreme family, the company maintains that optimized reinforcement solutions can be created that enable customers to reduce product weight while maintaining desired or required mechanical properties. textreme.com

PREPREG A WINNER IN MARINE TOUR DE FRANCE

Flexible cure meets "one-design" performance and cost targets.

The DIAM 24 trimaran (above) uses a CFRP mast (see close-up, below).

A ball-and-socket swivel enables mast movement during sailing and lowering for transport (shown below). The mast also can be disassembled into two pieces to accommodate trailer size limitations.

Source (all photos) | ADH Inotec

It's almost time for the 2018 Tour de France — no, not the one with bicycles, but the Tour de France à la Voile. It's a coastal sailing race, held this year July 6-22. Competitors will sail small trimarans, port to port, along the coast of France, from Dunkerque to Nice.

It's a one-design regatta. That means all sailors use identical boat and sails in a true test of sailing skill. Held since 1978, the race adopted a new boat design three years ago, called the DIAM 24. It's designed by VPLP (Paris and Vannes, France), a well-known naval architectural firm founded by Marc Van Peteghem and Vincent Lauriot-Prévos (read more about VPLP at **short.compositesworld.com/CarboFoil**). More than 90 DIAM 24s have been built, to date, by ADH Inotec (Port La Foret, France) and are sailing and racing on waterways in France, Switzerland, the UK, the Bahamas, New Zealand and the US. Reportedly easy to rig and launch, the trimaran's hulls feature glass fiber over PVC foam core, infused with polyester resin, with strategic use of carbon fiber reinforcement where needed. The beams, which join the three hulls, are of similar construction, but use an epoxy resin. The critical mast rotates around a metallic ball swivel fitting that enables mast movement during sailing as the crew adjusts sail position and attitude. The swivel also allows the mast to be laid down level with the deck for easy transport (see bottom photo). The mast is hand laid and cured in a female tool. It must be made in two sections that allow disassembly for transportation on a boat trailer. So it is made of sterner stuff.

The mast's uncored, monolithic laminates are built up from **Hexcel's** (Stamford, CT, US) trademarked HexPly M79 carbon fiber/epoxy prepreg, supplied through **Groupe Gazechim Composites Distribution** (Béziers, France). The laminate consists of longitudinal plies of unidirectional prepreg to achieve weight and stiffness targets, with an outer ply of M79 twill fabric prepreg to ensure both a good surface finish and impact-resistance.

HexPly M79 prepregs were specifically developed for the manufacture of very thick laminate sections with reduced exotherm. They can be used in combination with unidirectional fibers as well as multiaxial fabrics and they offer a flexible cure cycle so production times can be optimized to the builder's specific needs. In contrast to conventional prepreg systems, which typically require a 10-hour cure cycle at 80°C, HexPly M79 can be cured at 70°C for 8 hours, or can be processed more rapidly in 4 hours at 80°C. Says Vianney Ancellin, ADH Inotec's CEO, "The HexPly M79 prepreg system enables us to optimize our production efficiencies and still achieve the mechanical performance required for such a critical part."

For the same reasons, HexPly M79 glass/epoxy prepreg is used to build composite wind turbine blades. Cure cycle reduction is key to accelerating blade manufacture throughput; as the cycle times are reduced, the cost of blade production is also significantly reduced, says Hexcel. CW

Composites Events

June 13-14, 2018 — Novi, MI, US
CW amer*imold* 2018
amerimoldexpo.com

June 13-14, 2018 — Novi, MI, US
CW Composites Overmolding: A 1-minute cycle time initiative
compositesovermolding.com

June 20-21, 2018 — Nottingham, UK
Composites Innovation
compositesinnovation.com

June 21-23, 2018 — New York City, NY, US
Composites Pavilion – American Institute of Architects Convention 2018
conferenceonarchitecture.com

June 27-28, 2018 — Chicago, IL, US
The Future of Composites in Transportation
jeccomposites.com/knowledge/international-composites-agenda/future-composites-transportation-jec

June 27-28, 2018 — Las Vegas, NV, US
Global Composites 2018
globalcompositesconference.com

July 10-12, 2018 — Nottingham, UK
ICMAC 2018 – 11th Int'l Conference on Manufacturing of Advanced Composites
icmac2018.org

July 15-21, 2018 — Paris, France
ICCE-26, 26th Annual Int'l Conference on Composites/Nano Engineering
ice-nano.org

July 16-22, 2018 — Farnborough, UK
Farnborough International Air Show 2018
farnboroughinternational.org

July 31-Aug. 1, 2018 — Shanghai, China
Global Automotive Lightweight Materials Asia 2018
galm-asia.com

Aug. 21-23, 2018 — Detroit, MI, US
Global Automotive Lightweight Materials Summit
global-automotive-lightweight-materials-detroit.com

Sept. 5-7, 2018 — Novi, MI, US
SPE Automotive Composites Conference and Exhibition (ACCE)
speautomotive.com/acce-conference

Sept. 5-7, 2018 — Shanghai, China
China Composites Expo 2018
chinacompositesexpo.com

Sept. 10-12, 2018 — Toulouse, France
SpeedNews 19th Annual Aviation Industry Suppliers Conference in Toulouse
speednews.com/aviation-industry-suppliers-conference-in-toulouse

Sept. 10-15, 2018 — Chicago, IL, US
IMTS 2018
imts.com

Sept. 11-13, 2018 — Southampton, UK
SAMPE Conference 18 Southampton
sampe-europe.org/conferences/sampe-conference-18-southampton

Sept. 11-12, 2018 —Chicago, IL, US
AM2018: Additive Manufacturing Conference at IMTS
additiveconference.com

Oct. 2-4, 2018 — Tampa, FL, US
IBEX 2018
ibexshow.com/show-info

Oct. 3-4, 2018 — Loughborough University, UK
Composites in Sport
compositesinsport.com

Oct. 15-18, 2018 — Dallas, TX, US
CW CAMX 2018
thecamx.org

Oct. 30-31, 2018 — Bremen, Germany
ITHEC 2018 – 4th Int'l Conference and Exhibition on Thermoplastic Composites
ithec.de/home

Nov. 6-8, 2018 — Stuttgart, Germany
Composites Europe
composites-europe.com

Dec. 4-6, 2018 — La Jolla, CA, US
CW Carbon Fiber 2018
carbonfiberevent.com

MANUFACTURING SUPPLIERS

TESTING

RECRUITMENT/HELP WANTED

SHOWCASE

ADVERTISING INDEX

Low weight on the high seas

A new, award-winning composite shipbuilding material saves fuel, increases car shipping capacity.

By Karen Mason / Contributing Writer

Lightweighting a heavyweight

Siem's *Cicero*, an ocean-going car carrier shown here in Uljanik's shipyard, now travels the high seas with greater stability and offers its owner greater economy because its three uppermost roll-on/roll-off decks now feature composite floor panels. Source | Uljanik

» "First of its kind" and "best in class" are terms often misappropriated. But they're fitting labels for Siem Car Carriers' (London, UK) *Cicero*, a roll-on/roll-off (ro/ro) shipping vessel that now carries up to 6,900 cars per trip across the Atlantic Ocean. Designed and built by the Uljanik Group (Pula, Croatia), the *Cicero* features a 2018 JEC Innovation Award-winning composite innovation that reportedly makes it the most fuel-efficient vessel in the pure car truck carrier (PCTC) class of ro/ro ships.

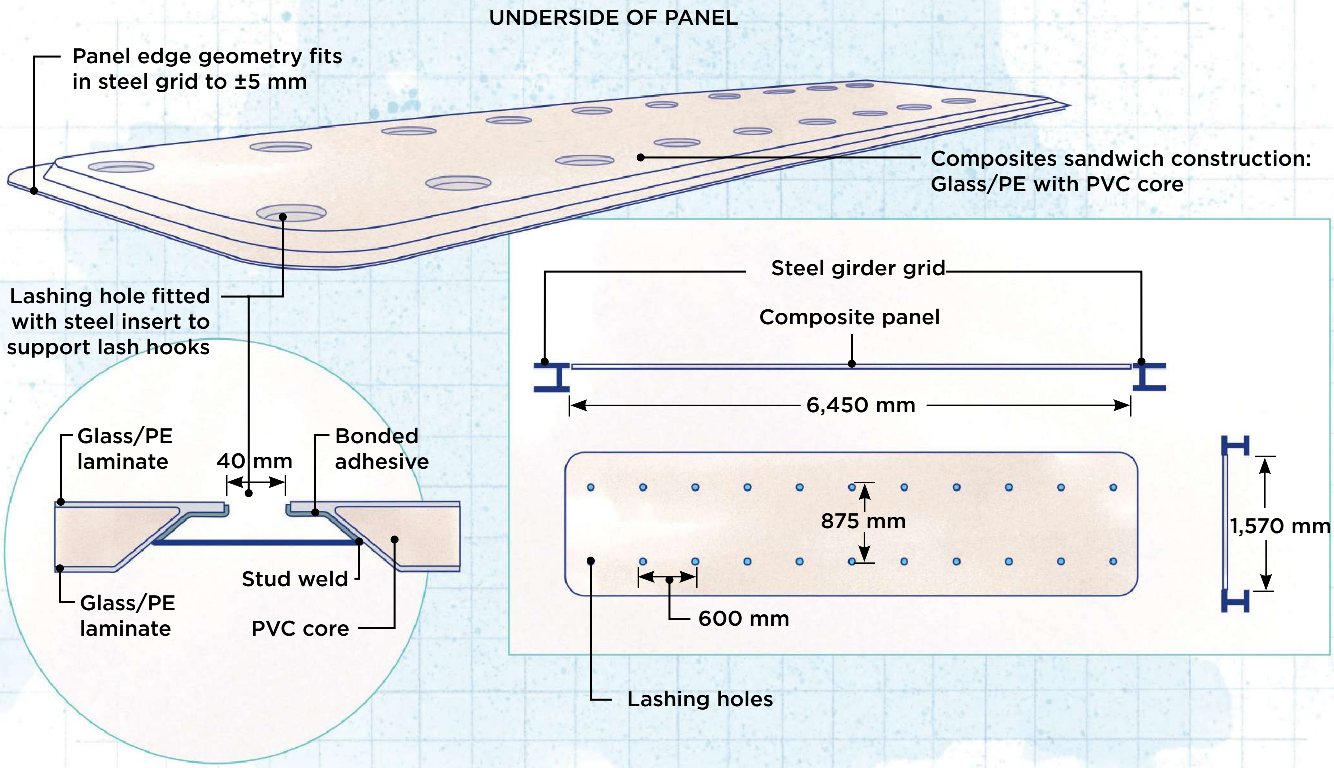
More than 1,000 PVC foam-cored glass/polyester sandwich panels form the floors of the top three of the ship's 13 vehicle decks, making *Cicero* not only the first vessel of its kind to use composite floor panels but, according to core material supplier Diab International AB (Laholm, Sweden), also the first extensive shipping industry application of sandwich composites.

Design challenges

Challenges were encountered immediately in the project's sheer size and the physical performance requirements for the decks. The 200m long, 32m wide *Cicero's* top three decks total 12,600m^2 and must accommodate, total, about 1,500 cars.

To achieve required strength and stiffness, conventional steel decks use steel plating stiffened by transverse web frames and longitudinal stiffeners. In the case of the composite decking, however, fire safety requirements established by the International Convention for the Safety of Life at Sea (SOLAS), a maritime treaty that sets safety standards for merchant ships, required that the deck's structural integrity still be fully ensured by structural steel components. For that reason, the composite panels were designed to provide enough strength and stiffness to minimize the under-panel steel support required. The new decks, therefore, support the composite floor panels with a grid of steel frames into which the panels are fastened with flexible bolted joints. Under-panel support is provided by two small transverse steel bars.

For this first composite deck application, Uljanik used one design for all the panels, optimized for the worst load case, which occurs at the foremost panel, where hydrodynamic forces are



DESIGN RESULTS | **Uljanik Composite Deck Panels for Ro/Ro Shipping Vessel**

- Composite decks are 25% lighter than steel decks, for a weight savings of 230 tons.
- Lower vertical center of gravity reduces ballast requirement by 575 tons.
- Weight savings enables 805-ton increase in payload or 4.5% reduction in fuel consumption.

Illustration / **Karl Reque**

greatest (due to the ship's movement through the seas), explains Vito Radolović, Uljanik's senior designer. "For future designs," he points out, "there could be two or more different panel types to reduce weight and cost even more."

Finite element analysis (FEA) revealed that the optimum sandwich panel faceskin design would be a three-ply biaxial laminate (±45°, 0/90°, ±45°). Although a combination of quadraxial and biaxial products also was considered, Radolović reports the all-biaxial schedule produced the necessary performance properties at a more desirable price point.

FEA results also favored poly vinyl chloride (PVC) over polyethylene terephthalate (PET) and polyurethane (PUR) for the foam core material. The Uljanik team designed the core using a mixture of Diab's Divinycell H80 and H100 PVC. The higher density H100 meets the needed strength requirements at the panel's edges, while the lower-density H80 is still sufficiently strong for the panel's interior but saves weight and cost. The three decks use a total of 7,700m^2 of H80 and 2,300m^2 of H100.

The floor panel design also needed to accommodate lashing fixtures that help immobilize cars during transport. Each panel features 22 holes into which lashing hooks are inserted (see drawing, above). Lashing holes are reinforced with 2-mm steel plate inserts, which are bonded to the laminate so that the hook contacts only metal. The final version of the steel insert closes the bottom of the lashing hole with a steel plate to improve fire safety.

Shipbuilding challenges

Although the ship meets SOLAS fire safety requirements independent of the composite panels (i.e., dependent exclusively on the steel structural elements), the ship's owner commissioned a fire safety assessment to demonstrate that the alternative design (with composite decks) achieves fire safety equal to that of the conventional design (with steel decks). Conducted by RISE Fire Research AS (Boras, Sweden), it revealed composite deck disadvantages that included the potential for greater linear (same deck) fire growth rate, more compromised panel structural integrity, »

■ **Vacuum infusion process**

A technician oversees application of vacuum consolidation to one of the 1,043 floor panels produced by fabricator Brzoglas for the *Cicero's* three reconfigured decks. Source | Uljanik

and toxic smoke due to hydrochloride creation from burning PVC. But, the panels also demonstrated delayed deck-to-deck fire spread, due to the panels' insulating effects and the closed lash holes. This is expected to improve both cargo and crew safety. Additionally, the composite panels — unlike steel plates — insulate crew members from the heat of a below-deck fire, so escape routes can cross panels on overhead decks. Another challenge, Radolović says, was how to integrate the composite panels into the shipbuilding process. "The main challenge was to adjust the composite part to standard shipbuilding practice in a steel-oriented production environment," he recalls. Specifically, Uljanik carefully scheduled assembly to finish all "hot works" (welding, cutting and other heat-producing operations) before the composite panels were installed, thus making panel installation a late-stage process. Additionally, assembly tolerances where steel and composite parts meet had to comply with standard shipbuilding practice of ±5 mm.

Manageable economics

To make composite decks economically feasible, Uljanik succeeded in finding fabrication materials and processes that result in a production cost equal to that of traditional steel decks. For the panel laminates, polyester, vinyl ester and epoxy resin systems were considered, and polyester chosen for its cost and its properties favorable to vacuum infusion, the panel fabrication method, also chosen for its cost-efficiency. Further, using well-established materials and simple geometries in the floor panels enabled shorter lead times as well as improved manufacturing reliability and quality.

Fabricator Brzoglas d.o.o. (Kaštel Novi, Croatia) produced the panels for Uljanik, using SAERTEX (Saerbeck, Germany) biaxial non-crimp glass fabric. "The factory helped us by producing the exact width of rolls that we needed," says Brzoglas' project lead Petar Rogulj. The panels' flat design made positioning of the glass "not a problem," he adds. "We just applied it on a horizontal mold." Brzoglas selected Polynt Composite USA Inc.'s (Durham, NC, US) trademarked Polylite isophthalic polyester resin. Lamination, vacuum infusion, cure and demolding took about 4 hours per 6.45m-by-1.57m panel. In the end, 1,043 panels were molded. Panel skins achieved 74% fiber content by weight. Each panel weighs 155 kg.

High watermark

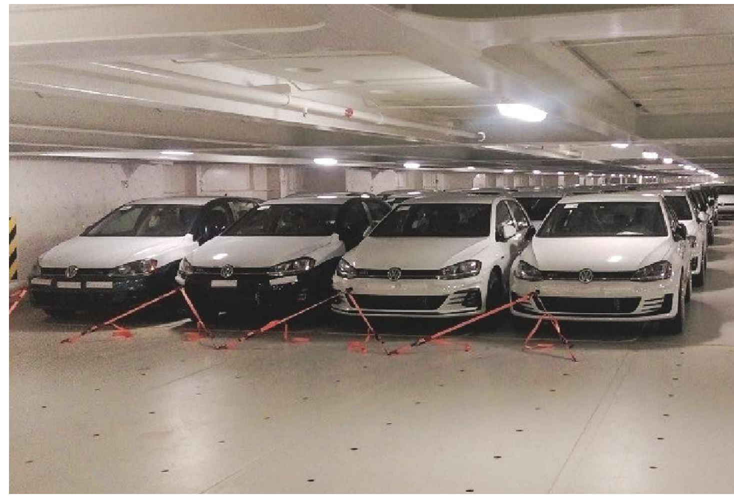
Because the floor panels reduce weight in the ship's uppermost decks, weight savings are doubly beneficial, Radolović says. First, the three composite decks are 25% lighter than three steel decks, saving 230 tons. Second, the lighter upper

■ **Finished gridwork for composite floor panels**

The steel grid for the new decks stands ready for composite panel assembly. Framing for all three decks can be seen. Source | Uljanik

Ready for transport

A completed deck with its composite panels secured in the steel framework. Lash holes can be seen in the floor panels and in the underside of the panels in the deck above. Source | Uljanik



Cars lashed in place

The lash attachments provide this simple means to immobilize cars during transport. The three decks with composite floor panels provide space for as many as 1,500 of the ship's total 6,900-car capacity. Source | Uljanik

decks lower the ship's vertical center of gravity (VCG). Therefore, less ballast is needed to ensure the ship's stability. "Because the weight reduction is in the upper zone," he notes, "we were able to reduce the weight of ballast in the double bottom, for about 2.5 times the deck weight reduction." The result is that the Siem *Cicero* has a 4.5% (equal to approximately 2.1 MT/day or more than 2,000 liters/day) comparative reduction in fuel consumption. Alternatively, for the same fuel consumption as a ro/ro with all-steel decks, the *Cicero* may increase its payload by as much as 805 tons.

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As measured by fuel consumption per car-equivalent unit (CEU), a standard fuel-economy rating for PCTC vessels, the *Cicero* reportedly has the lowest in its class. This means lower operating cost for Siem Car Carriers, which is using the *Cicero* to transport primarily Volkswagen cars from Europe to North America. The composite decks also will reduce maintenance costs because they do not corrode. Environmental benefits springing from the fuel savings include reduced fuel oil consumption and carbon dioxide emissions.

Uljanik is building a sister ship of Siem's *Cicero*, using the same design. Delivery is scheduled for this year.

Continuing developments

Since 2006, Uljanik has focused R&D efforts on lightweight ship structures, and this emphasis continues as the company participates in European Union (EU)-sponsored programs and collaborates with composites industry partners. Initial funding for the *Cicero* decks design was through the European Commission's (EC's) DE-LIGHT transport program (2006-2010). Today, Uljanik remains an active participant in the RAMSSES Project — Realization and Demonstration of Advanced Material Solutions for Sustainable and Efficient Ships — which also helped fund Uljanik's work leading to the *Cicero's* composite decks.

RAMSSES is part of the EC's Horizon 2020 Work Program, a €77 billion (~US$95 billion), seven-year (2014-2020) EU research and innovation funding program. RAMSSES is funding ongoing work on cargo deck systems, including advancements in Uljanik's composite floor panels, as well as pultruded composite beams, joints and outfitting elements (e.g., lashing devices, lifting elements). The work includes development of fabrication, assembly, outfitting and repair processes for these composite elements. The RAMSSES Web site points out that the composite panel solution may be applicable not only to other ships but to deck plating for bridges or offshore platforms as well.

Perhaps most encouraging about this project is that it demonstrates, once again, that the intelligent use of composites not only reduces weight and operational cost in a specific application at no additional manufacturing cost, but also generates additional benefits that cascade through a project to completion, with ripple effects that prolong a product's service life, reduce the need for maintenance and repair and protect the environment. CW

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