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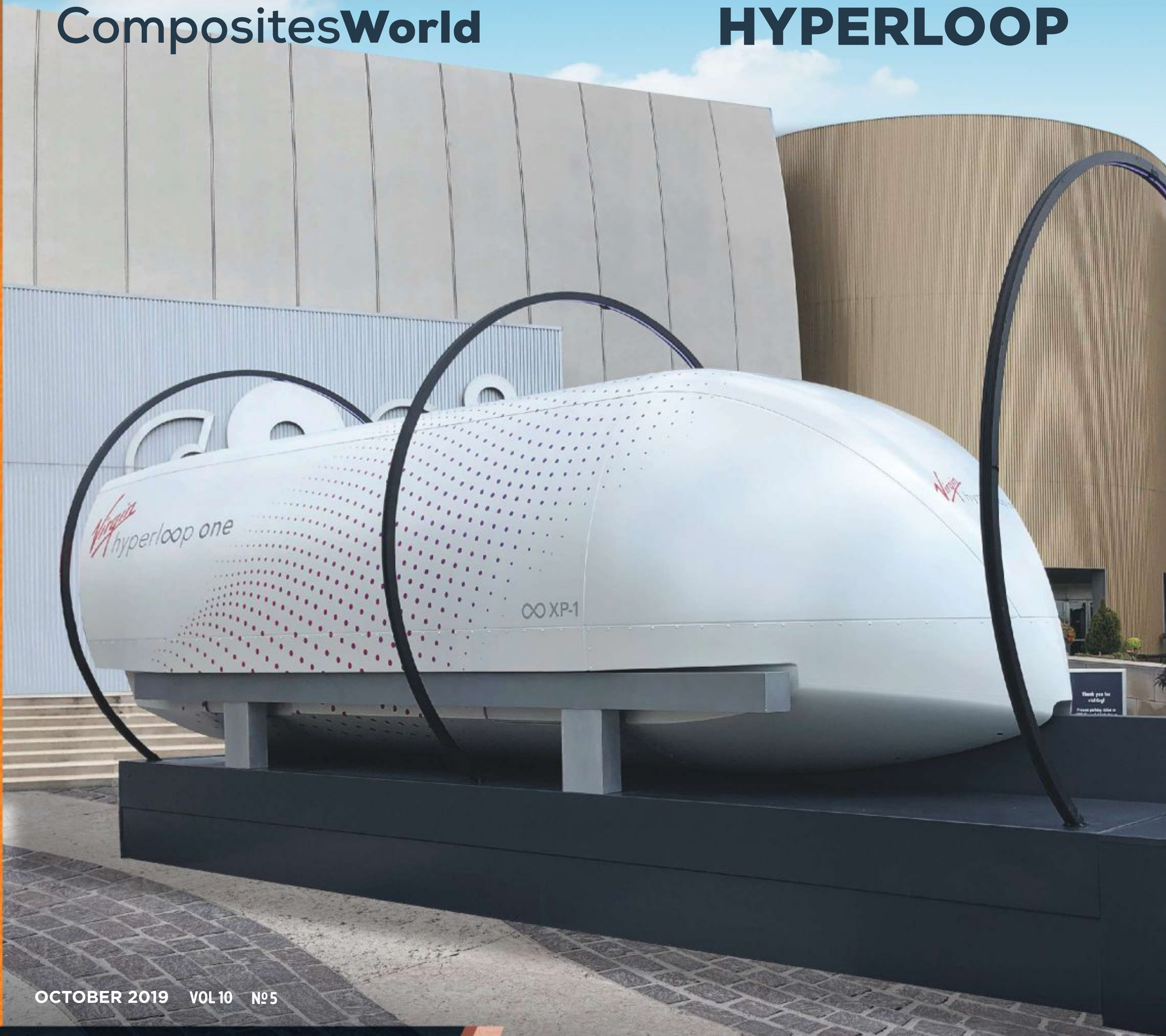
Building future mass transport:
COMPOSITES USE IN HYPERLOOP



OCTOBER 2019 VOL 10 № 5

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OCTOBER 2019 / Vol: 5 Nº: 10

COLUMNS

FEATURES

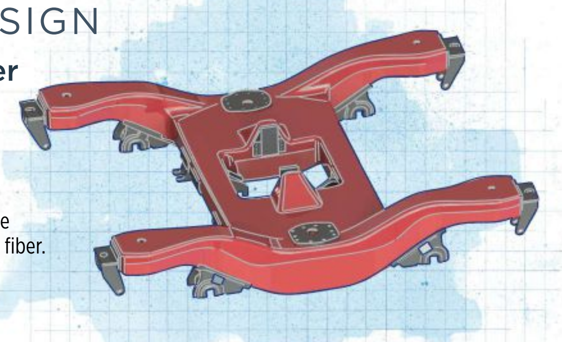
» DEPARTMENTS

» ON THE COVER

Virgin Hyperloop One is among the companies developing test pods and tubes for Hyperloop travel. Virgin Hyperloop's test pod, *XP-1*, is constructed from structural aluminum and a carbon fiber composite shell. Shown here, the test pod was recently on display at COSI (Columbus, Ohio, U.S.). See p. 18.

CW Photo | Scott Francis

FOCUS ON DESIGN



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EDITOR-IN-CHIEF	Jeff Sloan jeff@compositesworld.com
SENIOR EDITOR	Ginger Gardiner ggardiner@compositesworld.com
SENIOR EDITOR	Scott Francis sfrancis@compositesworld.com
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ADVERTISING PRODUCTION MANAGER	Becky Taggert btaggert@gardnerweb.com
GRAPHIC DESIGNER	Susan Kraus skraus@gardnerweb.com
MARKETING MANAGER	Chris Saulnier csaulnier@gardnerweb.com

CW CONTRIBUTING WRITERS

Sara Black	sara@compositesworld.com
Dale Brosius	dale@compositesworld.com
Michael LeGault	mlegault@compositesworld.com
Peggy Malnati	peggy@compositesworld.com
Karen Mason	kmason@compositesworld.com
Amanda Jacob	ajacob@compositesworld.com

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» Not too long ago, when my three boys were all much younger and in various stages of education and extracurricular activities, my wife and I, like many parents in our position, often found our evenings and weekends consumed by the chore of delivering or retrieving one of our boys to or from school, a practice, a game, a concert or a friend's house. The logistics of transportation alone were an exercise that was both physically and mentally daunting. And all around us were signs of a family environment that bespoke of the busy-ness in which we lived: Hastily consumed meals, laundry accumulated in intimidating piles, a dishwasher run at least daily, teenage possessions — backpacks, shoes, computers, phones — littering our house.

What will the future of aerocomposites look like after the 787 and the A350?

I remember, at some point during this time in our lives, talking about these challenging aspects of the modern family with the father of a friend of one of my boys. He lamented the difficulty of it all and pined for a day when he would not be so burdened by the work of parenthood. "I can't wait for this part of my life to be over," he said.

"Really?" I asked. "Because you know that if you don't have clothes to wash and carpools to drive and dinners to prepare and dishes to wash, it means your kids are gone — off to college or whatever their next step in life is. I'm not in a hurry for that day to come."

But, of course, such days do come. Sometimes we see them coming from a long ways away, and sometimes they sneak up on us. Sometimes we are prepared (or, we think we are) and sometimes we are knocked off balance.

I am reminded of this aspect of parenthood because, believe it or not, if you look carefully, it's not hard to see a future in which we refer to production of the composites-intensive Boeing 787 and the Airbus A350 in the past tense. How, you ask? Well, it's in the numbers.

Let's start with the 787. To date, Boeing has received orders for 1,464 787s. At my last check, in mid-September, Boeing had delivered 882 of these orders, which leaves a backlog of just 582 planes. Boeing is currently manufacturing 14 787s a month from its two assembly plants, one in Everett, Wash., and the other in North Charleston, S.C. If Boeing does not receive another 787 order, it will take the company 42 months — 3.5 years — to produce the backlogged orders. Of course, Boeing *will* receive more 787 orders, but probably only in small increments that will be relatively easy to fill quickly. In short, Boeing will probably face, sooner than later, the prospect of ending 787 production.

The situation at Airbus is similar. The A350 program has 913 planes on order, and 300 of those have been delivered. That leaves a backlog of 613 planes. Airbus is producing 10 A350s per month, but is expected, soon, to increase that to 13 per month. Even if we are conservative and assume a production rate of 10 per month, Airbus will meet its backlogged orders in 62 months — 5 years. At 13 per month, that number is trimmed to 4 years. Like Boeing, Airbus will receive more A350 orders, but those will also be incremental.

All of this is, of course, important to Boeing and Airbus, but it's equally important to the aerospace composites supply chain, because as these programs wind down, there will be a desire to replace them with something else — a program that is similarly composites-intensive. Such programs *are* on the horizon, including Boeing's New Midsize Aircraft (NMA), as well as replacements for the A320 and the 737. However, even if these programs were launched tomorrow, it would be several years before materials and equipment could be committed to production.

It appears, therefore, that there looms on the aerocomposites horizon a gap of uncertainty as the 787 and the A350 wind down and new-program manufacturing ramps up. It remains to be seen what effect this gap will have on the industry, but it's certainly fair to say that the largesse bestowed on composites manufacturing by the 787 and the A350 programs will be sorely missed, and not easily replaced.

JEFF SLOAN — Editor-In-Chief

Getting past "the stall"

» When I am home, I fire up the grill at least once per month, even during the winter — and multiple times per week during the summer. Sometimes it's a quick steak or salmon on the gas grill, and other times it's cooking on my ceramic Big Green Egg smoker using the "low and slow" approach at temperatures between 225°F and 275°F. In fact, I outlined this column while I had a whole chicken cooking away in the Egg, making the main course for a Thursday dinner. I don't use the smoker only in the summer months, though — I also make turkey in November and pastrami in March. And once you've had smoked prime rib for Christmas dinner, you'll never want to roast it in the oven again. Trust me, it's that good.

I grew up in Texas, where barbecue is a tradition and beef brisket is king. I've also traveled enough to appreciate smoked pulled pork shoulder. Both meats require a whole day to properly prepare, so about six to 10 weekends each year I smoke either a brisket or a couple of pork shoulders. Both cook at 225°F, the lower end of the smoking range, so they go on early in the morning. I insert a couple of temperature probes (just like thermocouples in curing composites), with a goal to hit about 203°F as the finish temperature before pulling the meat off to rest before slicing or shredding.

> After years of rapid improvements, the composites industry seems to have hit its own version of "the stall."

Once these big hunks of meat go on the smoker, they start to heat up internally at a rate that suggests they'll be done way before dinner. But somewhere around the four- to six-hour mark, when the internal temperature reaches 150 to 170°F, the temperature stops climbing. And sits there. For hours. For those new to this phenomenon, panic starts to set in. Will this get done to feed the hungry group I invited over for dinner tonight?

This point in the cook is called "the stall," and there are multiple theories about what is happening, but the most scientific explanation is that the meat is going through *evaporative cooling*, losing moisture, and indeed, at some point in time, the internal temperature will resume its rise to the desired endpoint. Some purists insist on waiting it out (which could make total cook times more than 12 hours), but I, as well as many competition cooks, rely on what is called the "Texas crutch." After the meat hits the stall, and has seen smoke for about six hours, it has built a good crust, or "bark," so we wrap the shoulder or brisket tightly in aluminum foil and return it to the smoker. Shortly, the magic happens, and in about two to three hours, you reach completion. The foil traps the moisture, creating a *braising* fluid, and ensures a succulent, melt-in-your-mouth outcome. And happy dinner guests!

So, aside from the aforementioned use of thermocouples, what does all this barbecue talk have to do with *composites*? Fair question. Frankly, after years of rapid improvements in composites manufacturing technology, the composites industry seems to have hit its own version of "the stall." Thermoset curing times are significantly lower than when BMW introduced the carbon fiber-intensive *i3* and *i8* in 2013, yet no other global automotive OEMs have followed suit, and none appear to be on the verge. Injection overmolding and stamping with thermoplastics have matured significantly as well, but this technology is not yet widespread. We have multiple processes with the capability of producing 100,000 to 200,000 parts per year from a single mold, but where are the high-volume applications?

It's not just automotive. In aerospace, we have new technology to infuse and cure large airfoils outside the autoclave, and we've seen plenty of innovations to speed fabrication of thermoset and thermoplastic fuselage structures. Such technologies may allow for production of 60-100 single aisle aircraft per month, but Boeing and Airbus seem nowhere close to announcing composites-intensive replacements for the 737 and A320 models.

Across the spectrum, we have improved the techno-economic competitiveness of composites and through modest volume applications, continue to see industry growth. Just not the big *game-changing* quantities that always seem to be "right around the corner." Like the barbecue purists, we can simply keep fueling the fire, patiently waiting for the outcomes we know should eventually come. Or, even better, can we find a composites version (or versions) of the Texas crutch and get there much sooner? 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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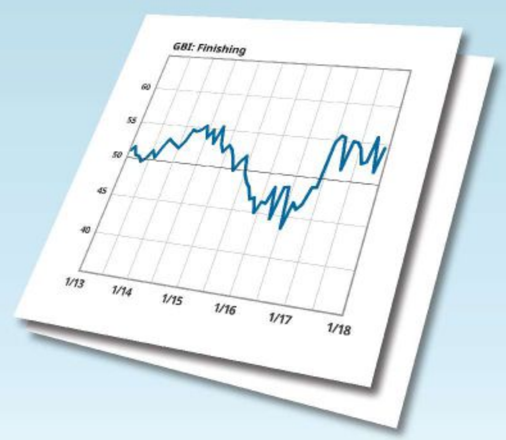

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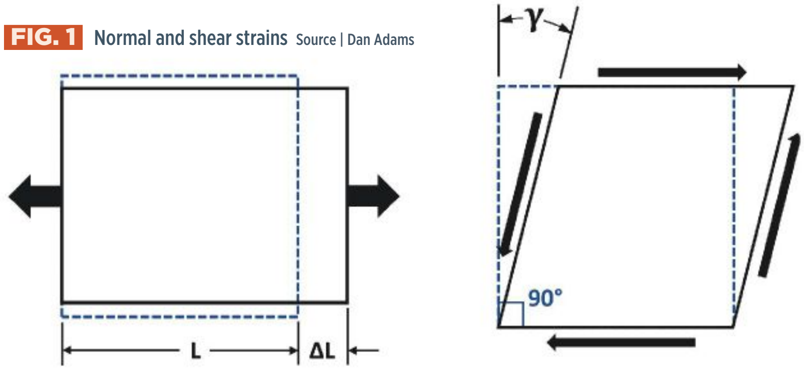
Strain measurement in composites testing

» Measuring strains during mechanical testing can be challenging, particularly when initially developing the capability. Additionally, there are multiple strain measurement methods to choose from, each with advantages and disadvantages. In this column, we focus on the aspects of strain measurement that are of importance when testing composites, particularly polymer matrix composites (PMCs).

For starters, strain is the measure of a material's deformation during loading. *Normal strain* is a measure of the elongation or contraction of a material in a particular direction during loading (Fig. 1 A). Normal strain measurements are required for determining the modulus of elasticity *E* and Poisson's ratio *ν* of a material. Additionally, *shear strain* γ is an angular deformation measurement defined as the change in a 90-degree angle at a point in the material during loading (Fig. 1 B). Shear strain measurements are used in determining the shear modulus *G*. For use in calculating these stiffness properties, strain measurements are obtained during the initial portion of the test, before the material begins to yield or fracture. Standardized test methods provide detailed procedures indicating the range over which strain measurements are to be obtained. Additionally, a material's limiting strain values, corresponding to yielding or ultimate failure, are often required. For PMCs, which typically experience a more brittle failure, the strain at *failure* is often obtained.

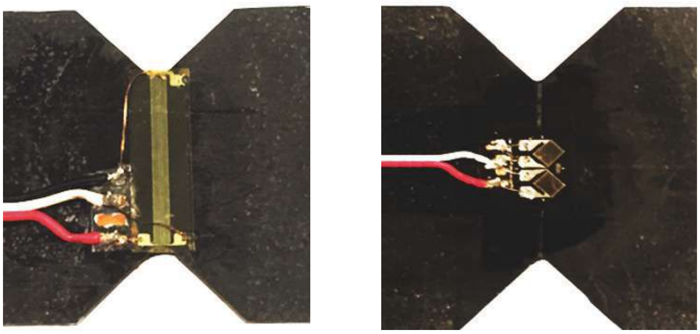
FIG. 1 Normal and shear strains Source | Dan Adams



A. Normal strain, ε
ε = ΔL / L (mm/mm)

B. Shear strain, γ
γ = Change in 90-degree angle (radians)

FIG. 2 Strain gaging options for V-notched shear specimens Source | Dan Adams



A. Narrow notch-to-notch strain gage

B. Small centered strain gage

Currently, the two most common strain measurement methods are strain gages and extensometers. Strain gages are thin metallic foil grids permanently bonded to the specimen surface. As the strain-gaged specimen is loaded and undergoes strain, the electrical resistance of the strain gage changes. This change in resistance is measured using specialized conditioning electronics, and then converted to a strain value using a manufacturer-provided *gage factor*. Strain gages are designed to be highly sensitive to strains in the designated gage direction, and relatively insensitive to strains in other directions.

When using strain gages with PMCs, attention must be given to two additional considerations. The first is the electrical resistance of the strain gage. Since strain gages are effectively precision resisters, the amount of heat produced depends on the electrical resistance of the strain gage (typically 120 or 350 ohms) and the excitation voltage used during operation. The effect of excessive heat generation is most noticeable when attempting to zero the strain gage output prior to testing; the strain reading will drift as the strain gage heats and expands the specimen locally. Therefore, the use of higher-resistance (350-ohm) strain gages coupled with reduced excitation levels is recommended when testing PMCs.

The second consideration is the selection of a proper strain gage size and shape, which can be important when testing PMCs because of *material-produced* and *specimen-produced* strain variations. Material-produced strain variations are of concern when testing textile composites due to their periodic geometry and undulating fiber tows. A sufficiently large strain gage is required to measure the *average* strain corresponding to the bulk material response. Additionally, specimen-produced strain variations are of concern when using the V-notched shear test methods for composites, ASTM D5379[1] and ASTM D7078[2]. For accurate shear modulus measurement using these V-notched test specimens, either a narrow notch-to-notch strain gage must be placed between the notch tips (Fig. 2 A) or a relatively small strain gage must be placed in the center of the test section where the average strain value occurs (Fig. 2 B). Note that although strain gages cannot *directly* measure shear strain, normal strain measurements obtained in designated directions can be used to *calculate* shear strains using equations of strain transformation.[3]

FIG. 3 Contacting extensometer for tension testing

Source | Epsilon Technology Corp.

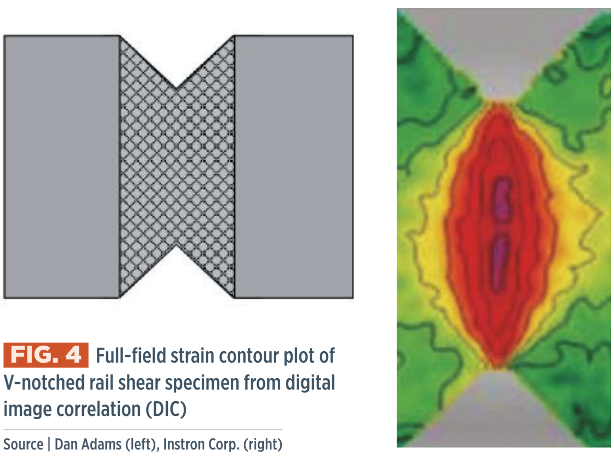


FIG. 4 Full-field strain contour plot of V-notched rail shear specimen from digital image correlation (DIC)

Source | Dan Adams (left), Instron Corp. (right)

For these V-notched shear test methods, the shear strain is calculated by summing the magnitudes of the normal strains measured at +45 and -45 degrees using the equation: $y = |\varepsilon_{+45}| + |\varepsilon_{-45}|$.

In addition to material property determination, strain gages are also used to monitor specimen alignment during testing. For example, back-to-back strain gages on the front and back specimen surfaces are used during compression testing to check for bending and buckling during loading. In fact, the two ASTM compression test methods for PMCs, ASTM D3410[4] and D6641[5], require that back-to-back strain measurements be used to determine the percent bending when performing compression tests.

In addition to strain gages, extensometers are also commonly used for strain measurement when testing. The most common type, contacting extensometers, usually contact the specimen using knife edges and are held in place with clips, springs or rubber bands (Fig. 3). Extensometers measure the average strain over a prescribed gage length, typically 25 millimeters. Although back-to-back extensometers are available for monitoring specimen bending, the short gage length (13 millimeters) commonly used in the compression test methods mentioned above makes the use of extensometers difficult. However, biaxial extensometers can be used for measuring the axial and transverse strains required for determining the modulus of elasticity E and Poisson's ratio v. Currently, however, there are no commercially available extensometers for use with the aforementioned V-notched shear tests.

Unlike strain gages, extensometers are reusable, and require less time and expense to install. However, they have a considerably higher initial cost and can be damaged when the specimen fails. Since high-energy specimen failures are common during mechanical testing of PMCs, the extensometer is often removed from the specimen prior to failure. This prevents damage to the extensometer, but also means that failure strain cannot be measured.

Two types of non-contacting extensometers are also available: laser-based extensometers and video extensometers. In laser extensometry, the specimen is illuminated using visible laser light, and a digital camera is used to record the change in distance between reflective markers placed on the specimen surface. Similarly, video extensometers use a high-resolution digital camera to accurately track the location of contrasting marks produced on the specimen surface to calculate strain. Both types can continue to measure strains up to specimen failure, and the range of permissible test temperatures can be extended since the digital camera may be placed outside the environmental chamber.

Finally, in addition to strain gages and extensometers, digital image correlation (DIC) has also become a promising method for strain measurement. Similar to video extensometry, DIC records the relative displacements of a random pattern of markers on the specimen surface using a high-resolution digital camera. In DIC, however, full-field strains are calculated within a region of interest, allowing for the generation of strain contour plots (Fig. 4) and subsequent strain averaging over any desired "gage area" of the specimen. The use of DIC appears promising, and suitable calibration methods are in the process of being developed and standardized within ASTM International (West Conshohocken, Pa., U.S.). CW

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ABOUT THE AUTHOR

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

Composites Index contraction slowed in August

August 2019 – 49.4

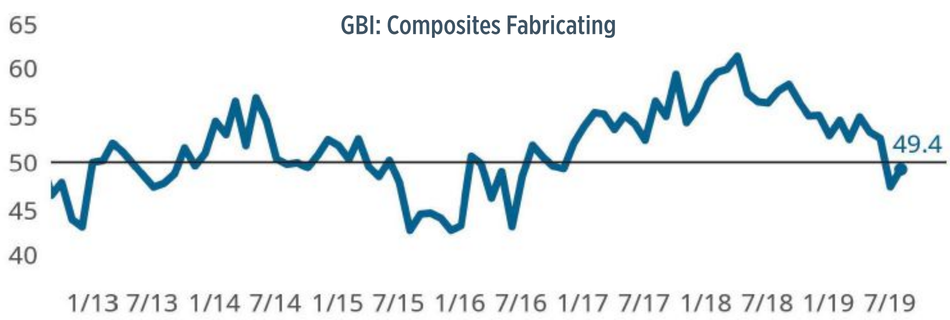
The Composites Index registered 49.4 in August, implying slowing contraction over the prior month. Index readings above 50 indicate expanding activity, while values below 50 indicate contracting activity. The further away a reading is from 50, the greater the change in activity. Gardner Intelligence's review of the underlying data revealed a surprise expansionary reading in export business activity in August. The Index — calculated as an average of its components — was raised higher by expansionary readings in production, supplier deliveries and exports, and was pulled lower by employment, new orders and backlogs.

The August Index indicated an unusually large eight-point spread between production and new orders. Since records began in 2011, the spread between new orders and production has often been very small, as fabricators often quickly adjust production to new orders. The combination of increased production despite weak new orders activity was apparent in August's backlog data, which reported another month of contraction.

Lastly, it should be noted that August's combination of an expansion in exports coupled with a quickening contraction in total new orders is rare, as it suggests that domestic demand for composite goods contracted during the month. Since mid-2018, the Composites Index has regularly reported the opposite, that contracting exports have typically been offset by expanding domestic demand. CW

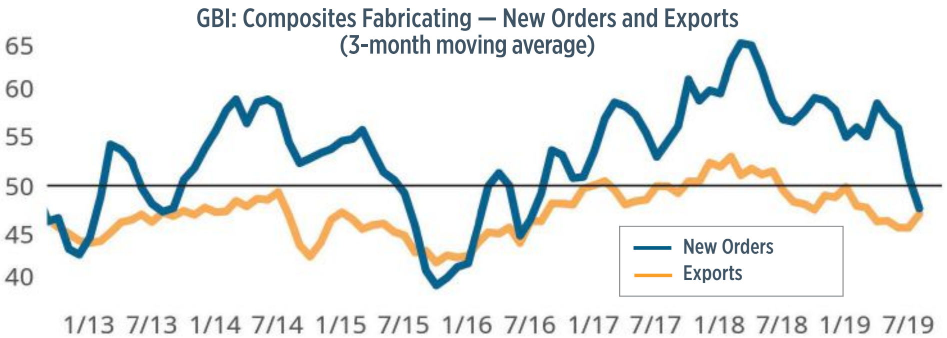
ABOUT THE AUTHOR

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



Slowing contraction

The Composites Index registered slowing contraction during the month as the Index moved higher towards a 'no change' reading of 50. Exports and production along with supplier deliveries all reported expanding activity.



Exports supported total new orders for the first time since 2017

August exports expanded faster than new orders for the first time since mid-2017, which has rarely occurred since records began in 2011. Increasing trade tensions since 2018 have depressed export activity, making fabricators more dependent on domestic orders.

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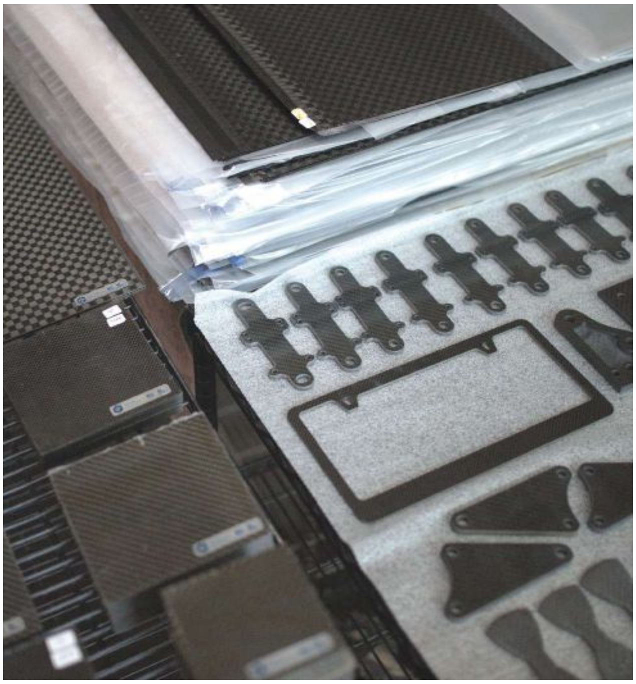
Q&A with Ryan Olliges and Jaysen Harris at Elevated Materials, development of plug-and-play AFP/ATL from a university startup, a review of automotive trends from SPE ACCE 2019 and more.

Q&A with Ryan Olliges & Jaysen Harris, Elevated Materials

CW senior editor Scott Francis talks to Ryan Olliges, founder and CEO, and Jaysen Harris, co-founder and CTO, of Elevated Materials, a contract manufacturer working to make reclaimed aerospace carbon fiber available for a variety of industries. They give their perspective on what their company is doing to keep carbon fiber out of the landfill and about the products the company offers. To listen to the full interview, go to compositesworld.com/podcast or download CW Talks on Google Play or iTunes.

Q: Elevated Materials has a little bit of an unconventional back story. Can you tell us how the company got its start and about your mission?

A: The idea came to me [Ryan] from this business when I was in school at USC [University of Southern California]. I was part of the rocket and propulsion lab and we got a call from a large aerospace company saying, "Hey, we're going to be getting rid of some carbon fiber, and if nobody comes and gets it, it's going to be going straight into the landfill." And at that time, our budget was pretty small and we were looking to get a roll of material and pay about $5,000 for it, so we were ready to go and pick this stuff up and save some money for the next couple of years. And when we show up, they came out with something like $500,000 worth of material … and we said, "Wow, we'll take all of it!" … That got me excited about the potential for putting this material to good use, and so I started working on making skateboards out of carbon fiber. I built a press — it took me about a year to get that press up and running — and I started selling carbon fiber skateboards to friends around campus, and ended up getting introduced to a professor who was well-connected in the aerospace industry, our other co-founder Greg Autry. … We launched the skateboards on Kickstarter and founded that business [121C] in 2015. Throughout that process of building carbon fiber skateboards, we started getting requests from other customers to do custom projects and we decided that to really scale this business and be a solution for the composites industry, what we needed to do was start contract manufacturing parts for tons of different industries.



Learn more about Elevated Materials' process and approach for manufacturing various products from recycled carbon fiber at short.compositesworld.com/ElevMat. Source | Elevated Materials

Q: Tell me a little bit about how you source the material that you use.

A: All the material that we get today is aerospace trim scrap. When a company is cutting something on a ply cutting table, they pull out material from their roll, lay it out on the ply cutting table, cut out the shapes they need to build whatever part they're making, and then the leftover material just gets balled into trash bags and thrown away. And that's where we come in. We go and collect those trash bags from the companies we work with, and bring [the material] back to our facility, where we lay it out on cutting tables and start cutting out unique shapes out of it to make the stuff that we're making. In addition to that, we also collect expired rolls or out-of-spec rolls, because those are fairly easy to work with and they still have a good useful life for products like skateboards or racing drones, and in some cases, other parts as well. … And we've really built the systems around making that efficient and making sure this resource is not wasted, and we're really hoping to move much further down the line of solving this problem for the industry.

Q: What kind of measures do you take to prevent material from expiring? How are you able to turn it around as quickly as you do?

A: So we have an onsite freezer where we store some of the rolls that we collect, but for the most part, the trim scrap that we collect is collected on a daily, or every-other-day, or weekly basis, so it's still in pristine condition when we get it in terms of outlife. … So just collecting at a rapid pace and making sure our throughput is quick enough that we're able to use the material within its shelf life, and then having a process in place for identifying when the material is no longer useful through tracking and through identification, making sure we don't use any material that's past its outlife.

Q: Can we go through the list of products that you produce? What sets your approach apart from other companies working with reclaimed materials?

A: Starting with skateboards, we launched the brand 121C to create a new skateboard, and really that was a proof of concept that we were able to take a trash material and turn it into something useful. And from there we started getting requests for products — custom brackets, sheets, frames — and decided that the next step was to start producing stock flat sheets. And because we now sit with an inventory of stock flat sheets, we're able to deliver parts to the drone industry, the aftermarket auto industry, and build parts like cam covers and water pump covers and valve covers, and different bracketry for it.

Q: Can you speak a little more about what all you're doing in the automotive space?

A: We are doing what I consider to be more cosmetic custom parts. We are working with the aftermarket industry at this point in time. However, there are lots of opportunities for internal components during primary manufacture to decrease weight, especially in electronic vehicles.

AEROSPACE

Startup introduces plug & play AFP/ATL for cost-effective composites manufacturing

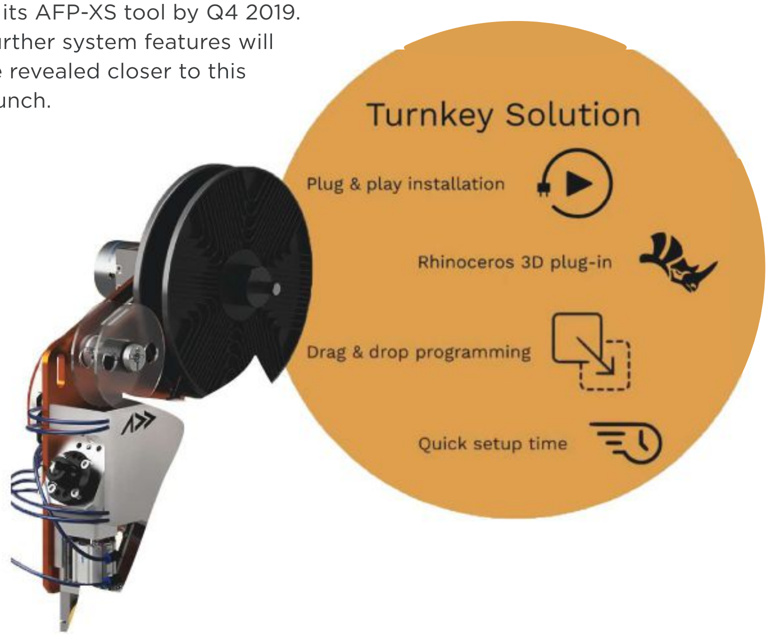
Addcomposites is a research project startup from Aalto University, Finland, specializing in an accessible automated composite manufacturing system. It has developed a plug-and-play solution called AFP-XS for automated fiber placement (AFP)/automated tape laying (ATL) processes, that mounts onto any existing robotic arm. By developing every subsystem, control and software element in-house, Addcomposites provides the lowest cost to consumers while maintaining aerospace-grade quality.

This cost and performance allows manufacturers to simply rent the toolhead for their facility and convert already-purchased robotic arms into a high-quality ATL/AFP system. The AFP-XS system works with dry fiber, thermoset prepreg and low-temperature thermoplastic composite tape, producing lightweight, complex-shaped structures that are optimized for load-carrying and efficiency.

Addcomposites was started as a research project in 2017 with the goal to combine all the necessary steps of AFP — fiber feed, tape cutting, impregnation and placement — into one single step. Its initial offering, AFP-XS, is the first step in that direction.

Addcomposites is currently based in the European Space Agency Business Incubator Center (ESA-BIC, Espoo, Finland) outside of Helsinki, and is conducting pilot production trials with new space companies to validate the technology for a variety of applications. The company is supported by an ESA-BIC grant and ESA-BIC customers, but will close its seed round funding by early Q4 2019.

Addcomposites has just completed a composite manufacturing automation project with the largest composite manufacturer in Finland and is preparing for the commercial launch of its AFP-XS tool by Q4 2019. Further system features will be revealed closer to this launch.



AUTOMOTIVE

SPE ACCE explores new trends, changing consumer behaviors

The theme of the Society of Plastics Engineers (SPE, Bethel, Conn., U.S.) 19th annual Automotive Composites Conference & Exhibition (ACCE) in Novi, Michigan, Sept. 4-6, was "Composites — Forming the Future of Transportation Worldwide." Much of the programming reflected a growing interest from transportation OEMs in the role composites technologies can play in next-generation mobility.

The first keynote, delivered by Cynthia Flanigan, chief engineer of Vehicle Research & Technology for Ford Motor Co. (Dearborn, Mich., U.S.), speculated about potential changes in the way society uses vehicles. Global population and overcrowding of urban areas are stimulating need to reshape modes of transportation and approach mobility differently than society has in the past. She theorized that we are moving from a society based on individual vehicle ownership to one where carsharing and e-mobility could become the dominant automotive models. Flanigan focused on five key areas that are driving change in the industry: sustainability, emerging materials, additive manufacturing, advanced processes and design, and artificial intelligence.

From reducing ocean plastic and atmospheric CO_2 to the use of blockchain technology to link data, track materials and enable sorting and recycling, to looking to nature for inspiration in new materials, Flanigan spoke of sustainability and environmental responsibility as key drivers of technology trends. She spoke of emerging materials, such as graphene and aerogels, as enabling the future, contributing to lightweighting and improving the consumer experience through noise dampening. She also spoke of advances in additive manufacturing and its role in the composites space, offering the opportunity for higher throughput and advancements in processing.

A featured talk from Clay Maranville of Ford Motor Co. echoed many of Flanigan's ideas, but with a focus on automotive interiors. Maranville looked at megatrends affecting mobility, from consumer behavior such as carsharing to manufacturing industry trends like additive manufacturing, generative design, embedded sensors and blockchain. He indicated a shift in design thinking is happening and that automotive interior design is becoming increasingly focused on the consumer experience.

The conference also featured a prominent programming track about sustainability, including several presentations on technologies aimed at enabling electric vehicles. Specifically, sheet molding compounds (SMCs) aimed at enabling battery systems in electric vehicles were featured heavily at the show. For example, Pritesh Patel of Evonik (Parsippany, N.J., U.S.) discussed an epoxy resin-based SMC battery case for electro-mobility vehicles, and Ian Swentak of Hexion (Columbus, Ohio, U.S.) showcased a phenolic resin SMC-based battery box optimized for fire resistance.

This flame-retardant battery box cover constructed of phenolic SMC from Hexion retains 60-70% of its material properties after aggressive fire testing.
CW Photo | Scott Francis

The composites-intensive 2020 Chevrolet Corvette *Stingray.* *CW* Photo | Scott Francis

Gulay Sherhatkulu, senior VP, Performance Materials North America, BASF Corp. (Wyandotte, Mich., U.S.), delivered the conference's second keynote, painting a picture of a new generation of car consumers whose main concerns are connectivity, comfort, convenience, the environment and sustainability. She spoke of a value chain shifting from a focus on the end consumer to fleet-based transportation companies, which would result in changes to R&D and design thinking, as well as a need to get products to market more rapidly.

Just how drastically the automotive sector will change remains to be seen, but it's clear that the industry is exploring what changing consumer behavior will mean for the future of automotive transportation. Growing populations and traffic congestion indicate that the way we travel as a society will have to evolve. Several conversations echoing around SPE ACCE considered the effects of carsharing on car manufacturing, such as the design of more modular components to make parts easy to replace, materials with low noise vibration and harshness (NVH) and materials with antibacterial qualities — all of which could mean a large role for composite materials.

At the same time, many people see individual car ownership as part of our identity. The final keynote at SPE ACCE was about composites use on the new Chevrolet Corvette *Stingray*, which features a range of composite structures, including primary body structural panels, underbody structural panels, Class A composite body panels, air ducts and a carbon fiber pultruded rear bumper assembly. For Corvette customers and many other drivers, a personal connection with the car remains, and it's a safe bet that carmakers will continue to capitalize on that connection as long as they can.

CW / MONTH IN REVIEW

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

Arevo introduces 3D-printed carbon fiber unibody bike frame and rim
Arevo unveiled its 3D-printed carbon fiber unibody production bike frame and 3D-printed thermoplastic rim at Eurobike 2019.
8/27/19 | short.compositesworld.com/Arevo_rim

Tex Tech Industries acquires coating, laminating and defense businesses of Highland Industries
The newly renamed Tex Tech Coatings is a supplier of coated and laminated products across end markets, including aerospace, defense, industrial and medical.
8/23/19 | short.compositesworld.com/TexTech

Embraer develops electric propulsion demonstrator aircraft
The first flight of the 100% electric propulsion single-aisle aircraft is scheduled for 2020.
8/20/19 | short.compositesworld.com/Embraer_EP

BAC launches graphene-enhanced carbon fiber-intensive supercar
Briggs Automotive Co.'s Mono R is the first production car in the world to fully incorporate the use of graphene-enhanced carbon fiber in every body panel.
8/16/19 | short.compositesworld.com/BAC_car

ULA selected for Dream Chaser launches
The composites-intensive *Dream Chaser* will launch aboard ULA's *Vulcan Centaur* rockets for cargo resupply and return services to the International Space Station, starting in 2021.
8/19/19 | short.compositesworld.com/ULA_Dream

Park Aerospace Corp. breaks ground on facility expansion
The 90,000-square-foot expansion to the Kansas facilities includes upgraded hot-melt film and tape lines, and a new R&D lab.
8/20/19 | short.compositesworld.com/Parkexpand

CSP to supply Ford with composite engine shroud
The SMC dual-wall dash shroud, developed for the 2020 Ford *Explorer*, is said to reduce powertrain noise, vibration and harshness (NVH) compared to metal.
8/13/19 | short.compositesworld.com/CSP_Ford

Prodrive Composites updates, expands U.K. facility
New cutting machines, in-house 3D printers, an additional autoclave, CNC machines and expanded production space aim to increase productivity.
8/13/19 | short.compositesworld.com/Prodrive

AFRL, Boeing, Thermwood partner to develop low-cost, autoclave-capable tooling
The project is using Thermwood's vertical, large-scale 3D printer to build a carbon fiber-reinforced demonstrator tool for an aircraft fuselage skin.
8/13/19| short.compositesworld.com/LSAM_tool

Rolls-Royce, Reaction Engines, BAE Systems to develop hypersonic propulsion systems
The two-year program is in collaboration with the U.K.'s Ministry of Defense.
7/31/19 | short.compositesworld.com/RR_RE_BAE

Covestro steps up investments in thermoplastic composites
The company introduces a new R&D tape line and hybrid injection molding machines for new fiber and resin combinations.
7/31/19 | short.compositesworld.com/CovestroTP

NASA announces U.S. industry partners for Moon, Mars programs
The partnerships will advance the commercial space sector and help bring new capabilities to market that could benefit future NASA missions.
7/31/19 | short.compositesworld.com/NASA_10

Teijin develops foldable fiber-reinforced plastic structure

Teijin Ltd. (Tokyo, Japan) and GH Craft Ltd., Teijin's composites design, development, prototype and evaluation unit, have developed ORIBAKO, a new foldable fiber-reinforced plastic (FRP) structure, said to be commercially available by 2022.

Source | Teijin Ltd.

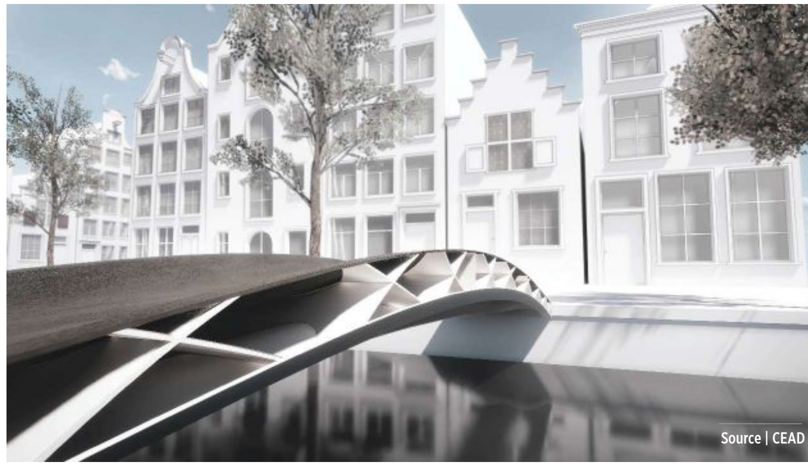
ORIBAKO comprises a polyhedron structure made of FRP panels and hinges said to be easily transported, deployed, folded away and stored. FRP with soft resin is used for the hinges to provide elasticity, flexibility and durability as well as a tight seal. The product can be produced in a variety of shapes and sizes, such as small boxes or simple architectural structures. The FRPs used for the panels and the hinged sections are designed for seamless integration to ensure airtightness and a smooth surface with no ridges. Depending on the application, the composition of materials used for the panels and hinges of the ORIBAKO can be adjusted to incorporate properties such as sound absorption, heat insulation or shock absorption, Teijin says.

Teijin and GH Craft say they will continue to enhance ORIBAKO's properties by expanding the range of materials used in its construction, aiming to make it commercially available by 2022. Expected applications of ORIBAKO include temporary indoor spaces with external solar panels, and for delivery containers requiring easy and rapid cargo changes and a tight seal.

INFRASTRUCTURE

FRP bridge prototype uses large-scale 3D printing

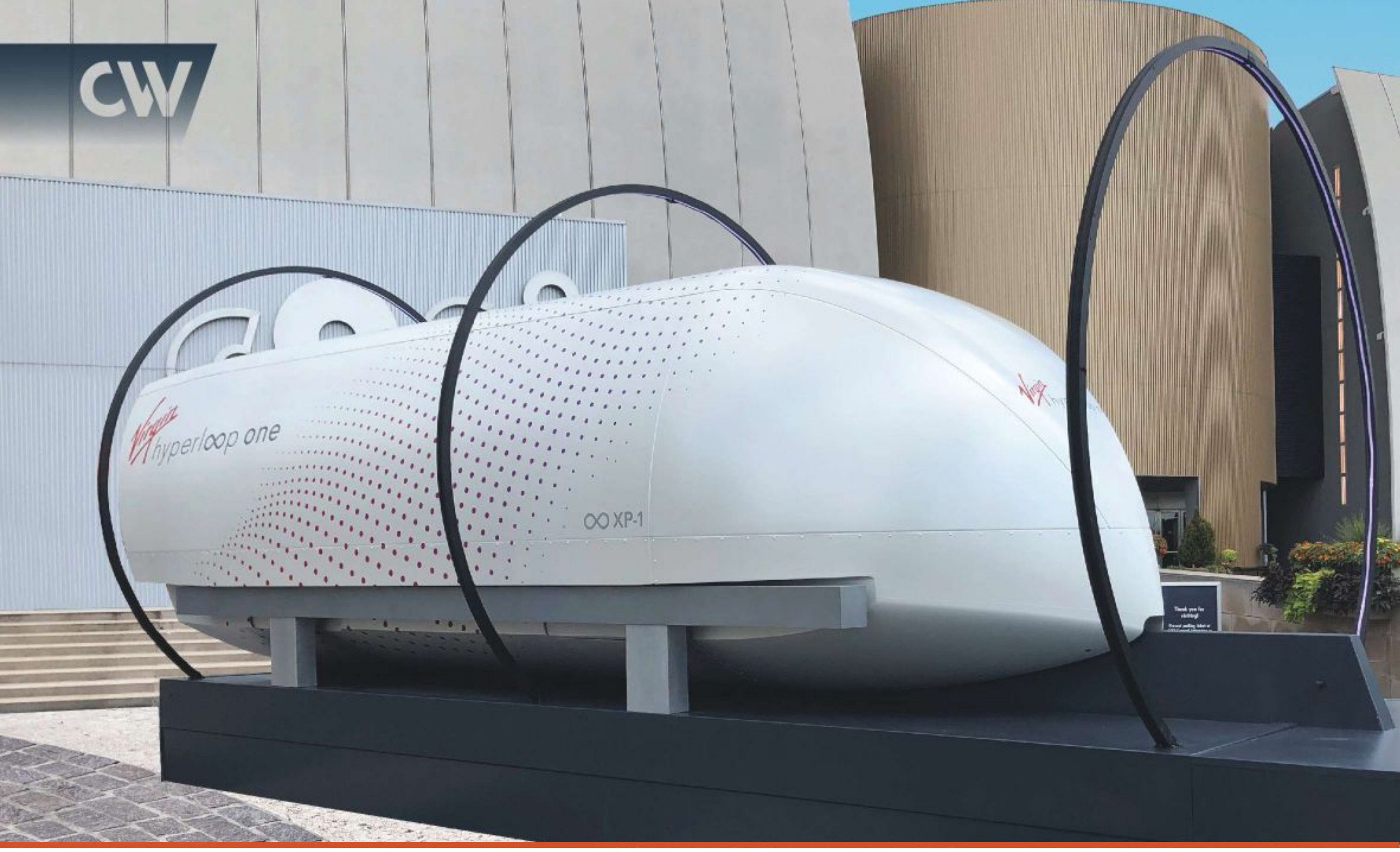
Royal HaskoningDHV (Amersfoort, Netherlands), CEAD (Delft, Netherlands) and DSM (Amsterdam, Netherlands) have designed a lightweight, 3D-printed, fiber-reinforced polymer (FRP) pedestrian bridge prototype. The bridge consists of a glass fiber-filled thermoplastic PET (Arnite) reinforced with continuous glass fibers during the 3D printing process. This combination is said to offer high strength, versatility and sustainability.


Source | CEAD

To build the bridge, Royal HaskoningDHV, an international engineering and project management consultancy, partnered with DSM, a global science-based company whose specialties include 3D printing materials, and CEAD, supplier of 3D printing equipment including large-scale composite additive manufacturing machines.

According to the companies, sensors are included in the design, enabling them to build a digital twin of the bridge that can predict and optimize maintenance. The sensors are also said to incorporate functionalities like monitoring environmental aspects and providing real-time reports on bridge conditions.

The companies used their combined experiences in generative design and predictive modelling to design a more efficient bridge, optimizing the printing process and eliminating waste material.



Into the Hyperloop

The role of composites in the fifth mode of transport.

By Scott Francis / Senior Editor

Hyping the Hyperloop

Virgin Hyperloop One's *XP-1* test pod on display at COSI (Columbus, Ohio, U.S.).

CW Photo | Scott Francis

» Since SpaceX (Hawthorne, Calif., U.S.) founder and CEO Elon Musk published his Hyperloop Alpha white paper in 2013, the concept of a Hyperloop system has captured the imagination of the public as a possible mode of transportation. Meant to compete with commercial continental air travel between cities separated by approximately 900 miles or less, the concept envisions use of a capsule — also called a "pod" — to transport passengers and freight at high speeds through a tube or series of tubes. The tubes are designed to reduce air resistance using a partial vacuum; the pods, either magnetically levitated or running on air casters, enjoy a nearly frictionless environment and can, theoretically, reach speeds of 600–760 mph (965-1,200 km/hr.).

Musk's Hyperloop concept was released as an open-source design meant to encourage others to build upon the ideas and further develop this transportation system. The concept has inspired several commercial companies and student teams to create Hyperloop prototypes, which are in various stages of development and testing. Virgin Hyperloop One (VHO, Los Angeles, Calif., U.S.), for example, has built a test pod as well as a full-scale Hyperloop test track, and has completed hundreds of test runs to date. The company has yet to develop a pod that can accommodate passengers. Meanwhile, Hyperloop Transportation Technologies (HyperloopTT, Culver City, Calif., U.S.) boasts the first full-scale Hyperloop passenger vessel and a 320-meter test track in Toulouse, France.

Although the Hyperloop concept evokes comparisons to traditional rail-based modes of mass transit, because of the low air pressure and high speeds involved, Hyperloop pods actually have more in common with aircraft fuselages. Traveling in a Hyperloop tunnel exposes the pods to speeds and air pressure conditions similar to those of an aircraft traveling at an altitude of around *200,000 feet*. To handle the demanding loads, high speeds and internal pressures, the pods require materials that combine stiffness and strength with light weight. Most of the Hyperloop prototype vehicles developed to date have employed carbon fiber composites in some way.

"With the lightweight needs [of the Hyperloop], the solution will be composites," says John Jackson, technical support engineer for Toray Advanced Composites (Langley Mill, Nottingham, U.K.). "With the demand we are experiencing from Airbus and Boeing for structural thermoplastics, and the general aerospace market trend for OOA [out-of-autoclave] and automated thermoplastics, we foresee this being reflected in the development of the Hyperloop pods."

A built-in proving ground

SpaceX has continued to support Hyperloop through its Hyperloop Pod competition, which has been held annually at the company's Hyperloop test track in Hawthorne, Calif., U.S., since its inception in 2015. The competition gives teams the opportunity to compete with a subscale prototype Hyperloop vehicle to demonstrate the concept's feasibility. Judging criteria take into account design, pod requirements and safety for the qualifying rounds. Qualifying pods are raced in the main competition. In the past, sub-competitions have been part of the event, focusing on aspects such as levitation, but the most recent competition focused on top speed alone.

In 2019, SpaceX held its fourth Hyperloop Pod competition. Twenty-one teams were selected to compete, with four qualifying for the final round on July 21 — Swissloop of ETH Zürich (Zürich, Switzerland), EPFLoop of Ecole polytechnique fédérale de Lausanne (Lausanne, Switzerland), Delft Hyperloop of Delft University of Technology (Delft, Netherlands), and TUM Hyperloop of the Technical University of Munich (TUM, Munich, Germany). TUM Hyperloop, formerly known as WARR Hyperloop, won the competition, setting a new record with a top speed of 463 km/hr. (288 mph). The team might have further exceeded the record speed, but its pod suffered damage due to derailment of one of its propulsion modules, and was forced to brake early.

TUM Hyperloop constructed its pod using »

■ **Students setting records**

TUM Hyperloop won SpaceX's 2019 Hyperloop Pod Competition in July, setting a new record with a top speed of 463 km/hr. (288 mph). Source | TUM Hyperloop

■ **A composite shell**

VHO's test pod, the XP-1, is constructed from structural aluminum and a carbon fiber shell.

CW Photo | Scott Francis

Smart composites

HyperloopTT's passenger capsule features a proprietary dual-layer smart composite material created using carbon fiber and embedded sensors.

Source | Hyperloop Transport Technologies

carbon fiber prepregs from SGL Carbon (Wiesbaden, Germany). Based on design and material optimizations, the carbon fiber shell of the current pod weighs around 10% less than that of the team's previous model (5.6 kilograms compared to 6.1 kilograms).

"We have replaced some parts that used to be made of plastic with carbon," says Paloma García Guillen from the TUM team. "This has made the shell around a kilo lighter, but at the same time extremely stable to withstand the high pressure and centrifugal forces in the tube."

"It's impressive to see what the [TUM team] achieved in such a short amount of time," says Dr. Christoph Ebel, head of the Lightweight and Application Center at SGL Carbon. "From the idea, to prototype development, to the finished part, the team only needed a few months. Behind the Hyperloop pod design are numerous innovative ideas based on modern lightweight construction, challenging to realize technologically."

The Hyperloop Pod competition helps foster constant redesign and innovation. The teams rework their pod designs each year and receive support from material suppliers and technology companies.

Swissloop's second-place pod — the *Claude Nicollier*, named after the first Swiss astronaut — is run by a linear induction motor that itself prompted an innovation award from SpaceX. The pod's chassis comprises carbon fiber, resulting in a total weight of only 200 kilograms.

EPFLoop's prototype, the *Bella Lui*, features a U-shaped carbon fiber skeleton with the motor on the inside and battery packs on the outside. A small pressurized chamber on top of the pod protects the electronic components, and the entire pod is covered in a carbon fiber skin. According to team leader Lorenzo Benedetti, EPFLoop used biaxial prepregs XC411 and RC200 from Gurit (Wattwil, Switzerland), as well as the company's

M80 and M200 foam cores.

Delft Hyperloop's *Atlas 02* pod comprises a full composite chassis and carbon fiber battery case. The vehicle was manufactured with automated tape laying (ATL) technology and support from Airborne (The Hague, Netherlands) using Toray Advanced Composites' unidirectional carbon fiber/epoxy prepregs.

Each year of the Hyperloop Competition, the pods get faster and set new records, but reaching the 600-700 mph speeds that Hyperloop promises has yet to be accomplished. The consensus is that longer tracks are needed for the pods to reach top speed. SpaceX's current track is about one mile long, but following the July 2019 competition, SpaceX announced plans to build a new Hyperloop track to be used for the 2020 pod competition. According to a Tweet from Musk, the new tunnel will be 10 kilometers (6.2 miles) long and will include a curve.

Built like an airplane

TransPod is working with carbon fiber aircraft manufacturer Blackshape Aircraft to develop its passenger pod. Source | TransPod

Passenger pods

Among the commercial Hyperloop companies working to develop passenger pods, set up test tracks and garner support for proposed routes, VHO and HyperloopTT are arguably the two leaders, with TransPod (Toronto, Canada) also in the running.

VHO's Hyperloop uses electric propulsion to gradually accelerate pods. A propriety magnetic levitation system allows them to glide at aircraft speeds through low-pressure tubes. VHO's test pod, the *XP-1*, comprises a structural aluminum chassis surrounded by a carbon fiber shell. The test vehicle, which is not designed for passenger use, has achieved speeds of up to 240 mph on VHO's 500-meter test track, known as DevLoop (Las Vegas, Nev., U.S.).

According to Ryan Kelly, marketing manager for VHO, the design of the company's Hyperloop pod was approached much like that of an airplane fuselage. The stress of loads, extreme speeds and internal air pressure all have to be taken into account for vehicle design and materials selection. While VHO has not yet »

■ **In the mix**

HyperloopTT's tubes are a combination of steel, concrete and carbon fiber.

Source | Hyperloop Transportation Technologies

developed a passenger pod, Kelly expects that composites will play a role in the design, just as they have in the test pod.

HyperloopTT boasts the first full-scale Hyperloop passenger vessel. The pod, *Quintero One,* is constructed almost completely out of a composite material HyperloopTT calls Vibranium (a nod to the fictional material conceived by Marvel Comics for Captain America's iconic shield). The material is, in fact, a specially made dual-layer smart composite material created using carbon fiber and embedded sensors. HyperloopTT's 32-meter-long capsule is made up of 82 carbon fiber composite panels and was built at the aerospace facilities of HyperloopTT's partner Airtificial (Madrid, Spain), a company that specializes in the design, engineering and manufacturing of sensor-enabled structures made of composite materials. Airtificial was formed by the merger of Carbures (El Puerto de Santa María, Spain), a composite structures manufacturer for the transportation and infrastructure sectors, and civil engineering company Inypsa (Madrid, Spain) in 2018.

Like VHO's *XP-1,* TransPod's vehicle design is also similar to an airline jet fuselage and is driven by magnetic propulsion. The passenger pod structure and shell are being co-developed by Blackshape Aircraft (Monopoli, Italy), which produces carbon fiber composite aircraft for the general aviation sector.

"Composites form certain parts (but not all) of the structure," says Ryan Janzen, co-founder and chief technical officer of TransPod. "It's all about being strategic with the different materials."

■ **Gathering support**

USDOT officials visit HyperloopTT's research facility in Toulouse, France.

Source | Hyperloop Transportation Technologies

Hyperloop infrastructure

In addition to the pods, there is also potential for composites use in the Hyperloop tubes themselves. Composites are, of course, lighter than traditional materials and still able to meet structural requirements, but they are also less susceptible to the elements. While weather conditions could potentially compromise the structural integrity of a steel or concrete tube over a period of time, a composite tube is less likely to suffer problems caused by thermal expansion or corrosion. Many of the existing Hyperloop test tracks have, for the most part, been built of either steel or concrete, but there are companies exploring the use of advanced materials.

HyperloopTT's tubes, like its passenger capsule, are manufactured by Airtificial and are a combination of steel, concrete and sensor-embedded carbon fiber. In 2018, Airtificial signed a contract for €19.9 million with HyperloopTT to manufacture a 5-kilometer pilot section of Hyperloop tube. Tube manufacturing and installation will be done after completing analysis of tube prototypes that are installed at HyperloopTT's research facilities in Toulouse, France.

Composites play a role in TransPod's tube design as well: "The TransPod infrastructure includes a tube, and many other materials inside and outside the tube segments," says Janzen. "The materials include metals, polymers and some composites. All of these parts work together to manage the loads, dynamics, pressures and propulsion forces."

Meanwhile, Delft Hyperloop and Jules Dock (Rotterdam, Netherlands), a developer and manufacturer of a range of composite products, are collaborating on research of composite tubes based on a concept Jules Dock is working on for offshore wind turbine towers manufactured via continuous filament winding (CFW). Delft Hyperloop and Jules Dock stated on the blog *Hyperloop Connected* that filament winding might enable pop-up factories to produce the composite tubes on-site as Hyperloop routes are built.

Commercial Hyperloop

While development of test pods and tracks is underway, Hyperloop companies are working with governments, partners and investors to drum up funding and support for proposed routes in the U.S. and around the world.

VHO plans to begin work in December 2019 on a 15-kilometer test track in India for a Mumbai-Pune Hyperloop route aimed at reducing drive time between the cities from 3-4 hours (including traffic) to 25 minutes. The company has also announced plans to conduct a study of a potential Hyperloop test track in Saudi Arabia. According to VHO, the study will focus on King Abdullah Economic City (KAEC), located 100 kilometers north of the Red Sea port of Jeddah. The proposed project includes a 35-kilometer test track and will create opportunities for the development of Hyperloop technologies and expertise in the region.

In the U.S., Hyperloop companies hope to build on the momentum of U.S. Secretary of Transportation Elaine Chao's Non-Traditional and Emerging Transportation Technology (NETT) Council. NETT was launched at the South by Southwest Conference (SXSW, Austin, Texas, U.S.) in March 2019 and aims to support new and innovative transportation projects like Hyperloops and autonomous vehicles.

VHO is conducting feasibility studies and environmental impact studies (EIS) for numerous U.S. routes, with its eye on a Chicago, Ill.-Columbus, Ohio-Pittsburgh, Pa. corridor in the Midwest, a St. Louis-Kansas City route in Missouri, and a Dallas-Fort Worth corridor in Texas. The company visited Capitol Hill in Washington D.C. in June 2019 to present its technology to members of Congress and federal stakeholders. In August, VHO launched a roadshow across the U.S., with stops in Missouri, Texas and Ohio, showcasing its *XP-1* test pod in an effort to connect with communities, and to educate local and state governments on how Hyperloop can help advance the country's transportation capabilities.

"We are now seeing the groundswell of support that's needed to realize the Hyperloop revolution with the formation of the NETT Council and support from lawmakers across the country," says Jay Walder, CEO of Virgin Hyperloop One. "As Hyperloop moves toward reality, it's becoming clear that it will not only transform how we travel but also create an entirely new industry with thousands of new jobs for Americans."

LEARN MORE

Read this article online | short.compositesworld.com/Hype_2019

The company that appears to be the furthest down the commercialization path is HyperloopTT, which expects to begin testing pods with human passengers inside them as soon as 2020. The company's work has attracted the attention of the U.S. Department of Transportation (USDOT, Washington, D.C.), which visited the company's research facilities in Toulouse, France in June 2019. USDOT officials were reportedly able to see the company's full-scale track system as it undergoes optimization and integration prior to the construction of a 10-kilometer track in Abu Dhabi, which HyperloopTT says is the first phase of development aimed at creating a commercial Hyperloop network across the Emirates.

The company presented to USDOT and the European Commission (Brussels, Belgium) a technical overview of Hyperloop technology and certification completed by global testing, certification, inspection and training provider TÜV SÜD (Munich, Germany). With tubes assembled and pumps installed at its test facility in Toulouse, France, HyperloopTT says it is now preparing its full-scale passenger capsule for human trials in 2020.

Behind the scenes

Interior of Virgin Hyperloop One's DevLoop test track in Nevada.

Source | Virgin Hyperloop One

"Not only are we building the only truly full-scale, insured and safety certified system in the world," says Dirk Ahlborn, CEO of HyperloopTT. "We are advancing our efforts to move the Hyperloop forward by sharing our technological experience and our perspective on regulatory frameworks."

"We are moving ever closer to the moment when we will move people in the Hyperloop for the first time," adds Bibop Gresta, chairman of HyperloopTT. "And by sharing our insights with our government colleagues in the United States and Europe, we are furthering our goal of creating the safest and most efficient form of transportation the world has ever seen."

Analogous to the way Hyperloop is meant to gradually accelerate to aircraft speeds, the vision for Hyperloop seems to be gaining momentum. Of course, Hyperloop has its detractors — concerns are continually raised about cost, safety of the tubes, problems with thermal expansion and susceptibility to terrorist attack, to name a few. Nevertheless, the original open-source idea of Hyperloop, meant to spark innovation, competition and collaboration, seems to have achieved its goal — there is, clearly, a global, multi-company effort to tackle the challenges Hyperloop poses, and to make the dream reality.

Richard Branson, founder of the Virgin Group, believes "we could see a Hyperloop in the U.S. in years, not decades." If that's the case and Hyperloop does reach full speed, the composites industry will most certainly continue to be involved to support it. CW

ABOUT THE AUTHOR

Scott Francis, senior editor for *CompositesWorld*, has worked in publishing and media since 2001. He's edited for numerous publications including *Writer's Digest*, *HOW* and *Popular Woodworking*.

Automated joining of hybrid metal-thermoplastic composite structures

The FlexHyJoin production cell combines surface structuring, induction and laser joining and NDT for automotive mass production.

By Ginger Gardiner / Senior Editor

Enabling industrial-scale hybrid joining

FlexHyJoin demonstrates a mass production process for producing a thermoplastic composite roof stiffener with welded metal brackets for assembly into a metal body-in-white, like that of the project's use case, the Fiat *Panda* city car. Source | IVW

» Hybrid metal-composite structures continue to be of interest for automotive and aerospace applications, offering reduced weight and improved performance by putting "the right material in the right place." Thermoplastic composites (TPCs) are attractive for such multi-material structures due to their rapid processing, including the ability to be welded and thermoformed. However, joining composites to metals has, until now, relied mostly on mechanical fasteners, which require drilling holes that damage load-bearing fibers. Adhesive bonding has also been used, but a number of thermoplastics are difficult to bond in this way; also, adhesives add material and weight. For example, the BMW *i3*, which uses a carbon fiber-reinforced plastic (CFRP) chassis and plastic body panels, uses 16 kilograms of adhesive, which partially counteracts the weight-saving potential of composites.

FlexHyJoin is a project funded by the European Union's Horizon 2020 research and innovation program, conducted from October 2015 to December 2018, which sought to address the challenges of joining TPCs and metal parts. Coordinated by the Institut für Verbundwerkstoffe (IVW) — a nonprofit research institution of the state of Rhineland-Palatinate and the Technical University of Kaiserslautern, Germany — FlexHyJoin brought together 10 partners from across Europe to develop an automated process enabling a TPC automotive roof structure to be assembled into a metal body-in-white (BIW).

The strategy was to produce a weight-neutral, high-strength join — without adhesives or fasteners — by laser pretreating metal brackets and attaching these to the roof stiffener via induction and laser joining. This was achieved in a single,

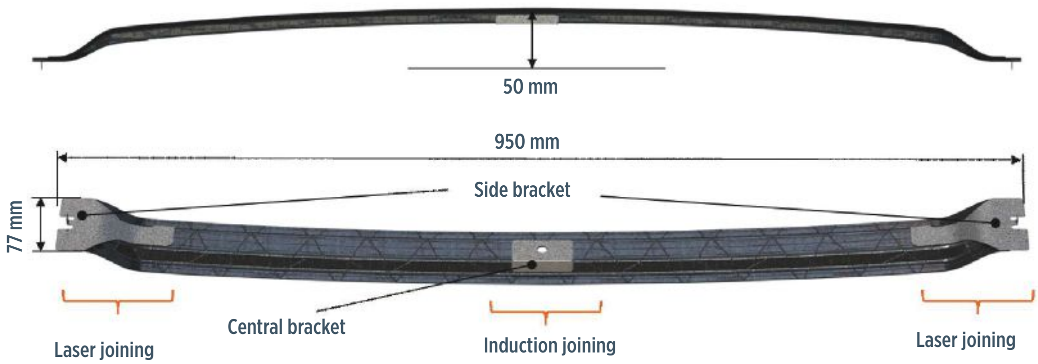
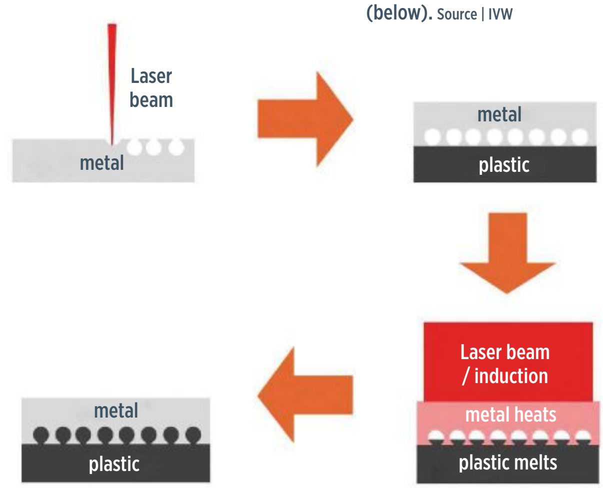


FIG. 1 Surface structuring for hybrid joining

FlexHyJoin demonstrates laser and induction joining of steel brackets to a stamped GF/PA6 roof stiffener (top). These hybrid joins rely on surface treating the metal brackets to create undercuts, which are filled with molten plastic during the joining process steps (below). Source | IVW



automated production cell with integrated process control and inline nondestructive testing (NDT).

Hybrid demonstrator in 140 seconds

Project partner Centro Ricerche Fiat (Pomigliano d'Arco/Naples, Italy) supplied specifications for the demonstrator part — a roof stiffener for the Fiat *Panda* city car that is currently fabricated from steel. For FlexHyJoin, the part was thermoformed from a thermoplastic composite (Fig. 1) by Gubesch Thermoforming (Wilhelmsdorf, Germany) using 1.5-millimeter-thick Tepex Dynalite 102 woven glass fiber/polyamide 6 (PA6) organosheet supplied by Bond-Laminates (Brilon, Germany). In order to join this TPC roof stiffener into the *Panda*'s steel BIW, a set of side brackets (left and right) made from 0.7-millimeter-thick DC04 steel were laser joined onto the ends. A center bracket made from the same material was attached using induction joining. FlexHyJoin showed that both joining methods can be used for industrial hybrid structures production.

Simply melting the PA6 matrix onto the steel brackets would not produce a join with enough strength to meet structural requirements. Thus, a laser surface treatment was required prior to joining. "The surface of the brackets was structured by a laser to create undercuts," explains Johannes Voithofer, project manager at Fill Gesellschaft (Gurten, Austria), which was tasked with assembling and integrating the automated production cell. "The treated brackets are placed onto the composite part. Heat and pressure are then applied during joining, causing the PA6 matrix from the composite to flow into the laser-induced undercuts [see Fig. 1]." The structuring process was developed by yet another partner, Fraunhofer Institute for Laser Technology (ILT, Aachen, Germany), and results in a metal-composite join that combines material adhesion as well as mechanical locking.

Joined parts are then transferred to an NDT station where they are scanned for defects using a type of thermography. "Halogen spotlights are used for modulated heating of the composite surface," explains Vitalij Popow, IVW research associate and lead for developing the FlexHyJoin NDT and process control. "This leads to an oscillating temperature field within the composite structure. We analyze the thermal response on the surface over time and identify defects in the joints." The fully automated »

FlexHyJoin Partners	
Centro Ricerche Fiat (Pomigliano d'Arco/ Naples, Italy)	Defined the demonstrator, a roof structure (currently metal) for the Fiat *Panda* city car. Also assisted with simulation for micro-structuring and analysis of joins under applied load.
EDAG Engineering (Fulda, Germany)	Validation of integrated production cell and process for mass production of parts.
Fill Gesellschaft (Gurten, Austria)	Assembled automated production cell and integrated process control for modular structuring, joining and NDT units.
Fraunhofer ILT (Aachen, Germany)	Developed laser structuring process and equipment.
Gubesch Thermoforming (Wilhelmsdorf, Germany)	Thermoformed the demonstrator composite roof stiffener. Pilot production cell resides at this facility for at least three years after project ends.
IVW (Kaiserslautern, Germany)	Project coordinator and leader of induction joining and NDT process development.
KGR (Brandizzo, Italy)	Supplied high-frequency induction generator for the induction joining unit.
Leister Technologies (Kägiswil, Switzerland)	Developed laser joining equipment and process; performed laser joining trials.
New Infrared Technologies (Madrid, Spain)	Supplied high-frequency IR camera for the monitoring of the laser structuring unit.
Tecnalia (Derio/Bilbao, Spain)	Developed alternative concept for laser joining.

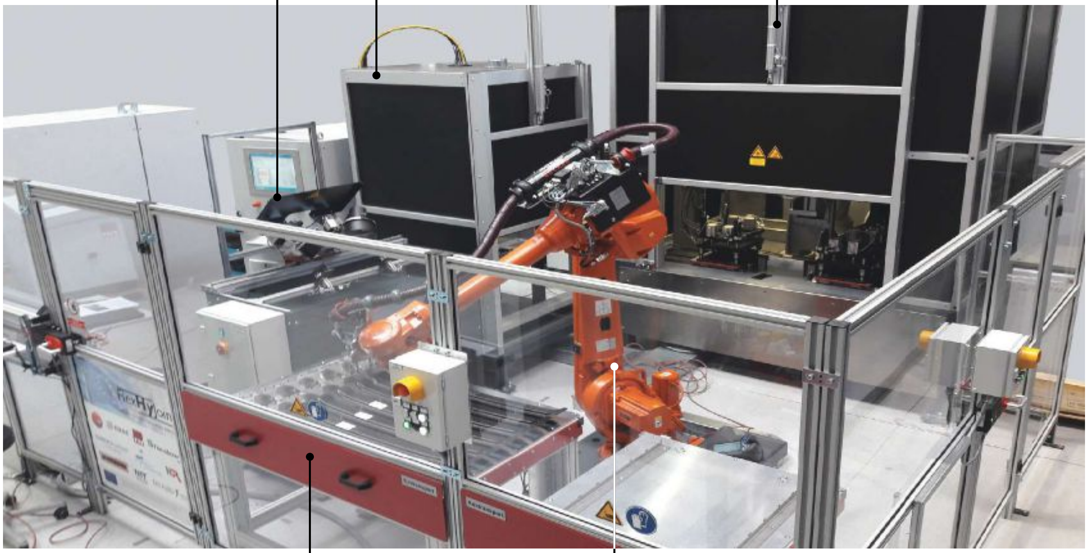


FIG. 2 Enabling industrial-scale hybrid joining

The FlexHyJoin pilot production cell features three modular stations for surface structuring, joining and NDT. The cell's single handling robot transfers components from the loading drawer to each of these stations, placing finished hybrid parts in an adjoining drawer.

Source | IVW and Fill

testing is completed within the production cell for each manufactured component. The validation of the process was performed on about 400 joints.

The FlexHyJoin automated production cell, as currently configured, runs laser structuring, joining and NDT in parallel with cycle times of 81 seconds, 98-108 seconds and 100 seconds, respectively, not including time for robotic transfer of parts between stations. Voithofer says cycle time per completed hybrid part is roughly 140 seconds.

Laser structuring

The laser structuring process produces lines with undercut geometries on the joining surface of the metal brackets. For FlexHyJoin, the undercuts measured 75 micrometers wide and 215 micrometers deep. These measurements, as well as the number of lines and overall pattern of lines can all be tailored, and, ideally, are matched to meet part and cycle time requirements.

"The position as well as the number of microstructures on the joining surface can be adapted to the loading in the component," explains Stefan Weidmann, IVW research associate and leader of the development team for the FlexHyJoin induction joining unit. "The distance between microstructures can be reduced in highly loaded areas of the joining surface and increased in less loaded areas to enable an efficient microstructuring process."

Structuring is achieved by ablating the metal bracket surface using a high-power, single-mode fiber laser supplied by IPG Photonics (Burbach, Germany). This YLR-1000-WC laser has a maximum output of 1,000 watts at an emission wavelength of 1,070 nanometers. "We used the single-mode fiber laser for the microstructuring process because of its high focusability, maintaining a spot size of roughly 40 micrometers," explains Christoph Engelmann, team leader of polymer processing at Fraunhofer ILT.

The laser is contained within an optical head mounted onto an ABB 1200 robotic arm. "Inside the optical head, we have two galvanometric mirrors to deflect the beam in a 240-millimeter by 240-millimeter working field," Engelmann details. "Furthermore, there is one movable lens to track the z-height (z-shifter). We only used the robot to position the scan head above the metal components, and then the beam is deflected by the mirrors and the z-position for each single line of the microstructure is adapted by the z-shifter. Thus, there is no movement of the head during processing. In this way, we are able to treat 2.5D parts, staying in the same z-position for each discrete line but able to adjust between lines."

> One of FlexHyJoin's greatest achievements is integrating all the technology units into an automated production line.

"For safety reasons, both the structuring and joining units are enclosed," explains Voithofer, noting the black cabinets in the pilot production cell (Fig. 2). Thus, an automated gate/door remains closed during laser operations, and opened for removal of finished parts and insertion of new ones.

Induction and laser joining

Adjacent to the structuring cell is the joining cell, which comprises two distinct operations: induction joining of the center bracket and laser joining of the left and right side brackets. "For larger parts with a moderate complexity like the center bracket, induction joining is a more suitable joining method," says Weidmann. "A ceramic consolidation tool with inductor applies pressure

FIG. 3 Induction and laser joining cell

In the joining cell, induction joining is used to attach the middle bracket while laser joining is used to attach the side brackets at each end of the composite roof bow. Source | IVW and Fill

on the joining area and is permeable for the electromagnetic field, leading to an efficient energy input into the metal bracket for heating. This is convenient for flat shapes, but more challenging for complex shapes, such as the geometry of the side brackets. Thus, it was more effective to use laser joining for these." Weidmann adds, "Induction joining is best for large parts and moderate complexity, while laser joining is more suitable for parts with high complexity."

A drilled hole in the composite roof stiffener aligns it on top of the support tooling, shaped to match the curvature of the thermoformed stiffener. A laser-cut hole in the center bracket locates it on the roof stiffener while the side brackets are aligned by their shape which matches the ends of the roof stiffener.

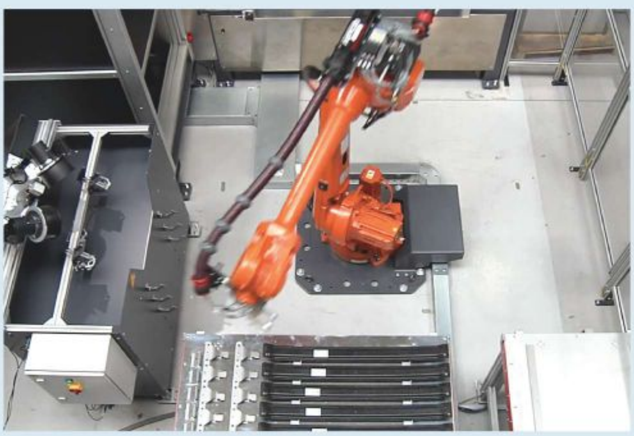
"The center bracket was joined using *discontinuous* induction joining. "This is essentially quasi-static press joining," says Weidmann, "which simply means it is a static process, achieving an areal join in one place, but there is movement in the z-direction because the thickness of the composite changes slightly due to the consolidation pressure applied during (induction) joining."

The induction joining unit contains a KGR (Brandizzo, Italy) high-frequency generator to supply an alternating electric field to the induction coil. The head is moved via an electric motor and spindle (Fig. 3) so that the ceramic consolidation tool presses down onto the metal bracket. The induction coil in the consolidation tool causes the metal to heat, which melts the composite matrix and creates the joint. "Pressure is applied throughout heating and cooling," notes Weidmann.

Laser joining of the side brackets begins simultaneously to induction joining. Two clamping devices, located on either side of the support tooling, can apply 4,000 Newtons of clamping force to the side brackets. "The clamping is necessary to minimize the gap between the composite and metal components," explains Voithofer. "This prevents voids in the joint." After the clamping force is applied, the laser head moves into position. It is equipped with a LineBeam diode laser supplied by Leister Technologies (Kägiswil, Switzerland). Johannes Eckstaedt from Leister explains that this laser has a maximum output power of 600 watts at an emission wavelength of 980 nanometers. The beam is formed to a 27-by-1-millimeter line by optical lenses, and is focused on the metal bracket. The laser head is mounted onto a robot arm that allows it to move along the shaped bracket surface. "We set different speeds for each area of the brackets to achieve a homogeneous joining temperature, reducing thermal stress for the best joining results," says Eckstaedt.

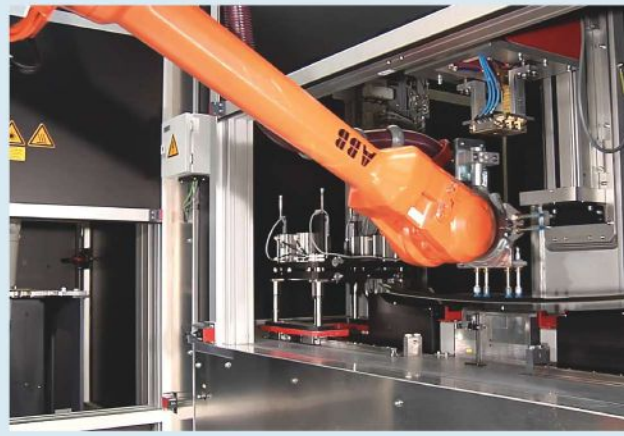
In general, laser joining can use either transmission or heat conduction joining. For laser transmission joining, the composite being joined must be transparent for the selected wavelength of the laser. The laser then passes through the composite, hits the metal surface of the bracket and heats it. However, this method was not used in the FlexHyJoin demonstrator because the roof stiffener's organosheet laminate was not laser-transparent. Instead, the alternative method of heat conduction joining was used. This simply applies the laser directly to the metal surface, which conducts heat through the metal base material to the composite, melting the PA6 matrix at 220-300°C and creating the joint. "Due to the high thermal conductivity of the steel brackets, the laser heat spreads quickly, efficiently joining the side brackets," says Voithofer. »

1 TPC roof bows and metal brackets are manually loaded into the parts drawer of the FlexHyJoin cell. The drawer is closed and production begins.
Source, all steps | FlexHyJoin

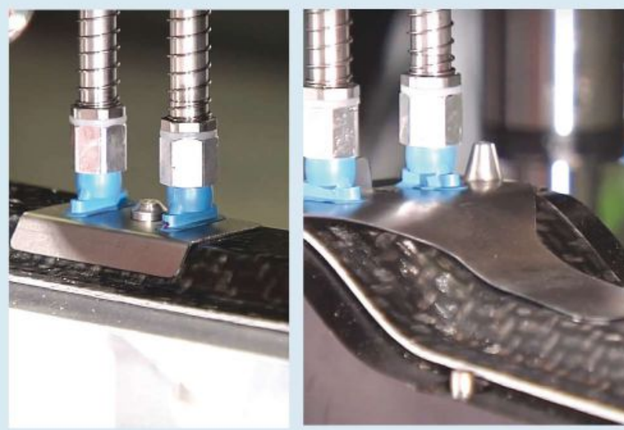


2 The robot picks up a set of metal brackets and places these in the structuring cell. The laser protection door closes.

3 Inside the structuring cell, a high-power fiber laser creates undercuts in the surface of the bracket to be joined to the composite roof stiffener.

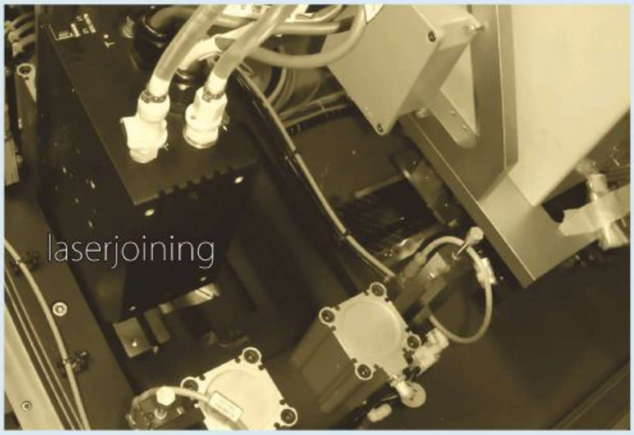


4 While the brackets are laser treated, the robot picks up a TPC roof bow from the parts drawer and places it in the joining cell, to the right of the structuring cell.

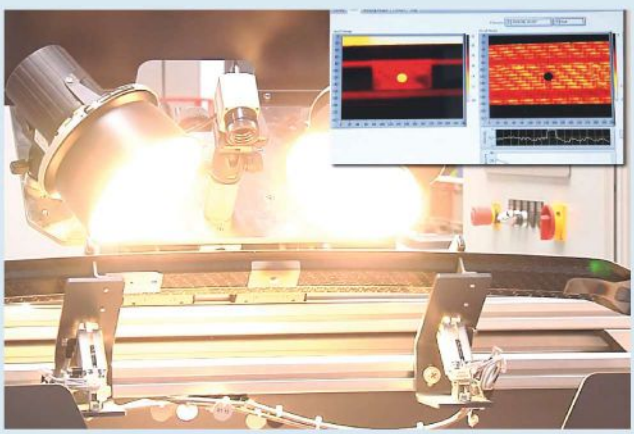


5 The robot goes back to the structuring cell, picks up the treated brackets and places them, structured side down, onto the TPC roof bow.

6 The robot then places clamping units on the three brackets, after which the induction joining unit lowers onto the middle bracket. The induction coil causes the metal bracket to heat up, melting the underlying composite's PA6 matrix.



7 While induction joining is completed, the laser joining unit lowers to join the left and then right side brackets. The laser heats the metal, causing the underlying PA6 matrix to melt into the undercuts, creating a high-strength join.



8 The completed hybrid structure is placed into the NDT cell where lock-in thermography is used to detect flaws. Halogen lamps heat the composite surface and an IR camera measures the response over time. Analysis of this data is processed to provide a visual quality assessment.

9 Once NDT is completed, the robot stacks completed hybrid parts into a second parts drawer for removal.

Joining process control

The basic method for controlling both joining processes is to measure the temperature and time versus a set of optimized parameters that were defined through testing. "Therefore, we produced joining test samples with different parameters and performed mechanical testing for each parameter set using special testing set-ups. For the side bracket, a combination of a shear test and peel test was developed, and for the center bracket we used a pressure load test, comparable to a lap shear test, but you push instead of pull, in order to get a shear load in the joining area," says Popow. The set-up of these special tests was designed together with EDAG Engineering GmbH (EDAG, Fulda, Germany), which also did the analysis of the test results. Following this procedure, the best set of parameters for the joining processes were identified and then used in the pilot production cell.

"The induction joining process was calibrated ahead of time," says Weidmann. "We know we achieve the joining temperature after approximately 30 seconds, but we also measure the temperature in-situ for safety reasons to avoid overheating." A pyrometer, which remotely measures a surface's radiation, was used to measure a known hot spot in the induction joining area. "But it cannot provide accurate measurements of the laser joining due to the high level of irradiated light and heat in-situ," he explains. However, contact sensors could be used on the composite side of the laser joining areas, though they were not applicable for the induction joining process because they are typically made of metal and would heat up by induction and distort the measurement.

"The heated areas for all of the joints are also covered by the pressing tool and clamping fixtures," notes Weidmann. "Thus, we have validated thickness change of the component due to pressure and heat before and after joining as a quality assurance method." This thickness change is measured by a distance sensor integrated into the positioning tool for the roof stiffener (also shown in Fig. 3, p. 27). "When we press the parts together, the distance sensor is moved," he explains. "When we apply heat and joining pressure, the molten matrix polymer flows into the cavities of the laser structuring and is slightly squeezed out of the joining zone until the joint cools. This leads to a change in thickness which is logged by the distance sensor." Weidmann and the IVW team have correlated this distance to part quality. "A thickness change — in other words, a compaction — greater than 0.1 millimeter means the joint quality is good," notes Weidmann.

Inline NDT

IVW developed another method for quality assurance: inline thermography testing. "For quality assurance, the main aim was to see the properties in the join area," explains Popow. "But this was very difficult, so we performed thermography on the composite side of the joins after the part was completed."

IVW chose an active thermography technique called Lock-In Thermography because it offers a better signal-to-noise ratio » than other active methods (e.g., Pulse Phase Thermography) and can also inspect for deeper defects. "The basic idea is to put heat into the composite, which then conducts into the join area and back to the surface," says Popow. "With Lock-in Thermography, the component is excited with a defined frequency over several periods. We then analyze this response over time. If you have areas between the composite surface and the join area which are not homogeneous due to a void or defect, it will show in the thermal response."

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The thermal response is captured as an image. The dots that comprise this image are pixels. Each pixel also functions as a measuring point. Thus, the temperature signal for each pixel over the whole inspection area can be analyzed. "As a result, you get amplitude and phase information for each pixel, and the software then reconstructs this to an image again, which can be visually inspected," he adds. But it also provided large sets of measurements for the 126 parts tested. "We have correlated these NDT results with the results of the mechanical testing performed by EDAG," says Popow. His team also tested the join area after removing the brackets — i.e., destructive testing. "We have thus correlated three sets of test results and can now identify low-strength versus high-strength bond areas from the visual analysis of the thermography results," he says.

Integrated cell for mass production

One of FlexHyJoin's greatest achievements, says Weidmann, is integrating all of the technology units, each developed by a different project partner, into an automated, optimized production line. Voithofer, the one integrating the equipment at Fill, explains that "each set of equipment shipped to us used a different controller. I had to devise a master PLC to control all of the different process units." This included the laser enclosures and the cell's handling robot, which were supplied by Fill. "It was also very difficult to make all of these process steps work together because they take different amounts of time," he adds.

Voithofer began by developing an architecture for each process unit and robot, considering how to position these for the best flow. "Our concept was to keep the three stations — structuring, joining and NDT — modular, in three separate housings," he says. "In this way, we could extract single units and use them at trade shows or other demonstration projects, and then return them. So, the work cell is modular, yet integrated."

Fill's decades of experience in this type of systems integration for serial composites production helped achieve what Popow sees as FlexHyJoin's greatest feat: moving from lab scale to industrial scale. "We are the first consortium to realize a process like this, which is suitable for mass production of composites joined to metal," he says. "This process can be used for many automotive parts such as stabilizer links, bumpers and doors," notes Voithofer. "There are many composite parts that connect to metal parts in a lightweight BIW."

Adaptation for multiple industries

However, a few changes are needed before the cell is put into serial production. "We would no longer keep the laser structuring and joining in separate enclosures, but combine them into one," says Voithofer. "This would remove the need for enclosure doors to open and close between these processes, reducing cycle time." He would also connect all of the stations linearly on a conveyor belt. The line would thus run continuously, with parts picked up and placed back on the conveyor for each station before exiting the cell ready for assembly into a BIW. This would further cut cycle time. Also, expanded drawers able to feed hundreds of parts would enable the line to run through whole shifts without the need for resupply.

Though this pilot production cell was targeted for the automotive industry, Popow notes it can be easily adapted to aerospace, sports/consumer goods and industrial applications. "That was actually one of the main guidelines," says Weidmann, "that it must be able to join different geometries and parts. The only change should be the induction joining compaction tool, the clamping fixtures for laser joining and the support tooling. The main parts of the cell should stay the same." He notes that IVW has also demonstrated hybrid joining of titanium and steel to woven carbon fiber/polyphenylene sulfide (PPS) organosheet composites and is now developing polyetheretherketone (PEEK) and polyetherketoneketone (PEKK) demonstrations. "This simply requires adapting the joining processes for higher temperatures and redefining optimum process parameters," says Weidmann. "The cell is open to a variety of materials, including aluminum and copper as well as other thermoplastic composite matrix systems such as polypropylene and polyethylene."

"The project partners have worked well together and are excited to go further in development," he notes. "We think this type of production is very promising, and the response we have received from industry so far shows there are a variety of companies that see this promise as well." CW

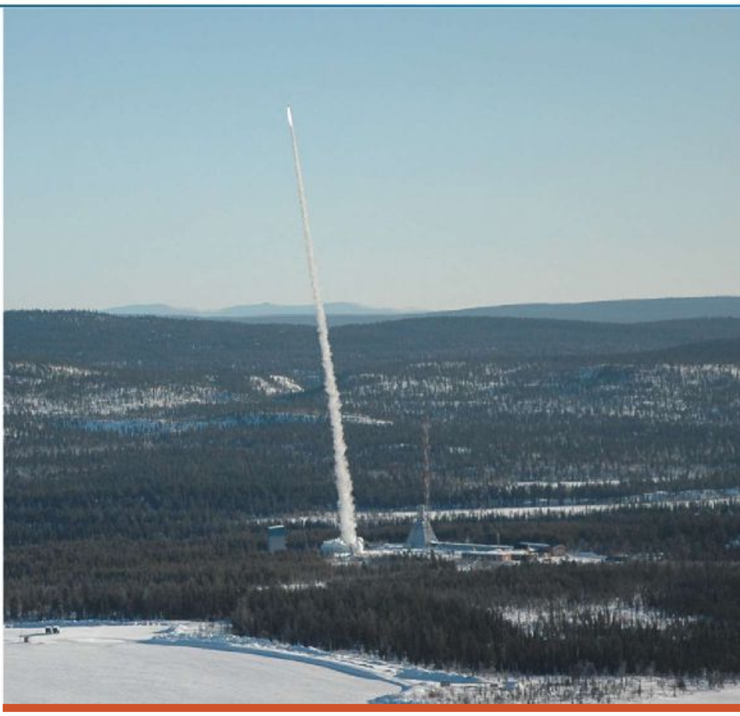
ABOUT THE AUTHOR

CW senior editor Ginger Gardiner has an engineering/materials background and more than 20 years of experience in the composites industry.
ginger@compositesworld.com

Rocket module manufactured with in-situ consolidation survives first flight test

A carbon fiber-reinforced thermoplastic module developed at the Technical University of Munich survived its first launch — and a "hard landing" — in March.

By **Thomas Sloan** / Contributing Writer



Moment of launch

The 23rd REXUS rocket takes flight on March 4, 2019, at the Esrange Space Center in Sweden. Source | DLR (German Aerospace Center)

» On the frigid morning of March 4, 2019, at the Swedish Esrange Space Center north of the Arctic Circle, Ralf Engelhardt, research associate at the Chair of Carbon Composites at the Technical University of Munich (TUM), was waiting for a rocket to launch. This rocket, part of the REXUS program (Rocket Experiments for University Students), jointly managed by the German, Swedish and European space agencies, contained a carbon fiber-reinforced thermoplastic (CFRTP) module that Engelhardt and his team had spent more than three years designing, manufacturing and testing. As far as they knew, it would also be the first such rocket module manufactured by in-situ consolidation. They also knew that the module, which was 40% lighter than the aluminum modules typically used in these rockets, had passed a battery of coupon-level, sub-component level and full-scale tests. Nevertheless, Engelhardt would have to admit, in retrospect, "the launch was a challenge for my heart." When the countdown began, the only way to be sure about the outcome was to sit back and watch.

In January — two months before launch — *CW* wrote about TUM's CFRTP rocket module experiment and the innovative manufacturing process behind it (see Learn More). Post-launch, *CW* was able to learn about the module's flight performance, hear TUM's next plans for composite rocket structures and discuss future applications of in-situ consolidation.

Module design and production

The module, located mid-fuselage between two other research modules, measures 356 millimeters in diameter and 300 millimeters in length. It consists of a cylindrical shell structure joined to two load input rings on either end, which allow the module to be connected to adjoining modules. The load input rings are molded from Victrex plc (Lancashire, U.K.) polyetheretherketone (PEEK) 450CA30 long-fiber thermoplastic (LFT) granules. In the original design, they are press-molded, while the launched module includes centrifugally molded rings (see image at the top of p. 33 for detail). The shell, made from Teijin (Tokyo, Japan) Tenax unidirectional carbon fiber/PEEK prepreg tape, is laid up and consolidated to the rings in-situ by thermoplastic automated fiber placement (TP-AFP). A robot arm (AFPT GmbH, Doerth, Germany) lays down the tape and heats it with a laser, consolidating the shell to the rings.

The launch

On the morning of March 4, the good news was that the module survived the launch and several important measurements were recorded. As is typical with the REXUS program, maximum acceleration (at the moment of launch) was 20G and top speed was 1,200 meters per second. The flight reached a maximum height of 75,422 meters. The team additionally recovered flight temperature data from fiber optic sensors (FOS) embedded in the module's shell (see story in Learn More for detail). The maximum temperature readings for the inner and outer sensors, respectively, were 125.69°F (52.05°C) and 140.576°F (60.32°C).

While these sensors were included to measure temperature, by recording data 10,000 times per second, they were also able to gather some vibration data as well. During flight, when the manacle ring that separates the payload from the motor opened, and when a student-developed project ejected three free-falling units from under the nose cone, several disturbances were caused in the high-frequency temperature recordings. These disturbances revealed vibrations and could also be filtered out to segregate thermal data from vibration data. Being able to gather multiple data types in this way minimized the number of sensors to be embedded in the shell structure, which in turn preserved the integrity of the structure.

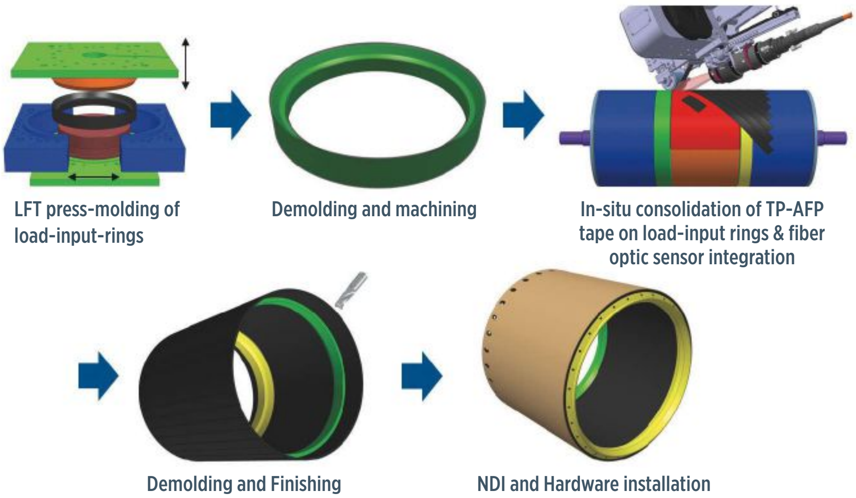
Unfortunately, there was also a complication with the test flight: a hard landing. Engelhardt says the parachute had a "non-nominal fill," and as a result the rocket had an unplanned ground impact at 58 meters per second. Based on visual inspection, TUM's module appears to have retained its structural integrity, and for Engelhardt, that is a win in its own right. The team is awaiting a post-launch CT scan, which will be performed by the German Aerospace Center (DLR) in Stuttgart and provide the final assessment of how well the module performed during the impact.

Because they have CT scans from before the launch, DLR and TUM expect to jointly publish a comparison of the before and after scans. Engelhardt expects the CT scan results will be most interesting because of the hard landing, and he suspects that if the module did suffer delamination, the hard landing will be to blame for that: "Based on qualification [tests], we were sure it withstands loads during flight. This is something we proved. If we see there are delaminations [in the scans], we cannot prove it's not coming from the flight, but everything we know lets us assume it is not coming from the flight."

What's next?

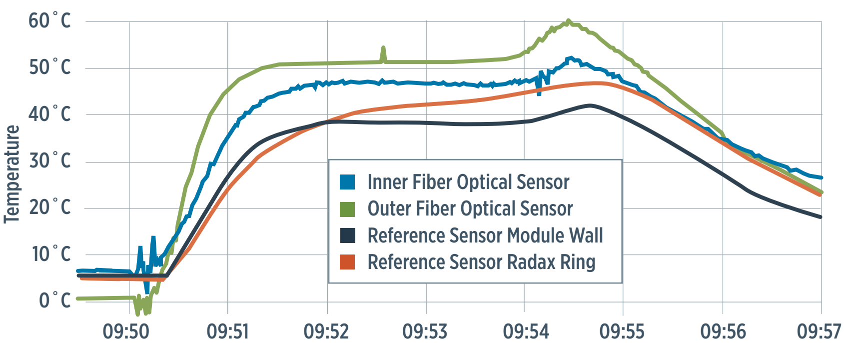
With a mostly successful launch to its credit, TUM is pursuing more rocket and aerospace work. The team would like to launch a similar REXUS module without the cork insulation layer included in the March launch, primarily because the thermal loads recorded during the test were not as high as expected. Ideally, the team would also use a lower-performance material than the PEEK used in the March launch structure. However, that would entail an expensive and time-consuming requalification process, which would make material changes difficult.

Engelhardt would also like to manufacture the module's load input rings with an in-house press-molding process, as the team envisioned originally. Creating the press-molded rings would also enable the team to experiment with a recycling process. The recycling vision is to use waste carbon fiber tape from the TP-AFP process used to fabricate the shell as feedstock for the next module's rings. The rings used in the launched module were centrifugally molded by Elekem Ltd. (Lancashire, U.K.). »



Fabrication process for the module

The module is created by in-situ consolidation of the rings and shell. This particular illustration includes the press-forming of the rings. Source | Technical University of Munich



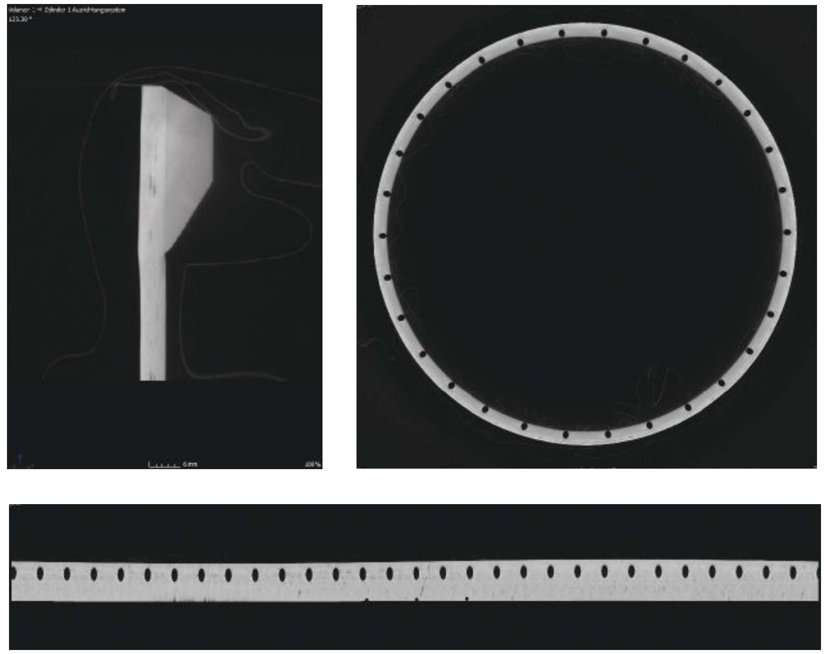
In-flight temperature data from the TUM's module

This chart illustrates one-measurement-per-second live downlink data from the module's fiber-optic temperature sensors. Source | Technical University of Munich

The module post-landing

While much of the internal sensing apparatus was dislodged, the module itself appeared to have survived the hard landing with little to no damage.

Source | Technical University of Munich



CT scans of rocket module

Top left: a cross-section scan of the upper interface between the load input ring (right) and cylindrical shell (left). The interface between shell and rings was revealed as a crucial section in Finite Element Method (FEM) analysis and was consequently scanned multiple times. This scan reveals an interface with "no noticeable problems," according to Engelhardt, who added that "the TP-AFP laminate shows some dark spots, presumably being resin-rich areas coming from gaps between the tapes." Top right: top-down CT scan of one of the module's load input rings. Bottom: side-on CT scan of one of the module's load input rings.

Source | Technical University of Munich

The module in flight

The TUM module is just visible as a brown segment between blue segments in the upper half. The brown is the cork insulation surrounding the module.

Source | Thomas Schleuss, DLR (German Aerospace Center)

If the team had more freedom and resources, it might consider even more ambitious modifications to the module. For instance, it might be possible to form a hatch in the module's side by laying down a thickened frame of tape around the opening. Such a hatch is useful in missions where a probe or other object must be deployed from within the fuselage. Or, they could attempt to alternate the shell laminate's thickness as a stiffening alternative to stringers.

In-situ joints

The in-situ consolidation used to join the module's shell and ring could have varied applications. TUM has incorporated the technique in some of its other projects, such as INSCAPE, in which a curved shell was in-situ consolidated onto stringers using TP-AFP. Engelhardt sees other uses as well: "Whenever you want to combine complex parts with a monolithic structure — brackets, hinges or clips — if you want to combine something like this with a shell structure, then this process of combination can make sense." He also envisions using this process to apply carbon fiber tapes to metal surfaces, resulting in hybrid material structures.

In-situ consolidation as practiced with the REXUS module presents multiple benefits. It shortens the process chain by combining part manufacturing and consolidation into a single step, eliminating costs and time delays along the way. This process may also be able to create further weight savings by eliminating fasteners. Such benefits may make it an appealing choice for future aerospace and rocketry research. Engelhardt points out that this technology could be an asset to the EU Clean Sky program, which aims to reduce aviation's carbon dioxide emissions, in part through weight savings.

LEARN MORE

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

Read about the REXUS module design | short.compositesworld.com/REXUS

The REXUS rocket has certainly demonstrated the appeal of the method, along with the weight-saving benefits. Further scans are on the way to test the module and more innovations are sure to follow, but the future of composite materials in rocket flight has already taken a significant step forward. CW

Composites Events

Oct. 1-3, 2019 — Tampa, Fla., U.S.
IBEX 2019
ibexshow.com

Oct. 7-9, 2019 — Orlando, Fla., U.S.
2019 Polyurethanes Technical Conference
polyurethane.americanchemistry.com

Oct. 8, 2019 — Enschede, Netherlands
Future of Thermoplastic Composites conference
tprc.nl/events

Oct. 8-9, 2019 — Novi, Mich., U.S.
Lightweighting World Expo 2019
lightweightingworldexpo.com

Oct. 8-10, 2019 — Milan, Italy
GOCarbonFibre 2019
gocarbonfibre.com

Oct. 9-10, 2019 — Munich, Germany
Munich Technology Conference on Additive Manufacturing 2019
munichtechconference.com

Oct. 16-23, 2019 — Düsseldorf, Germany
K 2019
k-online.com

Oct. 22-23, 2019 — Oxford, U.K.
Composites in Motorsport
compositesinmotorsport.com

Oct. 22-23, 2019 — Boston, Mass., U.S.
AWEA Offshore WINDPOWER Conference 2019
awea.org/events

Oct. 30-31, 2019 — Birmingham, U.K.
Advanced Engineering UK 2019
easyfairs.com/advanced-engineering-2019

Nov. 5-7, 2019 — Farnborough, U.K.
Vertical Flight Expo and Conference
verticalflightexpo.com

Nov. 6, 2019 — Bristol, U.K.
NCC Discover: Composite Overmoulding 2019
nccuk.com

Nov. 7-8, 2019 — Krakow, Poland
Chemistry and Automotive 2019
chemiaimotoryzacja.pl

Nov. 13-15, 2019 — Seoul, Korea
JEC Asia 2019
jec-asia.events

Nov. 19-21, 2019 — Knoxville, Tenn., U.S.
CW Carbon Fiber 2019
CarbonFiberEvent.com

Nov. 20-21, 2019 — Vienna, Austria
Composites in Building & Infrastructure Summit
volanthengroup.com/en/events

Nov. 20-22, 2019 — Mumbai, India
World of Composites at Techtextil India
techtextil-india.in.messefrankfurt.com

Nov. 26-28, 2019 — Copenhagen, Denmark
WindEurope Offshore 2019
windeurope.com/offshore2019

Nov. 28-29, 2019 — Istanbul, Turkey
Eurasian Composites Show
eurasiancomposites.com

Jan. 29-31, 2020 — Tokyo, Japan
TCT Japan 2020
tctjapan.jp

March 3-5, 2020 — Paris, France
JEC World 2020
jec-world.events

April 20-24, 2020 — Birmingham, U.K.
MACH 2019
machexhibition.com

April 21-24, 2020 — Rheinstetten, Germany
PaintExpo
paintexpo.com

May 4-7, 2020 — Seattle, Wash., U.S.
SAMPE 2020
nasampe.org/events

May 19-21, 2020 — Chicago, Ill., U.S.
UTECH North America 2020
utech-north-america.com

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Fiberglass industrial fan manufacturer builds on tradition

Collaboration produces large-diameter, low-noise composite axial flow fan.

Hudson Products turned to Wickert Hydraulic Presses for a press similar to its existing presses, yet with updated controls and a higher degree of functionality and control. Source | Wickert Hydraulic Presses

Hudson Products needed a press capable of handling the 5-by-1-meter tool that would be needed to mold the Tuf-Lite IV fan blades. Source | Wickert Hydraulic Presses

› Hudson Products (Hudson, Beasley, Texas, U.S.) is a leading manufacturer of air-cooled heat exchangers and axial flow fans. The company's fiberglass Tuf-Lite axial flow fans have been in production for more than 60 years and are preferred for industrial applications. More than 250,000 Tuf-Lite fans are in use worldwide.

The Tuf-Lite fan series got its start in 1955 with the Tuf-Lite I, featuring a glass fiber-reinforced composite blade. Since its creation, the fan has gone through a few iterations. The original fan was manufactured as a monolithic one-piece airfoil that was molded as a hollow part. Tuf-Lite II was introduced in 1984 to increase the manufacturability of the fan's parts. According to Hudson Products operation manager Nick Rizzo, it was challenging to maintain the profile of the original monolithic airfoil and still meet part requirements. A new, two-part design was conceived featuring a blade comprising an airfoil and holder, or neck. The design also saw a change in its center hub. In the Tuf-Lite I design, the monolithic blade's molded neck fit into a socket in the hub, while in the Tuf-Lite II design, the blade's cylindrical neck was held in place by two clamp halves sandwiched between a top and bottom hub plate. The Tuf-Lite III was introduced in 2004, reverting to the monolithic blade design but keeping the clamping convention.

Hudson's Tuf-Lite II and Tuf-Lite III fan designs use a proprietary vinyl ester resin in a resin transfer molding (RTM) manufacturing process. A proprietary leading edge protection system is also embedded, and a UV-resistant coating is applied to the blade exterior. The fans are designed to resist corrosion and to maximize the strength-to-weight ratio. The fan blades incorporate an aerodynamic twist and taper design to provide even airflow distribution and energy efficiency while also minimizing vibration.

Hudson recognized a need in the marketplace for a large-diameter, low-noise fan and saw an opportunity for yet another iteration of the Tuf-Lite series. For the Tuf-Lite IV, the company employed computational fluid dynamics (CFD) technology for a design that focused on noise reduction and efficient airflow.

"The design concept behind the Tuf-Lite IV was to allow us to put a blade into service that would operate as efficiently as our existing designs, however at a lower operating speed," explains Rizzo.

The resulting Tuf-Lite IV design is modeled after the Tuf-Lite III, but is about 20% larger. Because of the fan's increased size, the new design was not compatible with Hudson's existing manufacturing equipment.

"This is a significantly larger blade than what we've molded before in the monolithic style," says Rizzo. "It has a much wider chord, it is significantly longer and the airfoil shape has a pronounced sweep or curve."

Hudson needed a press capable of handling the 5-by-1-meter tool required to mold the parts. Hudson's composites presses were previously developed and built in-house, but for the new fan design the company turned to Wickert Hydraulic Presses (Hebron, Ky., U.S.; Landau, Germany) for a new custom press. In addition to increased size, the new blade design presented several production challenges. These included changes in layup sequence, type of fiberglass, material configuration, number of layers, resin injection points and positioning of vent lines. A new epoxy-based resin system was also considered during the design phase, but over the course of development, Hudson reverted to the vinyl ester it has used in past iterations.

"Several custom options were included to the press that were specific to their molds," says Tony Ackerman, regional sales engineer for Wickert. "We got together with [Hudson's] mold vendor and collaborated on the design."

"We didn't know exactly how the resin front would flow across the part within the mold cavity," explains Rizzo. "The point of convergence of that resin front was also a concern. With our existing designs — being an RTM application — the closed mold is vented so as we're pumping in the resin over the part, air is escaping through the vent lines. Once the part is completely wet, the idea is to have the resin bleed out through the vent lines — so the positioning of those vent lines is very important in the mold tool. We want to put those vent lines at the point of convergence of the resin front as it is flowing over the part."

Wickert also collaborated with Hudson on the control system for the press to set up the specific sequence, alarm system and integration with resin pump system. The automatic cycle the companies developed was designed to optimize injection timing and pressure heating and cooling. Because an air bladder is used to create a cavity in the hollow fan blade, Wickert installed air actuation controls that "tell" the air bladder when to inflate at a specific time during the manufacturing cycle.

"Our existing machines have a level of automation as part of the manufacturing cycle where the operator is able to initiate a resin injection, wet-out cycle and then a heating cycle cure followed by a cool-down cycle," says Rizzo. "[Wickert] gave us a press that accomplished all those requirements — we were able to program an automatic operator cycle that functioned similarly to what our existing presses give us, with updated controls and a higher degree of functionality and control compared with our older machines."

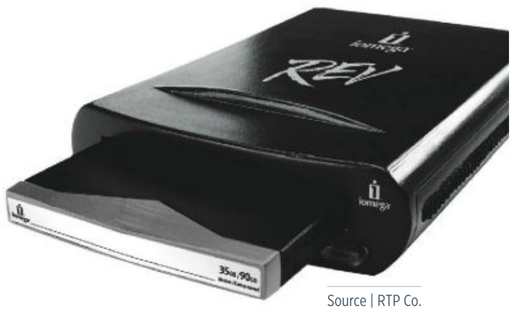
In addition, Wickert designed the press as a top-acting hydraulic machine, which produces a low working height, making it easily accessible for the operator.

"One of the custom features on the press is an upper heating platen that is able to swivel to present itself to an operator for cleaning and visual inspection," adds Ackerman.

While the automation for the press is still being finalized and some software adjustments are still being made, Hudson has begun producing the Tuf-Lite IV fans and is shipping units.

"The wider chord width and the swept profile allow the blade to operate with increased efficiency at lower RPM, providing a lower overall noise output," says Rizzo of the new Tuf-Lite fan blades. "Plus, we were able to meet these requirements with significantly fewer blades compared to the existing design." CW

New Products



Source | RTP Co.

» RESIN ADDITIVES AND MODIFIERS

Conductive additive compounds

RTP Co. (Winona, Minn., U.S.), a global custom-engineered thermoplastics compounder, has expanded its line of conductive compounds to include new CCX Conductive Masterbatches, designed as safe, productive and reliable solutions for environments that are prone to electrostatic discharge (ESD).

CCX Conductive Masterbatches are available in a variety of resin systems, and can be formulated with one of four additive technologies: carbon nanotubes, carbon black, stainless steel fiber or PermaStat dissipative polymer technology.

Stainless steel fiber CCX Masterbatches are created using the company's long-fiber manufacturing process, and are said to enable the highest level of conductivity, providing EMI shielding for sensitive electronics, colored parts and components, or FDA-compliant applications. Available in most resin systems, they are said to exhibit similar shrinkage and mechanical performance as the unfilled base resin, which makes them suitable for injection molding and compatible with existing molds and tooling.

Carbon nanotube CCX Masterbatches can be used in high-purity applications, and are said to have almost no effect on shrinkage or mechanical properties compared to the unfilled base resin. The carbon nanotubes, when incorporated into a thermoplastic, are said to provide highly uniform ESD protection and/or electrical conductivity at a low loading level.

Carbon black CCX Masterbatches are also reported to have similar isotropic shrinkage, strength and stiffness to the unfilled base resin, and are designed to be an economical method for introducing versatile, high-performance conductivity to a plastic part.

PermaStat CCX Masterbatches are formulated for applications that require permanent antistatic or static dissipative performance. These masterbatches reportedly can be used in most resins with processing temperatures below 520°F (270°C). They provide uniform dissipative performance, full colorability and transparency in some resins, but are said to retain or even enhance the impact performance of the base resin. Additionally, they are said to be suited to intrinsic safety applications and can meet the surface resistance requirements of the ATEX directive. They are compatible with injection molding or extrusion equipment. **rtpcompany.com**

Source | Eastman

» CUTTING & KITTING

Compact cutting conveyor system

Eastman Machine Co. (Buffalo, N.Y., U.S.) has announced the fall 2019 release of its Eagle-C125 conveyor cutting system, in three new configurations. The latest release features several options designed to minimize overall required factory space while maintaining complete cutting automation for industrial cutting applications.

The Eagle-C125 conveyor is a computer-controlled ply-cutting system engineered for single- to low-ply automatic cutting of fabrics including fiberglass, carbon fiber and aramid fiber. The machine continuously conveys rolled material goods with reportedly consistent speed and control. The system is said to require minimal operator guidance to automatically feed and spread material to the identified start position, and it is available in a range of widths — from 60" to more 14 ft. — and several lengths.

The Eagle-C125 system has been produced for more than 25 years at larger configurations; the fall 2019 highlight is the release of a smaller, 8-ft.-long, single-frame design in 60", 72" and 78" widths, which has been designed to minimize production space. Eastman says this system is ideal for companies that need to cut long parts, require continuous conveying or want to minimize the material handling associated with a static table cutting system. It features cutting speeds up to 60 in/sec (152 cm/sec).

Additional options are available to either further streamline floor space on the 8-ft. model, or to add new features to existing larger-sized configurations:

- All computer hardware and electronic control mechanisms are contained within the base of the machine, an upgrade from the standard free-standing kiosk (though not available for the 60" system).
- Positive air pressure may be added for further protection in high-particulate environments and to meet IP55 compliance demands.
- The computer monitor and workspace are machine-mounted at an ergonomic height and pivot for operator preference.
- Internally mounted variable frequency drive for vacuum control and step-up or -down transformer ensure simple access for operators but also eliminate the need for external mounting or additional enclosures (both optional).
- A belt-scraping device stops material scrap and debris from going under the machine but also deflects hands from gaining access to pinch points.
- Fork pockets welded to the frame are available for ease of unloading or movement. **eastmancuts.com**

Source | Smarter Building Systems

» RESIN SYSTEMS

Non-toxic fire-retardant epoxy

Smarter Building Systems LLC (Newport, R.I., U.S.) and Innovative Formulations (Tucson, Ariz., U.S.) have developed a non-toxic fire-retardant epoxy, said to self-extinguish in seconds, eliminating smoke emissions and flame spread.

Developed for use with basalt fibers and fabrics, the epoxy is designed to be an affordable but effective fire protection solution that is also environmentally safe. Rather than emitting harmful smoke when burned, the epoxy reportedly builds up a char layer, similar to an intumescent paint, that prevents fire from penetrating to the lower layers of cloth and resin while maintaining structural capacity.

The fire-retardant epoxy reportedly comprises a new molecular structure that is described as having the quad functional ability to graft oleophobic and hydrophobic properties together. The epoxy is said to be capable of bonding to itself even after cure.

The epoxy has been tested for use with basalt fiber, fiberglass and carbon fiber, and the first application of the product was for a bridge deck coating surface for the California Department of Transportation.

smarter-building-systems.com

» SIMULATION SOFTWARE

Molding simulation software released for Turkish market

CoreTech System Co. Ltd. (Hsinchu, Taiwan), provider of engineering simulation solutions for the plastics industry, has added a Turkish language pack to the latest version of its plastics molding simulation software, Moldex3D R17 SP1. With the addition of the Turkish language, Moldex3D's user interface is now available in 11 languages, including English, German, French, Spanish, Italian, Russian, Korean, Japanese, Traditional Chinese, Simplified Chinese and Turkish.

CoreTech says it has been experiencing demand from the Turkish market for plastics molding simulation software to maximize productivity and achieve faster time-to-market. According to the Turkish Plastics Industrialists' Association (PAGDER), Turkey ranks second in the European plastics market and seventh in the world in terms of production capacity. **www.moldex3D.com**

Source | Mahr

» TESTING, MEASUREMENT & INSPECTION SYSTEMS

High-performance length measurement

Mahr Inc.'s (Providence, R.I., U.S.) Precimar SM 60 is a length measurement instrument designed for fast and precise external measurements on shop floor parts. The SM 60 has a measuring range of 60 mm and is configurable with Mahr readouts such as digital indicators or LVDT probes. It incorporates a 25-mm sensitive contact and a fixed-reference jaw with a 35-mm adjustment to obtain its full 60-mm measurement capacity.

According to the company, the SM 60 is designed for high-performance gaging at the point of manufacture, and is easily adaptable for new workpieces, enabling the system to act either as a long-range measuring system or as a high-performance comparator for sub-micron applications.

The user selects the preferred readout for level of performance and application of the measurement. For applications that require versatility, a 25-mm MarCator 1086 or 1087 is available, featuring a large display or analog dial. If higher resolution and performance are required, a Millimar P2004 LVDT with ±2-mm range and C1200 bench amplifier are available to provide sub-micron performance at the machining process.

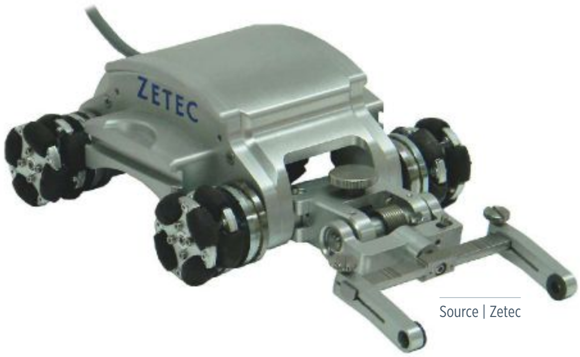
The SM 60 also features integrated coupling to protect against overrange damage, hardened contact surfaces on both the sensitive and reference contacts, and an easy-to-adjust support table and optional floating micro-center support. For increased versatility, a family of measuring attachments for the standard contacts is available, including contacts with radius surfaces, flat-edge contacts and flat contacts with various diameters, allowing for plain OD checks for adding gage pin wires, OD thread checking and a threaded contact set for adding any of Mahr's standard threaded contacts. **mahr.com**

» THERMOPLASTIC SOLUTIONS

Thermoplastic UD tape production line for mass production

Karl Mayer Technische Textilien (Obertshausen, Germany), a specialist in non-crimped fabrics for lightweight structural components, has introduced its latest production line, called SIM.PLY, which produces thermoplastic, unidirectional (UD), fiber-reinforced tapes.

The high-quality tapes, featuring precisely aligned, continuous fibers, are reportedly suitable for use in highly stressed, fiber-reinforced, lightweight structures. The thermoplastic matrix is said to make them easy to process for large-scale production. The SIM.PLY system operates at a high production rate and produces tapes in range of widths. **karlmayer.de**



Source | Zetec

» TESTING, MEASUREMENT & INSPECTION SYSTEMS

Scanner for ultrasonic testing

Zetec Inc.'s (Snoqualmie, Wash., U.S.) NDT Sweeper Scanner is said to be a versatile manual 2D encoded scanner for ultrasonic inspections for oil and gas, aerospace and other applications.

NDT Sweeper has two integrated encoders for precise 2D scanning. It can support up to two phased array probes at once for pitch-catch ultrasonic inspections, and the individual probe suspension can be fixed axially or laterally to meet specific needs. The scanner is said to be simple to deploy, able to encode in raster scan across long distances and able to provide C-Scan mapping of large components.

NDT Sweeper features non-marring wheels with integrated magnets designed for safe and effective use on various materials, including composites. The wheels are optimized for easy movement in the scan and index directions.

The scanner is designed to be compact, lightweight and ergonomic, and is said to be suited for ultrasonic inspections ranging from long-seam welds to corrosion mapping and more. It is intended to eliminate the need for multiple specialized scanners, reducing equipment costs, and is deployed with a TOPAZ portable ultrasonic instrument and UltraVision software. **zetec.com**

Source | Zetec

Source | Polygon

» COMPOSITE TUBING AND BEARINGS

Composite bearings for construction, mining and agricultural equipment

Polygon Co. (Walkerton, Ind., U.S.), a producer of composite tubing, bearings and pneumatic cylinders, has developed a line of PolyLube high-performance, custom-engineered and standard composite plain bearings. The bearings are said to be ideal for applications in construction and mining equipment, such as wheel loaders, excavators, back hoes and compact track loaders, as well as other applications requiring pivot joints with a very long life expectancy.

The bearings are made of continuous filament-wound glass fibers, polymer resins and polytetrafluoroethylene (PTFE) fabric liners. The fiberglass filament and epoxy resin combine to form a high-strength backing. This precise filament-wound fiberglass structure is said to allow for thin-walled, lightweight bearings. The bearings are typically retained through outside diameter (OD) interference fit and are tailored to fit custom requirements.

Featuring high load-bearing capacity, low frictional values and corrosion resistance, the Polygon composite bearings are self-lubricated, which is said to reduce maintenance labor costs and to increase the interval before maintenance is required on equipment. This feature is also said to reduce the number of greasing locations, ultimately resulting in fewer equipment warranty claims.

In addition, the field-retrofittable bearings reportedly can replace existing metallic bushings without changing mating parts, so they can be used to improve wear material without requiring complete equipment redesign.

The company says the bearings are also suitable for high-cycle agricultural equipment, including implements, foraging and harvesting equipment, applicators, carts and spreaders. The greaseless bearings are said to help maintain cleanliness inside warehouses, avoiding potential contamination of the work area by pallet lifting equipment. **polygoncomposites.com**

» RESIN SYSTEMS

Toughened epoxy prepreg system

PRF Composite Materials (Dorset, U.K.) has introduced RP542-4, its latest epoxy prepreg system for unidirectional (UD) and woven carbon fiber fabrics. RP542-4 has been designed as an intermediately toughened system to complement the company's RP542-1 and super-toughened RP549 systems.

Source | PRF Composite Materials

According to the company, the system has exhibited excellent tensile, compressive, flexural and interlaminar properties through mechanical testing, and has shown a glass transition temperature (T_g) of 138°C after curing at 120°C. The onset T_g can reportedly be improved by 20-120°C after postcuring at 140°C for two hours. The system has an outlife of 60 days at 20°C. RP542-4 is available on 300-gsm and 600-gsm UD carbon fiber reinforcements as well as on a variety of fiber types in PRF's range of high-quality woven fabrics. **prfcomposites.com**

» CORE MATERIALS

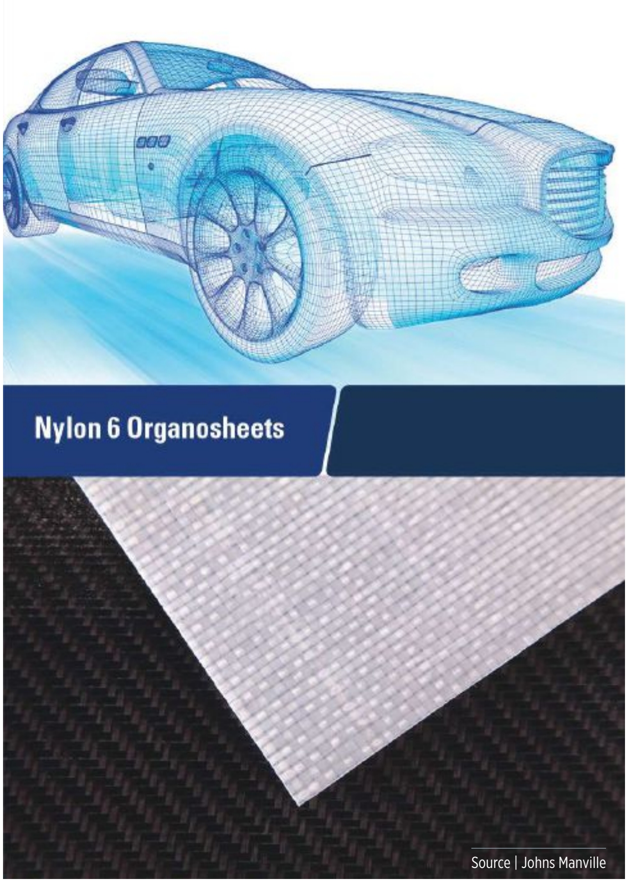
Foam core for composite building panels

Source | Diab

Diab (Helsingborg, Sweden), in collaboration with Butech, a materials and building systems division of ceramic tile manufacturer Porcelanosa Group (Villarreal, Spain), has developed a new foam core sandwich panel for use with lightweight composite panels.

The sandwich panel system, called System X light XXL, has been developed as a fixing solution for building façades. The panel comprises a ceramic facing and an aluminum backside with a core of Divinycell P that ensures improved thermal insulation and complies with the FST (fire, smoke and toxicity) classification Euroclass B-s2, d0. The panel's dimensions are 3,000 × 1,000 mm, and it weighs 8 kg/m^2 .

Due to its light weight, the panel is said to offer faster installation and decreased need for a back-up structure. The ceramic finishing is said to achieve a stable and even surface, and the panel is designed to ensure no change in color over time and to reduce the risk of warping due to thermal stresses. **diabgroup.com**



Source | Johns Manville

» THERMOPLASTIC SOLUTIONS

Nylon thermoplastic organosheets offer enhanced properties

Johns Manville (JM, Denver, Colo., U.S.), a manufacturer of continuous filament glass fiber and a Berkshire Hathaway company, has launched three nylon thermoplastic composite product series for lightweight applications: OS-6, NCF-6 and CR-6 series.

The OS-6 series is a nylon composites sheet reinforced with continuous woven fabric and impregnated with the company's proprietary technology to enhance impact resistance, strength and stiffness in thermoplastic composites.

The CR-6 series uses chopped roving reinforcement to combine formability with impact resistance. Its quasi-isotropic properties reportedly enable a range of high-formability applications for thermoplastic sheets.

The NCF-6 series is reinforced with high-density continuous non-crimp fabric to offer high strength, stiffness and impact resistance in structural applications.

The company says its nylon thermoplastic composite sheets, produced via its in-situ polymerization technology, offer superior properties, short cycle times, recyclability and competitive costs. **jm.com**

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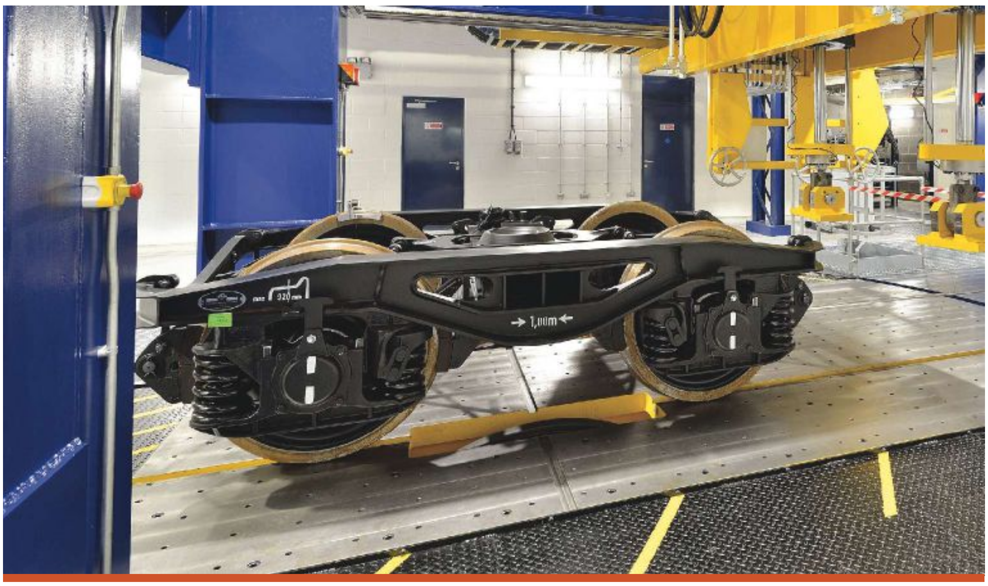
Recycled carbon fiber on the rails

Aiming to increase the cost-weight viability of carbon fiber-reinforced composite structural components in railway vehicles, a prototype rail bogie prominently features recycled carbon fiber.

By Karen Mason / Contributing Writer



HAROLD testing to come

The Huddersfield Adhesion and Rolling Contact Laboratory Dynamics (HAROLD) test rig at the University of Huddersfield will take the prototype composite rail bogie (not shown here) through its testing phase. During this testing, the fiber-optic monitoring system will collect data to be evaluated against design and FEA models, and at the same time the testing will verify that the monitoring system itself can withstand proof and fatigue loading. Source | AMI *Composites in Rail*

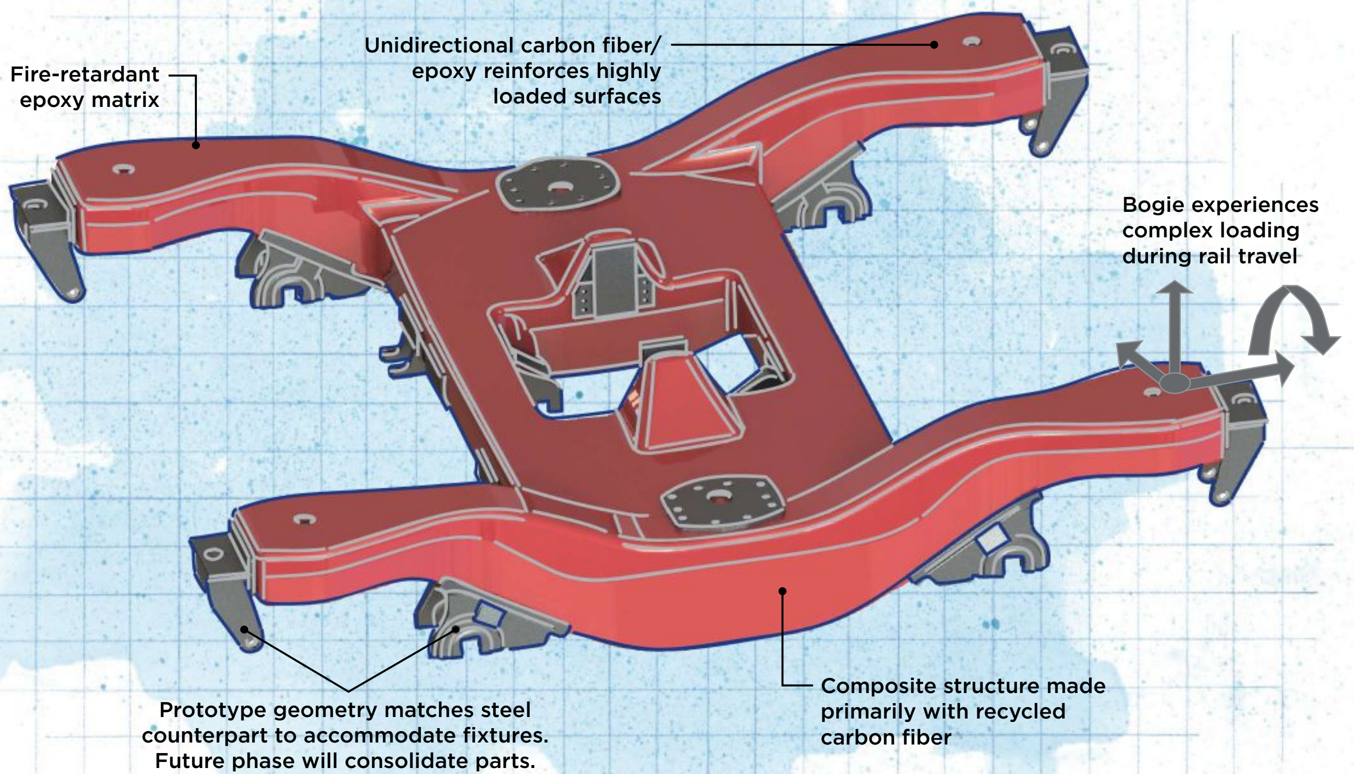
» A large market for composite structural components may be opening up within a decade, and recycled carbon fiber may be the key. At least, this seems to be the promise proffered by the recent completion of a prototype rail bogie by a United Kingdom industrial-academic consortium. Bogies are the four- or six-wheel trucks that support rail vehicles and provide traction and braking. Usually each rail vehicle has two bogies, one near each end. Funded by the U.K.'s RSSB (Rail Safety Standards Board), the composite bogie prototype represents the culmination of a three-year effort, which has included conceptual and design work, materials testing and qualification, manufacturing engineering and fabrication of the bogie and assembly with standard fittings. The bogie, which is made primarily with recycled carbon fiber composites but is supplemented with virgin carbon fiber composites in places that require additional strength or stiffness, was the subject of two presentations at the "Unlocking Innovation Scheme — Composites in Rail" event in June 2019, and it is scheduled to undergo full-scale testing this month.

Initiated by ELG Carbon Fibre Ltd. (Coseley, Dudley, U.K.), the consortium now consists of ELG, which supplies the recycled carbon fiber and performed much of the materials testing; Magma Structures (Portsmouth, U.K.), designer and fabricator of the rail bogie; the University of Birmingham Sensors and Composites Group (Birmingham, U.K.), which worked with Magma to develop an embedded health monitoring system for the bogie; and the University of Huddersfield (Huddersfield, U.K.), on whose dynamic test rig the prototype is to undergo initial full-scale testing. Alstom U.K. (London) helped to assemble the consortium and has provided additional support through consulting and existing bogie design information.

In the past, this market's pursuit of composite structural components has stalled due at least in part to the high cost of carbon fiber. The lower cost of recycled carbon fiber has tipped the scales enough to prompt the consortium's funding and current work, and perhaps enough for the eventual opening of this market to production bogies. With the potential for some 36,000 bogie frames to be built in the next 10 years for passenger rail vehicles in the U.K. alone, pursuing this market is certainly a worthwhile endeavor.

A promising application

The RSSB's interest in the project stems from the U.K. government's expenditure of millions of pounds each year in track repairs and



DESIGN RESULTS — Carbon fiber-reinforced rail bogie

- Basic frame structure 590 kg (64%) lighter
- Bogie frame and fittings: 36% weight reduction in prototype; up to 50% in future versions
- Up to 40% reduction in wheel-rail transverse loading
- Reduction in cost and environmental footprint through recycled carbon fiber

Susan Kraus / Illustration

maintenance. Railway service providers offset this cost to a degree through track access charges, which are computed based on railcar weight and stiffness (both of which affect track wear and tear), but maintenance costs still add up. This means that both the track provider and the service providers are financially motivated to reduce railcar weight while optimizing structural strength and flexibility. Rail operators employing composite bogies will also be able to optimize operating costs by balancing the energy savings gained from the lighter weight bogie with the opportunity to increase payload weight and thus increase delivery volume per railcar.

One kilogram of carbon fiber-reinforced composite typically replaces 3 kilograms of steel in a structural application, so considering that the typical steel rail bogie with fittings weighs about 1,500 kilograms, lightweighting can be expected to reduce railcar travel costs substantially. In fact, using the annual miles traveled by trains in the U.K. and inflation-adjusted RSSB values for the cost of electricity and maintenance, the consortium estimates potential annual savings ranging from £10.16 per kilogram of weight saved in inner suburban rail transit, to £105.80 per kilogram of weight saved for high-speed rail transit.

The consortium selected the Alstom Class 180 bogie frame as the target application, reports Frazer Barnes, managing director of ELG Carbon Fibre, because it is representative of many bogie frame designs, has well understood performance and has a ready supply of the fittings that attach to the frame. These advantages, however, also placed restrictions on the prototype's design. Specifically, the geometry of fitting attachment points on the composite bogie had to conform to those on its steel counterpart in order to properly incorporate existing fittings and equipment. The prototype's design, therefore, is not fully optimized to take advantage of composite properties, but this leaves a good opportunity for greater benefits in future designs.

A lighter bogie directly contributes to the anticipated cost-in-use savings generated by a composite version, and so will the greater flexibility afforded by composite materials. As a train travels around curves, it places dynamic forces on the rail, explains Damon Roberts, Magma Structures engineering director, and the bogie needs flexibility in the lateral plane as it negotiates these turns. Optimizing the bogie's rotational (yaw) stiffness could contribute to a reduction in lateral loads on the track rails of up to 40%. "Many composite designs aim to optimize stiffness more than strength," Roberts notes. "In the bogie design, we have

»

Lightening the economic load

Reclaiming carbon fiber through its recycling process, ELG Carbon Fibre is providing a lower cost alternative to composites designers and manufacturers, one that may help open new markets to composites applications, like the rail bogie discussed here. Source | ELG Carbon Fibre

Bogie reinforcement

The primary reinforcement in the prototype rail bogie is ELG Carbon Fibre's Carbiso M recycled carbon fiber nonwoven. Virgin carbon fiber/epoxy supplements the composite where additional strength and stiffness are required.

Source | ELG Carbon

introduced more flexibility with plenty of strength."

Additionally, the lighter weight bogie should experience reduced suspension maintenance costs. In fact, Roberts reports, at the conceptual stage the design team considered integrating suspension and steering functionality into the bogie, which would result in a more flexible primary suspension that would further reduce lateral forces on the rail tracks. This plan proved too involved to incorporate in the prototype, but is under consideration for future efforts.

Building a case for recycled carbon fiber

With recycled carbon fiber reducing the cost premium of a composite bogie, one of the early tasks for the consortium was to characterize recycled carbon fiber-reinforced composites to the satisfaction of rail stakeholders. This characterization was especially important given the rail industry's perception that composites are a basic material for non-structural, interior applications. "This is a very, very conservative industry," Barnes says, "and rightly so. They are extremely safety conscious, given the impact that an accident or structural failure might have."

In an effort to convince this industry that recycled carbon fiber-reinforced composites are suitable for *primary* structures, the consortium reported numerous physical and mechanical property comparisons. ELG Carbon Fibre has demonstrated that interfacial shear strength, critical to the performance and durability of a composite material, is comparable between recycled and virgin carbon fiber reinforcement in epoxy. The recycled carbon fiber/epoxy selected for the rail bogie demonstrates comparable tensile strength to bogie frame steel. (The consortium chose epoxy resin because of its adaptability, durability and well-understood mechanical properties.)

The consortium needed to demonstrate that the recycled carbon fiber would meet the fatigue and fire performance requirements of rail applications. The consortium selected ELG Carbon Fibre's Carbiso M, a nonwoven mat made with standard modulus fiber (strength of 4 to 5 GPa) in an epoxy matrix. They demonstrated that the fatigue performance of the recycled carbon fiber/epoxy is similar to that of conventional woven carbon fiber laminates — and better than that of structural steel, Barnes emphasizes. Finite element analysis (FEA) performed by Applied FEA Ltd. (Southampton, U.K.) verified fatigue service loads as well as exceptional static loads.

For acceptable fire performance, the consortium selected a fire-retardant epoxy that offers properties similar to a conventional epoxy. However, determining how to *test* the composite for fire performance presented another hurdle for the team to overcome. "The standards are there, but how do you test for those standards?" Barnes asks. "For example, does the standard apply to the surface of composite laminate or the full depth of material? We decided to have all the material pass the fire test standard, taking a conservative approach." The composite material was required to achieve the HL2 rating under the European Union's EN 45545-2 railway standard for fire safety, which includes specifications for spread of flame, heat release, smoke density and smoke toxicity. It achieved the more stringent HL3 rating.

Design particulars

The Carbiso M recycled carbon fiber nonwoven is the key reinforcement used in the "skin" of the rail bogie, prepregged with the selected epoxy by Gurit (Newport, Isle of Wight, U.K.). The prototype also employs composite lamina made with virgin unidirectional carbon fiber oriented at 0 and ±45 degrees in places where

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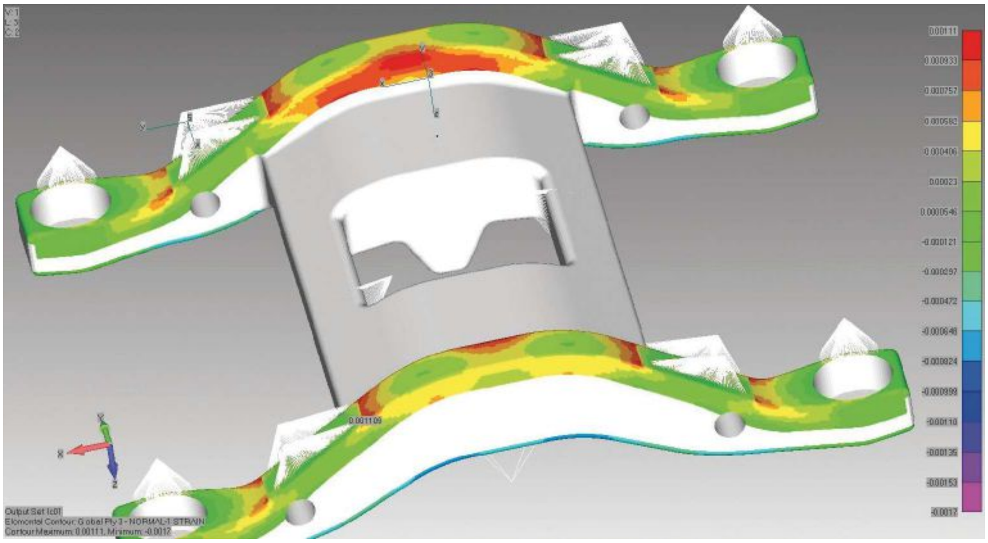

Complex bogie-rail interactions

Finite element analysis helped to verify both the need for and the adequacy of unidirectional virgin carbon fiber/epoxy lamina in key areas on the rail bogie that would experience high strain levels.

Source | AMI *Composites in Rail*

additional strength and stiffness are required, primarily along the upper and lower faces of the bogie's outer legs. Virgin carbon fiber composites comprise about 50% of the total composite material in the bogie. The design analysis that led to this combination took into account the complex interaction on each leg of strength, stiffness and safety factor calculations in the three principal planes (x, y, z) and torsionally.

With Magma Structures' experience in building high-pressure offshore composite pipes (see Learn More) with robotic material deposition, the company was able to employ some robotic deposition to lay up the prepreg plies, followed by autoclave cure. Roberts reports that the company intends to increase the level of robotic deposition when the bogie development process reaches a large batch production stage. "When it first came up to do this, one of the main aims was to do it with a cost-effective technique," he recalls.

The consortium also benefited from Magma Structures' experience with embedded fiber optic strain monitoring and managing fixtures on composite structures like the large composite masts for which they are known (see Learn More). Including these masts, Magma has built some of the largest and most highly loaded carbon fiber composite structures in the world. "We rely on monitoring technology very heavily on our composite rigs," Roberts says. "We see the rigging's loads every day; they come to me on my desk." The company worked closely with the University of Birmingham to incorporate the bogie's fiber-optic strain monitoring system.

Compared to the original steel Alstom 180 bogie frame and fittings, the prototype is 36% lighter. The composite frame itself yields a 64% weight savings, but the prototype suffers a weight penalty from paint and the tapping plates needed to attach the steel fittings — a penalty that may be largely eliminated in a fully optimized design. Considering the frame alone, the 590 kilograms of weight saved is estimated to produce an annual savings in operating costs of £8,000 to £62,000, depending on the train's service type and mileage. Additionally, each bogie frame could reduce CO_2 emissions through its lifetime by as much as 68 metric tonnes.

In transit

The full-scale tests scheduled for this month will take place at the University of Huddersfield on the Huddersfield Adhesion and Rolling Contact Laboratory Dynamics (HAROLD) test rig. During this testing, the fiber-optic monitoring system will collect data to be evaluated against design and FEA models, and at the same time the testing will verify that the monitoring system itself can withstand proof and fatigue loading.

Development and track testing of a more optimized bogie prototype is next for the consortium. Magma Structures plans to build two such bogies for this in-field testing. Barnes points out that the integration of fittings into the composite structure may save another 100 kilograms per bogie. "It would make the structure more elegant but not significantly more complex to manufacture," he says.

Roberts sees future developments taking a path similar to that seen in other composites markets: start with a metal design and substitute with composites, then take greater advantage of composite materials' heterogeneous, anisotropic properties.

"Steel structures have often been designed on an empirical basis with a homogeneous isotropic material," Roberts says. As the consortium moves forward, they'd like to take a different approach. "We want to move back one stage and ask what we are trying to achieve, and whether we can quantify it. You need to know what you want. It sounds obvious, but if it's difficult to define what you want, it's difficult to achieve what you don't know." CW

ABOUT THE AUTHOR

CW contributing writer Karen Mason focused academically on materials science and has been researching and writing about composites technology for more than 25 years.
kmason@compositesworld.com

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