CompositesWorld.com

CW CompositesWorld

FRP bridge fairings: FIRE RESISTANCE MEETS INFRASTRUCTURE

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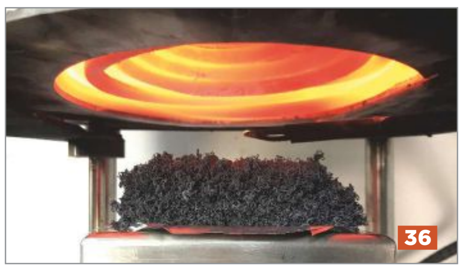
COLUMNS

DEPARTMENTS



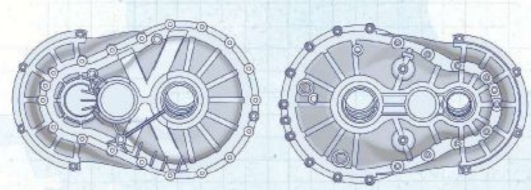
FEATURES

ON THE COVER

Technical Fibre Products' Tecnofire intumescent nonwovens were used in the FRP wind fairings for the Whitestone Bridge in the Bronx, NY, US, replacing steel and cutting weight to reduce bridge load by 6,000 MT. See p. 38.

Source / *CW*

FOCUS ON DESIGN



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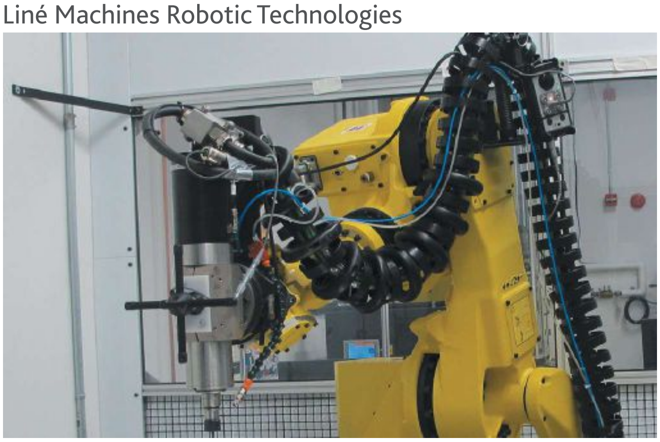

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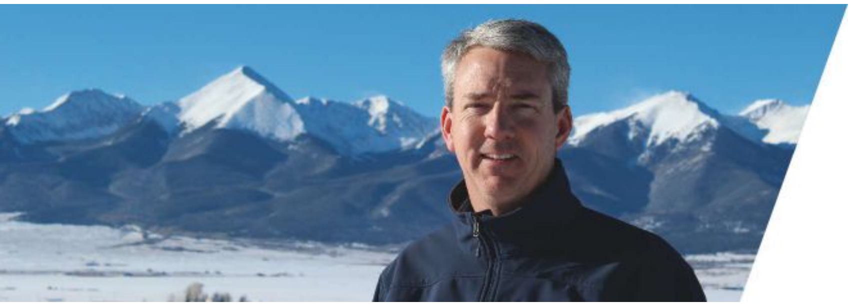


When I joined *CompositesWorld* as editor-in-chief in the fall of 2006, I was coming off of a 10-year stint as editor and eventually publisher of a trade publication that served the injection molding industry. As I transitioned to my new job at *CW*, I anticipated some modest crossover in materials and manufacturing concepts between injection molding and composites. Both industries are polymer-based, and there are principles of robust injection molding manufacturing that, I assumed, must have application in composites manufacturing as well.

My assumptions, of course, turned out to be wrong. Injection molding is a machinery-intensive, fast-cycle process that uses thermoplastics almost exclusively. The name of the game is speed (measured in seconds), consistency, repeatability and tight, highly automated process control. In composites, I discovered a vast and complex world composed of multiple fiber types, fiber formats, resin types, tooling types and process types. And although machinery is important in composites fabrication, it is not the centerpiece of fabrication. Further, the highly engineered, multi-ply, quasi-isotropic nature of composites manufacturing depends, in many cases, on touch labor of the type that would be unheard of in injection molding.

> We are recognizing Sara and Mike for helping make *CW* the publication that it is.

So, in short, I had a learning curve to ride when I became editor-in-chief. And to climb that curve, I needed help. I wisely turned to the folks who were already here at *CW*, namely managing editor Mike Musselman and senior editor Sara Black. Both were knee-deep in composites and had a wealth of institutional and industry knowledge under their belts.

Mike, as managing editor, was responsible for the day-to-day management of all editorial functions. His was a name you might not have seen often in the magazine, but his presence was keenly felt in every issue. His editing pen was the first to touch all content generated by staff writers and contributors and he was famous for the breadth and depth of his composites manufacturing knowledge. Further, he was able to bring clarity to complex, highly technical stories, ideas and concepts that seemed, at times, impossible to sort out. I leaned on Mike heavily to help guide me through the maze of suppliers, converters, fabricators and technologies. And as I came up to speed, I leaned on him further to help me develop and organize the editorial content that was, and still is, the backbone of *CW*'s mission.

Sara Black, as senior editor, is someone you likely know by name, and possibly have met. She has been the eyes and ears of *CW* since 1999, representing us at trade shows, conferences and plant tours. She has authored, each year, at least 12 features or major articles, covering everything from the design of wind blades to the fabrication of fuselage skins. She was unfailingly kind and patient in helping me get to know the industry and continued to be my right hand — the person who, I knew, could always be trusted to produce content that was well-researched, well-written and highly respected by our audience. And in the industry, you will not find a single person who did not know Sara as uncommonly kind, thoughtful, interested, curious and generous.

I say all of this because Sara is retiring at the end of February, and Mike departed *CW* in late 2018. They deserve my many thanks for their service, and recognition by all of our readers for helping make *CW* the quality publication that it is. I wish them both much happiness.

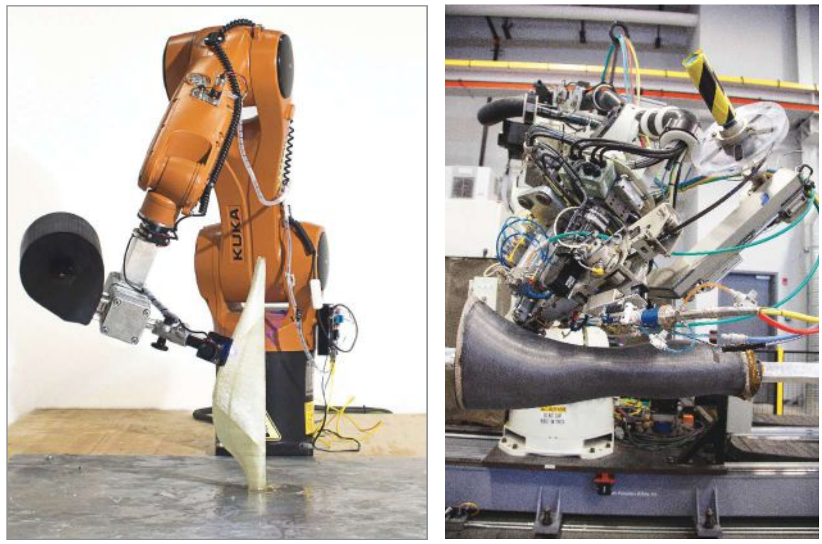
Of course, Mike and Sara's departure provided us the chance to bring new people into the *CW* fold, so there are two new names for you to get used to. The first, Scott Francis, was hired in early 2018 to be our digital editor, and he has done a great job of helping make our digital content (newsletters, website, social media) as robust and engaging as it ever has been. Scott will now transition to senior editor, taking over Sara's role, and I have every confidence that he will fill her shoes ably.

Taking Mike's place is Hannah Mason, and she has quickly and ably taken on the task of not only managing all of our editorial content (as well as the editors and writers who produce it), but learning about the complex world of composites manufacturing. Hannah is off to a wonderful start and I expect that her imprint will be as keenly felt at *CW* as Mike's was.

JEFF SLOAN — Editor-In-Chief

3D printing is missing the third dimension

» Composites manufacturing is inherently an additive process and has always been about structural efficiency in our three-dimensional world[1]. However, the 3D printing community has been slow to catch on. For more than 30 years, 3D printing has been stuck in 2.5D, building parts a layer at a time on a flat (2D) base to form a 3D structure with little strength in the third dimension. This Z direction weakness has been known since the 1980s, but little has been done to address it. However, 3D printing has caught the public's imagination and grown to a US$7 billion/year industry. This success is primarily due to incredibly resourceful young minds that have leapt over many of the hurdles presented by these early 2.5D technologies. But they neglected the third dimension.



Printing structures in three dimensions

Processes such as moi composites' continuous fiber manufacturing (CFM; left) and Automated Dynamics' in-situ consolidation (ISC; right) are enabling composite structures to be printed in all three dimensions. CFM uses UV-curable thermoset composites and ISC uses laser-heated thermoplastic composites. Both are continuous fiber-reinforced in all three dimensions.

Source | moi composites and Source | Automated Dynamics

Enter composites

These early rapid prototyping technologies have evolved into additive manufacturing (AM) — not just prototypes, but functional parts in real-world structural applications. The composites community has been doing this since the beginning, but we are progressing from hand layup to automatically "printing" composite structures. Automated fiber placement (AFP) was a huge step forward and is a process that is now widely used to place continuous fibers precisely where they are needed in the direction of the load paths to manufacture high-performance, three-dimensional structures. The Boeing 787, Airbus A350 and Lockheed F-35 are good examples of structures that feature composite parts produced via AFP. However, AFP with thermoset prepreg still requires a manually placed bag and an autoclave cure step, and therefore is not considered true additive manufacturing.

Innovators like Stratasys and Markforged have added chopped and continuous fibers, respectively, to their 2.5D printers to significantly improve properties in two dimensions, but the third dimension is still lacking.

Evolving a third dimension

Finally, after all these years, the 3D printing community is realizing that it neglected the third dimension. Stratasys created its RC3D (Robotic Composite 3D) technology, extending fused deposition modeling (FDM) with extruded, chopped fiber-filled thermoplastics into three dimensions by using articulated arm robots[2]. Putting low-strength chopped fibers in the direction of load paths, as the RC3D does, is an improvement, but what about high-performance, continuous-fiber reinforcement? AREVO and moi composites[3] (see photo, left) are doing just that — placing continuous fibers in three dimensions using advanced robotics and creative variations on the FDM theme to print high-performance 3D composite structures.

> Finally, AM and ISC are converging on optimal processes and structures.

Adjacent to the 3D printing community, a small but growing group of researchers has been developing in-situ consolidation (ISC) of thermoplastic composites (TPCs). The goal from the beginning has been additive manufacturing with continuous fiber-reinforced TPCs. The third dimension was always critical to the goal of high-performance ISC structures, and Automated Dynamics has employed ISC to manufacture high-performance TPC parts in serial production for more than 30 years (see photo, right). Finally, after all these years, AM and ISC are converging on optimal processes and structures.

Optimizing structures

Human beings are amazing creatures (most of us anyway) that have evolved over millions of years. I can't wait that long for our industry to evolve. Fortunately, we can take nature's most important algorithm and accelerate it using computers instead of genes. Diversify-select-replicate-repeat can be performed billions of times a second using modern computers and genetic algorithms to find optimal solutions. This is exactly what is done in topology optimization and generative design to optimize structures for maximum strength with minimum weight[4]. It is fascinating to watch this process as structures evolve from the blocky-looking parts we are used to being produced through subtractive processes (like CNC machining) to the more organic structures produced through AM. The real beauty of this is that it is less expensive to make these optimized structures with AM because complexity is free — meaning, with more complex shapes, less material is printed, so it takes less time and materials to print a topology-optimized structure. Automated Dynamics and others are using this technology for tools, cores and even composite structures.

Tool-less manufacturing

Better yet, why not eliminate the tooling and print composite parts in free space? This is the goal of the tool-less composites fabrication process being developed by General Atomics[5]. The idea is to use one robot to place the composite material with FDM or ISC and another, synchronized robot to act as the tool to form a structure in free space. This technology is in its infancy, but is clearly a preview of what the future could look like for composites manufacturing. (See Trends, p. 14, for more on this technology)

The future

Yogi Berra once said, "It is difficult to make predictions, especially about the future." However, what I can predict is that innovative young minds will build on the formidable foundation we have constructed and create composite structures that we can't even imagine today. I can't wait. CW

NOTES/REFERENCES

[1] Physicists prefer four dimensions and string theorists use 11 dimensions; the rest of us are stuck with 3D

[2] blog.stratasys.com/2016/08/24/infinite-build-robotic-composite-3d-demonstrator/

[3] www.compositesworld.com/blog/post/continuous-fiber-manufacturing-cfm-with-moi-composites

[4] www.compositesworld.com/blog/post/generative-design-and-continuous-3d-fiber-deposition

[5] patentimages.storage.googleapis.com/a9/e5/50/0121ebc8ee29a1/US20180257305A1.pdf

ABOUT THE AUTHOR

David Hauber is the engineering manager for Automated Dynamics, which is part of Trelleborg Group (Niskayuna, NY, US). He has more than 45 years of experience in textile research, robotics and automation, AM and composites manufacturing. He helped start Automated Dynamics in 1984 and has led the development of ISC technology.

Composites recycling — no more excuses

» In April 2016, I authored a column titled "Can we make recycled carbon fiber sexy?". It was written after I had seen a roof panel on a BMW *i8* at the North American International Auto Show in Detroit that was made from a visible, clear-coated carbon fiber mat, recovered and repurposed from cuttings in BMW's composites manufacturing process. It demonstrated significant forward thinking at the time, as all other examples of visible carbon fiber on display at the show were woven fabrics, yielding the classic carbon fiber "look" under their clear finishes.

A lot has transpired since then, as various composites recycling technologies have matured and spawned multiple entrants. Composites recycling has also attracted investment from venture capital funds as well as strategic investors, such as Hexcel (Stamford, CT, US) taking an equity position in Carbon Conversions Inc. (Lake City, SC, US) in 2016, and the December 2018 announcement of Mitsubishi Corp. (Tokyo, Japan) taking a 25% stake in ELG Carbon Fibre Ltd. (Coseley, UK). Perhaps most significant is the growing list of end-use applications incorporating recycled composite materials, from manhole covers to park benches to materials for 3D printing, among others.

> Composites fabricators need to consider including recycling companies as part of the composites supply chain.

At *CompositesWorld*'s Carbon Fiber conference in December 2018, speakers from ELG, Vartega Inc. (Golden, CO, US) and Composite Recycling Technology Center (CRTC, Port Angeles, WA, US) presented material properties of recycled composites (which are comparable, they say, to those of virgin material) and already-created end-use applications that could increase demand.

There are two main goals to recycling composites and composite materials waste: the first is to avoid placing waste in landfills, and the second, and perhaps more important, is to find ways to recover and reuse these materials in useful (and profitable) applications. But which methods achieve which objectives, and which make sense for various feedstocks? To start a dialogue around this, I propose a method to categorize the various recycling technologies on six levels:

Level 0 is minimization of scrap going to landfill, led by improving material utilization and reincorporating offal in other products inside the same facility. This includes using low-waste processes like automated tape laying (ATL) and automated fiber placement (AFP) of dry fiber and prepregs, and regrinding or chopping scrap pieces and using them in combination with continuous or discontinuous materials in center layers, or injection or compression molding. It is applicable to thermosets and thermoplastics and should be a priority for all fabricators.

Level 1 is repurposing of scrap materials headed for the landfill. This includes milled, chopped and mat forms of dry fiber scrap, as well as taking uncured prepregs that may be expired or off-spec and molding them into products with less stringent performance requirements. There are numerous scrap fiber processors, and several "repurposing" entities for prepreg, such as the CRTC.

Level 2 is taking cured composites or scrap fiber and uncured prepreg, shredding them and combining them with additional resins to bind them all together in various panels and products replacing metal, wood and concrete. Feedstock can include end-of-life wind turbine blades, boats, airplane parts and automotive components, and can be glass fiber, carbon fiber or foam cored. Global Fiberglass Solutions Inc. (Bothell, WA, US) and GreenTex Solutions LLC (Charleston, SC, US) are two companies at this level.

In Level 3, fibers are reclaimed from intermediate product forms such as uncured thermoset and thermoplastic prepregs, yielding fibers with properties essentially equivalent to the original fibers, albeit mainly in a discontinuous "fluff" or pelletized form, or in a nonwoven format. ELG and Carbon Conversions (both using pyrolysis), and Vartega (using solvolysis), offer carbon fibers at this level.

Recovery of fibers at Level 4 (cured composite scrap and rejected parts) and Level 5 (end-of-life parts) is the "holy grail" of composites recycling. Available technologies include high-temperature pyrolysis (ELG and Carbon Conversions), wet chemical polymer breakdown (Adherent Technologies, Albuquerque, NM, US) and a dual energy production/fiber recovery pyrolytic method developed by CHZ Technologies (Auburn, AL, US). Economic scaling of these technologies will be essential to achieving long-term success.

Given the options available, composites fabricators need to consider including recycling companies as part of the composites supply chain just like fiber, resin and prepreg suppliers. In so doing, they need to be prepared to invest R&D funds to help these evolving technologies achieve maturity. In December, Boeing announced a five-year agreement with ELG to send its composite waste, cured (Level 4) and uncured (Level 3), from 11 manufacturing sites to ELG for recovery of carbon fiber. It's a start, and it's time for other manufacturers to follow suit. No excuses allowed. 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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Index moves higher as five of six indicators report expansion

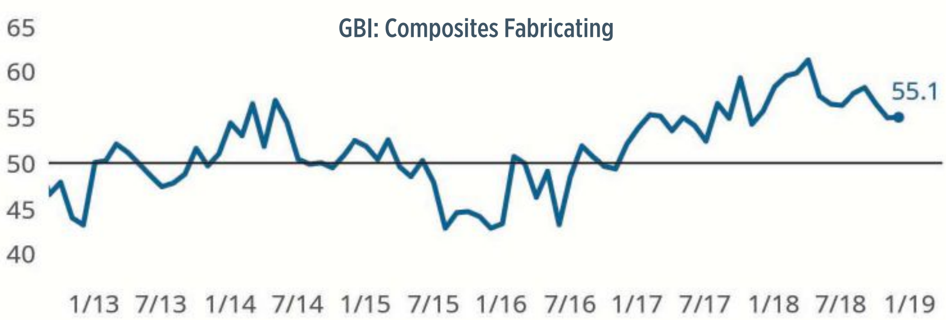
December 2018 — 55.1

» The December reading of the GBI: Composites Index of 55.1 was slightly above the prior month's reading. Furthermore, the latest reading means that the Composites Index has now been expanding for a full two years. In comparison, the prior upcycle ended in 2014 after only eight months of continuous expansion. December's reading also establishes 2018 as the fastest expanding calendar year since records began in late 2011. Gardner Intelligence's review of the underlying data indicates that the Index was propelled higher during the month by supplier deliveries, production, new orders and employment. The Index — calculated as an average — was pulled lower by backlogs and exports. Exports was the only component to contract. Exports reported contracting during six of the last seven months.

Supplier deliveries led the Index higher for a fourth consecutive month, followed by production and new orders. Stronger production growth relative to new orders and contracting exports were among the factors that potentially slowed backlog growth for a third consecutive month. Over the course of 2018, backlog growth set multiple records both in duration and magnitude. The overall strength of the industry continues to be positive as evidenced by hiring in the industry, which has expanded consistently for nearly 2.5 years. One would have to go back nearly four years to find the last instance when employment contracted in two consecutive months. CW

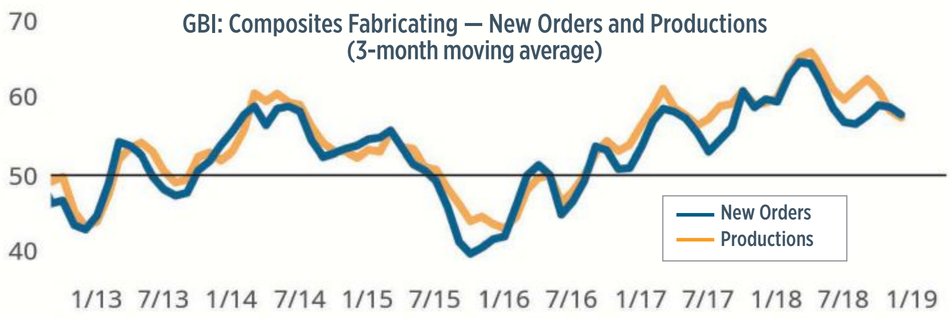
ABOUT THE AUTHOR

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



Supplier deliveries leading growth

Supplier deliveries led the Composites Fabricating Index higher in December, followed by production and new orders. The closing month of 2018 also saw employment growth propel the Index higher.



Composites Index closes year with strong production and expansion

Production and new orders both finished 2018 achieving impressive levels of expansion. For the calendar year, production and new orders averaged readings of 61.5 and 59.6, respectively. Five of the six components of the Index reported expansion during the last month of the year.

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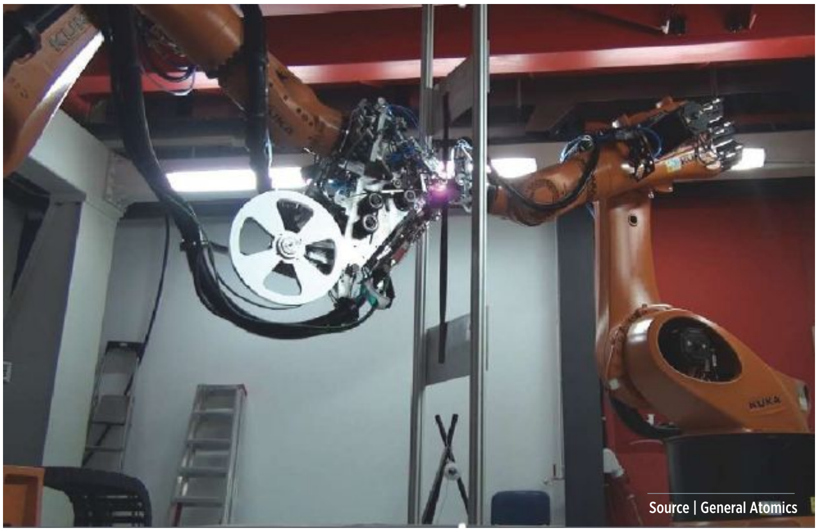
New thermoplastic composite technology with aerospace potential from General Atomics, composites from natural fibers including bamboo and date palms, newly-qualified unidirectional thermoplastic tapes and more.

General Atomics Aeronautical developing tool-less thermoplastics composites process

Aerospace manufacturer General Atomics Aeronautical Systems Inc. (GA-ASI, San Diego, CA, US) is developing a novel process for the fabrication of thermoplastic composite structures that obviates the need for traditional molds or tooling. The system is expected to have applications in the aircraft, space, marine and wind energy end markets.

Although it has not been formally named, the tool-less process uses two 6-axis robots working cooperatively to place thermoplastic tape into open space within a metallic or similar frame that provides the boundaries of the structure being fabricated (see photo). Composite Automation LLC (Cape Coral, FL, US), using Mikrosam (Prilep, Macedonia) equipment, worked with GA-ASI to develop the automation.



General Atomics' tool-less thermoplastic composites process employs two robots. One (left) applies the carbon fiber/thermoplastic tape. The other (right) provides a movable tooling surface against which the tape is applied.

One robot consists of a standard unidirectional tape placement system that provides laser heating to perform in-situ consolidation of the thermoplastic material. The second "support" robot works directly *opposite* the automated tape layer (ATL) and consists of a flat metallic surface, providing, in effect, a *movable* tooling surface against which the ATL places its tape. The tape head and the support head thus move together through 3D space, placing material. Each end of each tape placed is anchored to the frame, which can assume a variety of shapes, depending on the application. Further, the tape can be manipulated by the robotics to change direction within the 3D space to build contoured and complex shapes.

John Geriguis, innovations leader/advanced product development at GA-ASI, has been working with Adam Jones, manufacturing engineering manager, and Paul Sherman, design engineer, on this technology for four years. He says development of the process is ongoing, noting that the company is still working to optimize software systems guiding the robotics. He also says the process is highly dependent on a camera-based in-situ inspection system that detects material and other flaws during the placement process; the system, called real-time virtual assembly tooling (RVAT), developed for GA-ASI by Trilion Quality Systems (King of Prussia, PA, US), is designed to compare the as-manufactured structure with the as-designed CAD data, and then implement tape placement adjustments on the fly to maintain compliance with design specifications.

GA-ASI, says Geriguis, has evaluated several thermoplastic resin systems using the process, including polyetheretherketone (PEEK). However, Geriguis reports that the company has had the most success with Toray's TenCate Advanced Composites' (Morgan Hill, CA, US) Cetex TC1225 low-melt polyaryletherketone (PAEK) using a Toray carbon fiber reinforcement.

GA-ASI has applied for a US patent for the process, but Geriguis says this is being done primarily to protect the company's use of the technology. In fact, says Geriguis, "we hope that others might want to partner and help develop this technology and mature it."

Interest in the process so far, outside of General Atomics Aeronautical, has come from NASA, which, says Geriguis, sees the potential for its use to build structures in a space environment. He also believes the process could be deployed effectively to fabricate aircraft fuselage and wing structures, as well as wind turbine blades and naval vessels.

MARINE

TAHOE Boats' T16 uses 3D-printed tooling from Thermwood


Source | Thermwood Corp.

TAHOE Boats (Springfield, MO, US), part of White River Marine Group (Springfield, MO, US), the marine manufacturing arm of Bass Pro Shops (Springfield, MO, US), has announced its new T16 boat design, an affordable lightweight design engineered with families in mind.

White River worked with Thermwood Corp. (Dale, IN, US), using Thermwood's Large Scale Additive Manufacturing (LSAM) system to custom-print the tool used to manufacture the boat's hull. According to TAHOE Boats, this is the first time 3D printing has been used on actual boat production at this scale. The company says the technology led to greater efficiency in the T16's planning, design and construction.

Thermwood printed the master pattern for the boat hull at its Development/Demonstration Labs in Dale, IN, US. The pattern was printed in six sections from 20% carbon fiber-filled ABS supplied by Techmer PM (Clinton, TN, US). The joints between the pieces were machined, pinned and bonded together and the assembled hull was then machined to final size and shape. The process was reportedly completed in ten days. After printing and machining, the tool was sent to White River where they applied, sanded and polished a proprietary coating.

The technology continues to advance. According to Thermwood, this type of tool can now be produced in even less time using the company's Vertical Layer Printing, which wasn't yet available at the time the aforementioned tool was made. A similar tool can now be printed as one piece in just more than two days, eliminating the machining between sections and the bonding process.

Master patterns, like the tool created for TAHOE Boats, are used to make molds for high production rates requiring multiple molds. For larger boats or lower production rates, Thermwood says it may be possible to print the actual mold itself. The company recently announced the successful production of a 7-foot-long, 1/7 scale model of a yacht hull mold using Vertical Layer Printing.

AEROSPACE

Consortium works to develop bio-sourced composites from bamboo fiber

A consortium of companies have come together to design new bio-sourced technical composites based on bamboo. Known as BAMCO (bamboo long fiber-reinforced bio-based matrix composite), the innovation aims to reduce the environmental footprint of aircraft and deliver benefits said to extend beyond the aerospace industry.

BAMCO composites aim to be a potential replacement for glass/phenolic composites as a result of their lightness (reducing overall weight, and therefore fuel consumption), their thermal resistance and their mechanical properties in terms of strength and impact/vibration absorption. In aerospace, the biocomposites are said to show potential for use in cabin interiors, in cover panels and fuselage cladding panels and in the onboard galleys used to prepare and store in-flight meals on aircraft. They reportedly could also have applications in the manufacture of finished components for use in the marine and leisure sports markets.

Source | Clerkwheel via Wikimedia Commons

The BAMCO project draws on the expertise of eight industry stakeholders, company and research laboratory consortium members. The list of partners in the consortium includes Assystem Technologies (Paris, France), Arkema (Colombes, France), Cobratex (Carbonne, France), Specific Polymers (Castries, France), CIRIMAT (Toulouse, France), Compositadour (Bayonne, France), Lisa Aeronautics (Le Bourget du lac, France) and Mécano ID (Toulouse, France). Assystem Technologies is involved in designing the prototype components. Arkema and Specific Polymers have responsibility for the formulation and application of the bio-sourced polymers used for the composite matrices.

Cobratex will research and propose candidate species of bamboo, some of which are grown in France. In responding to the constraints involved in using the full range of matrices and composites processes, Cobratex will optimize its own conversion process, as well as its own innovative reinforcement technologies. The company will also be responsible for the upscaling of the techniques used to apply the technical reinforcement solutions and semi-finished products developed directly by CIRIMAT.

The research laboratories CIRIMAT and Compositadour are involved in using the biocomposites in the laboratory and on an industrial scale, respectively. The CIRIMAT contribution focuses on the design and laboratory-scale production of continuous bamboo fiber composites using thermoplastic and thermosetting matrices. Mécano ID is responsible for conducting the vibration absorption tests and modeling biocomposite behavior.

Aircraft manufacturer Lisa Aeronautics plans to incorporate a prototype component in its future aircraft. The BAMCO project has just entered its operational phase with the launch of development work. The first prototype components are scheduled for 2021.

BIZ BRIEF


Source | MHI Vestas

Vineyard Wind (New Bedford, MA, US), the 800-MW project off the coast of Martha's Vineyard in the Commonwealth of Massachusetts, has named MHI Vestas Offshore Wind (Aarhus, Denmark) as the preferred wind turbine supplier for the project. The announcement comes as Massachusetts advances its leadership in the integration of offshore wind energy to help replace decommissioned coal power plants. Massachusetts state law seeks to have 3.2 GW of offshore wind providing electricity to the Commonwealth by 2035, which represents more than 20% of electricity consumed in the state.

MHI Vestas' V164 9.5-MW turbine, reportedly the world's most powerful wind turbine, will be employed for the project. The 800-MW offshore wind project, scheduled for installation in 2021, is said to be large enough to serve as a catalyst for the build-up of a local supply chain in the region. Once the turbine supply order is confirmed, MHI Vestas says it will begin the process of local hiring and supply chain investment to support the project as it nears the construction phase.

INFRASTRUCTURE

Joinlox and USQ recognized for composite pile repair system

Source | University of Portsmouth

Joinlox (Brisbane, Australia) and the University of Southern Queensland (USQ, Darling Heights, Australia) recently received the JEC Asia 2018 Innovation Award under the category of Civil and Infrastructure Engineering for their collaboration on a new type of composite pile repair system. The technology uses a prefabricated fiber-reinforced polymer (FRP) jacket to create an innovative joining system for infrastructure rehabilitation. Joinlox has now commercialized the technology under the trade name PileJax, following a successful three-year collaborative development program with USQ.

Most existing composite repair systems for reinforced concrete pilings and columns involve composite wraps — typically wet-out at the job site — that are placed directly over the existing concrete. Considerable surface preparation of the concrete is involved, and in some cases, concrete spalling or damage makes these traditional "two-material repair systems" (the existing concrete and the wrap) impossible to complete. In contrast, PileJax is a "three-material repair system," including the existing concrete, the FRP jacket and grout infill. The FRP jacketing system has interlocking edges that, the company says, fit together like the teeth of a zipper. A "joint key" is pushed in between the interlocking composite teeth, to lock the jacket into place. Expansive grout is then pumped into the space between the existing column or pile and the jacket, filling any voids or irregularities in the column and creating "composite" load-bearing action between the column and the enclosing jacket. The jackets can be made with fiberglass or carbon fiber, depending on the project, and in any thickness, diameter or profile, says the company.

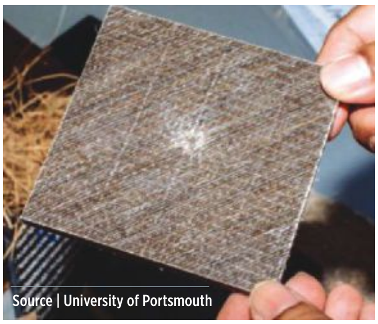
PileJax has been used in several bridge rehabilitation projects, including rail bridges across the Gold Coast canal system in Australia, and was selected for a major jetty rehabilitation project in Papua New Guinea involving rehabilitation of 150 marine piles.

BIZ BRIEF

Ingersoll Machine Tools Inc. (Rockford, IL, US) has announced that Chip Storie was appointed as CEO in October 2018, assisted initially by the company's previous CEO Tino Oldani. The company is part of the Camozzi Group (Brescia, Italy) and is the manufacturer of automated fiber placement (AFP) machines for composite part manufacturing — including the world's largest AFP machine, the Mongoose — as well as the WHAM (Wide and High Additive Manufacturing) 3D printing system for large components. The Camozzi Group Machine Tools division, which is made up of Ingersoll and Brescia-based Innse Berardi, offers specialized machining technologies for applications such as railway switches, rotor turbines, aerospace and defense components, and the laying of carbon fiber composites for the aviation industry. In 2018, Camozzi received offers for Ingersoll Machine Tools but announced that the machine tool builder will be retained by the Group as a key component in its portfolio.

Researchers develop biocomposite material from date palm fiber

A team of researchers, led by the University of Portsmouth (Hampshire, UK), has developed a biocomposite material using date palm fiber waste material to be used in non-structural parts such as car bumpers and door linings. The team also involved researchers from the University of Cambridge (Cambridge, UK), agricultural science research institute INRA (Institut national de la recherche agronomique, Paris, France) and University of Brittany, South (Morbihan, France).


Source | University of Portsmouth

The date palm fiber polycaprolactone (PCL) biocomposite is said to be fully biodegradable, renewable, sustainable and recyclable. In a study, published in the journal Industrial Crops and Products, researchers tested the mechanical properties of the biocomposite. They found that the date palm fiber PCL had increased tensile strength and achieved good low-velocity impact resistance when compared to traditional man-made composites.

Dr. Hom Dhakal, who leads the Advanced Materials and Manufacturing (AMM) Research Group at the University of Portsmouth and is co-author of the study, says, "Investigating the suitability of date palm fiber waste biomass as reinforcement in lightweight composite materials provides a tremendous opportunity of utilizing this material to develop low-cost, sustainable and lightweight biocomposites."

Date palm fibers are one of the most available natural fibers in North Africa and the Middle East.

BIZ BRIEF

LG Carbon Fibre Ltd. (Coseley, UK) recently announced that **Mitsubishi Corp.** (MC, Tokyo, Japan) has entered into an agreement to acquire 25% of shares in ELG Carbon Fibre Ltd. from ELG Carbon Fibre International GmbH (ECFI), a subsidiary of ELG Haniel GmbH (ELG, Duisburg, Germany). The agreement is subject to regulatory approval and other closing conditions.

Under the new agreement, Mitsubishi Corp. will promote the sales and marketing of ELG Carbon Fibre products through Mitsubishi's channels already engaged in the business of plastic resin sales. By uniting ELG's technology and Mitsubishi's global network and broad interface with different industries, the two companies aim to enhance the global business development and provide a reliable supply of reprocessed carbon fiber.

Source | TenCate

NIAR's NCAMP qualifying TenCate thermoplastic composite

The National Center for Advanced Materials Performance (NCAMP), a laboratory within the National Institute for Aviation Research (NIAR) at Wichita State University (Wichita, KS, US), reports that it is performing a full qualification on TenCate Cetex TC1225 T700GC 12K T1E unidirectional tape, 145 gsm with 34% resin content. The material is a low-melt polyaryletherketone (LM PAEK) that has a processing temperature of 50-75°C less than typical PAEK materials.

Rachael Andrulonis, senior research engineer at NIAR, told *CW*, "For this qualification program, an industry steering committee has been involved in the development of a test matrix best suited for the material type and potential applications. As this is the first PAEK thermoplastic NCAMP qualification, a number of trial studies (physical and mechanical) were completed prior to qualification testing. At this time, the prepreg material and most panels have been fabricated and delivered to NIAR. We are currently preparing the panels for machining and will begin testing in the next month. All mechanical and physical tests will be completed in 2019."

NCAMP has already qualified or is completing qualification of two other thermoplastic materials, both from Teijin (Rockwood, TN, US): Tenax-E TPWF PEEK-HTA40 E13 3K 5HS semipreg and Tenax-E TPCL PEEK-HTA40 E13 3K 5HS laminate.

Andrulonis also reports that NCAMP expects to begin qualification of other thermoplastic materials in 2019. "We are currently assessing industry needs and have not made a final selection of the materials," she says.

BIZ BRIEF

MTorres (Torres de Elorz, Spain) announced recently that, as of Oct. 9, 2018, Luis Pérez Oliva has assumed the role of chief executive officer (CEO), replacing César Fernández de Velasco who will become one of the company's directors. Oliva previously held the position of senior vice president for customers and markets for MTorres. He has broad experience in the aerospace sector and has held positions at Gamesa, Aernnova, CASA, Pratt & Whitney and BASF. Oliva holds master's degrees in aeronautical engineering (Madrid Polytechnic University) and finance (Rensselaer Polytechnic Institute).

CW MONTH IN REVIEW

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

New Zealand-based joint venture to design fully electric, carbon fiber passenger ferry
Stimson Yacht Design and Naval Architecture, Kit Carlier Design and Malcolm Tennant Designs have formed a partnership focusing on designing high-efficiency catamaran commercial ferries.
12/4/18 | short.compositesworld.com/CF_ferry

Audi, Airbus and Italdesign test flying taxi prototype
Audi, Airbus and Italdesign Pop.Up Next model flies and drives at Amsterdam Drone Week.
12/4/18 | short.compositesworld.com/flyingtaxi

Boeing to supply ELG carbon fiber for recycling
Under a five-year agreement, Boeing will supply carbon fiber recycling specialist ELG Carbon Fibre with cured and uncured material from its 777X wing manufacturing facility, as well as other locations.
12/5/18 | short.compositesworld.com/boeing_ELG

Web Industries joins National Composites Centre
As a member, Web Industries aims to cut aerospace component costs by determining optimum composite formatting procedures early in the design stage.
12/5/18 | short.compositesworld.com/Web_NCC

Composites One to distribute Solvay process materials and tooling products
Solvay has appointed Composites One as a new North America distributor for its process materials and tooling product lines.
12/12/18 | short.compositesworld.com/COneSolvay

Virgin Galactic completes successful spaceflight
The flight marks the first human spaceflight to be launched from American soil since the final Space Shuttle mission in 2011.
12/14/18 | short.compositesworld.com/VG_flight

OceanGate CEO pilots carbon fiber submersible in 4,000m solo dive
4,000m dive is the culmination of a comprehensive testing program in preparation for the vessel's planned 2019 Titanic Survey Expedition.
12/14/18| short.compositesworld.com/CFsubdive

BMW chooses SGL Carbon as supplier for iNEXT
SGL Carbon will supply carbon fibers and semi-finished textile products for a range of components in BMW's upcoming next-generation electric vehicle.
12/18/18| short.compositesworld.com/iNext_SGL

Gurit to divest composites components business
Gurit has decided to restructure its composite components business and has begun a divestment process for its business unit.
12/19/18| short.compositesworld.com/Gurit

JEC World 2019 Preview

The JEC World trade show and conference, the largest composites event in the world, will be held at the Paris Nord Villepinte Exhibition Center, March 12-14, 2019.

» The JEC World trade show and conference will be held at the Paris Nord Villepinte Exhibition Center from March 12-14, 2019. More than 1,300 exhibitors are expected this year, and they feature many of the established and new materials, machinery, software and services that are shaping the global composites industry.

JEC World 2019 includes a three-day technical conference, sponsored by Altair Engineering Inc. (Troy, MI, US) and featuring six sessions, each with a different market focus. This year, JEC is focusing on what it considers the hottest topics in the industry: additive manufacturing, aerospace, architecture and construction, automotive, simulation/design, and sports and leisure. As in past years, the JEC Innovation Awards will identify, promote and reward the most innovative composites projects worldwide, in a range of market sectors that include automotive and road transportation, aerospace, defense, security and ballistics, renewable energy, building and construction, infrastructure and civil engineering, oil and gas, medical and prosthetics, electronics, industrial equipment, furniture and appliances, sports and leisure, and marine. A panel of 10 technical, research and market experts will decide the award winners, to be announced on Wednesday, March 13. The Innovation Awards are supported by industry sponsor Kordsa (Istanbul, Turkey).

Four "Innovation Planets" will again be set up on the show floor. These are highly focused display areas featuring aerospace, auto and transport, construction and energy, and sports and lifestyle (which includes energy, sustainability, medical and other markets). The Planets allow companies or R&D centers to present novel and innovative parts or finished products to OEMs and suppliers visiting the show and will reportedly reflect the latest trends in each industry area. The Planets are supported by industry partners Hexion (Columbus, OH, US), Huntsman Advanced Materials (The Woodlands, TX, US) and Saint Gobain (Courbevoie, France).

For the third year, the Startup Booster competition, designed to foster entrepreneurship, will offer a forum for young companies to present themselves and their technologies to the industry. With the support of aircraft OEM Airbus (Toulouse, France) and automaker Daimler (Stuttgart, Germany), as well as a number of other industrial partners, the program highlights innovations that offer the potential to have a substantial impact. Attendees can listen to the pitches of the 10 finalists, which have been selected by a prestigious jury, on March 12 on the Agora Stage located in Hall 5.

In addition to the startups, more speakers have been engaged for the Agora Stage, including Bertrand Piccard, founder and chairman of the Solar Impulse Foundation; Enrico Palermo, president of The Spaceship Co.; Luciano De Oto, head of Advanced Composites Research Center & Body Structures Engineering for Lamborghini; and Carlo Ratti, architect and professor at the Massachusetts Institute of Technology.

Launched in 2018, the Composites Challenge will again give show visitors a chance to enjoy a competition for Ph.D. students, who have been selected based on the quality of their research work in the field of composites. The selected candidates will each have five minutes to pitch their theses using just one graphic. The Composites Challenge is supported by industry partner Zoltek Corp. (Bridgeton, MO, US), part of the Toray Group. CW

For more about JEC World, or to register, visit www.jeccomposites.com.

Bringing together composites professionals

JEC World 2019 is expected to host 1,300 exhibitors and more than 43,000 attendees, representing as many as 115 countries. Source | CW / Photo | Jeff Sloan

ABOUT THE AUTHOR

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Thermoplastic door a first for automotive composites

A team of automotive researchers is engaged in a four-year project with goals of building a lighter, 100% recyclable, carbon fiber-reinforced thermoplastic door.

By Sara Black / Senior Editor

FIG. 1 Designing a lighter door

The 2019 *MDX* A-Spec three-row SUV from the Acura division of Honda Motor Co. is the baseline for development of a thermoplastic composite replacement door in a project at Clemson University's Composites Center. Source | Honda

» Automotive OEMs and Tier 1s are grappling with the need to reduce vehicle mass to meet fuel economy and carbon emission targets. Composite materials have the potential to contribute significantly to this lightweighting push in many areas, but cost, design issues, unfamiliar processing and competition from other materials continue to present obstacles. To overcome these, many projects are investigating how composites can be integrated into multi-material automotive structures for maximum benefit.

One project addressing how composites can reduce automotive load-bearing structures is being conducted by the Clemson University (Clemson, SC, US) Composites Center, the Clemson University International Center for Automotive Research (CU-ICAR) and Honda R&D Americas (Raymond, OH, US), with support from the University of Delaware Center for Composite Materials (CCM, Newark, DE, US) and funding from the US Department of Energy (DOE, Washington, DC, US).

The project's focus, says principal investigator Dr. Srikanth Pilla, who is the Jenkins Endowed Professor of Automotive Engineering and Dean's faculty fellow at Clemson, is the question of whether composites can enable ultra-lightweight closure systems — doors, hoods, trunk lids — to complement concurrent advances in powertrain technology and better aerodynamics: "Within the technology portfolio for lightweighting, much of the 'low-hanging fruit' has been implemented already — for

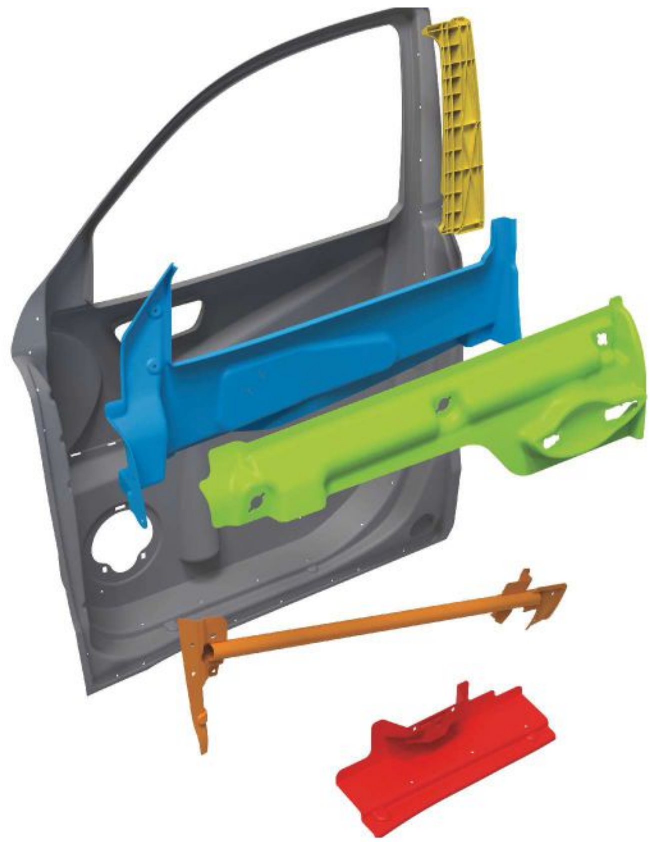

FIG. 2 The final design

The final conceptual design for the thermoplastic door, shown here, includes an inner frame structure (in gray), with beltline stiffeners (blue and green) and an anti-intrusion beam (in orange, made of steel) with a lower reinforcement plate of steel (in red). Sash reinforcement is shown in yellow. The outer, Class A panel, not shown, snap-fits to the inner frame. Source | Honda

example, engine downsizing. We believe there's potential for efficiency gains in the area of load-bearing, structural closure systems at a reasonable price point."

Collaboration, teaming are key

The four-year project, which began in 2016, came about as a DOE solicitation, part of the Obama administration's series of Grand Challenges to further science and engineering on many topics, including meeting automotive emission standards. The request for proposal asked for design and development of a car door that offered a 42.5% weight reduction over a standard OEM door, while maintaining similar crash performance, durability and use/misuse performance, and similar noise, vibration and harshness (NVH) performance. And, regardless of how the lightweight door was designed, it had to use commercially available material systems and scale to production volumes of at least 20,000 vehicles per year.

Honda came on board as the research project's OEM advisor because the project aligned with "our vision of ultimately creating an emission-free society," says Skye Malcolm, principal engineer, Advanced Planning & Verification Vehicle Development Foundations at Honda R&D Americas. Honda also added its own constraints to the project, he adds: "The door design to be developed by the team must use the same sealing geometry, have all of the same functional equipment as the baseline door, provide a Class A finish indistinguishable from the baseline and meet Honda durability and aging requirements." The team has brought an additional goal that the door be 100% recyclable. Perhaps most important, the DOE mandated a maximum allowable cost per pound of saved weight (over the baseline door) of $5. This meant that for a typical Acura *MDX* door weighing 31.8 kg, a 42.5% weight reduction would bring the overall target weight to 18.3 kg, which (at $5/lb of saved weight) meant the composite door could only *add* $150 to the cost of the door.

Supporting Pilla on the project are several undergraduate and graduate students, Dr. Gang Li, a professor of engineering mechanics at Clemson, and Drs. Bazle Haque and Shridhar Yarlagadda of the University of Delaware CCM, experts in multi-material composites. The team, says Pilla, faced a daunting challenge: "Simple material substitution was not a solution. We had to look at a systems approach, and Honda helped us to understand all of the door system elements down to the component level. Indeed, their partnership and involvement is unparalleled."

Designing a new door

Initial analysis included benchmarking of other OEM efforts at lightweight closures for limited market models, including Audi's aluminum door frame for its *A8* model, the Porsche *Panamera* magnesium door frame and BMW's *i8* carbon fiber-reinforced thermoset door frame. None of these previous OEM approaches, however, met this project's cost or weight goals. Says Pilla, "I wanted »

FIG. 3 The manufactured door

These renderings show the final carbon fiber-reinforced thermoplastic doors for the *MDX* as they will be manufactured. Source | Honda

to be part of something that would benefit the future, that would contribute to a circular economy. A thermoplastic door hadn't been attempted before, and it would be recyclable." When stacked up against other candidate materials, including thermoset composites, aluminum and steel, thermoplastics offered not only recyclability but very high potential for lightweighting and fast processing speeds (compared to thermosets) to meet production targets.

With the original Acura *MDX* door as the baseline (Fig. 1, p. 24), the team broke down its material mix: 62% metal, 21% rigid neat polymer, 13% glass and 4% elastomer. The greatest opportunity for lightweighting, 60%, would come from the metallic door frame, which the team intended to reduce from a baseline weight of 15.4 kg down to the target weight of 6.2 kg. While there was no chance to reduce weight in the door's internal components and electronics (radio speaker, servo for raising and lowering the window, door lock, etc.), the team determined the window glass weight could be reduced by 20%, perhaps making the glass thinner but without compromising the target metrics of NVH and durability. Further, the team estimated that the weight of trim elements on the door's inner surface could be reduced by 30%, or even eliminated.

The project's major tasks ran concurrently for the first two years. Some team members worked on material data generation, while others tackled door design specifics. The material data group generated material testing data for a variety of thermoplastics — continuous tapes, mats, short and long fiber-reinforced polymers and more — to determine candidate materials for the inner frame and outer panel; materials were contributed by a number of industry supplier partners. Data were evaluated via spider charts, with overall strength, shear strength, allowable cost, allowable density, stiffness and toughness making up the chart axes.

The best-performing material options following initial data evaluation — continuous fiber tapes and long fiber-reinforced thermoplastic pellets — underwent material modeling, explains Pilla: "It was possible to construct a simple orthotropic material stiffness matrix for the continuous fiber tapes, based on Hooke's law." For the long fiber-reinforced polymer, however, secondary simulations were needed to predict the strength and stiffness of an injection molded door part, because of anisotropy introduced by both the final part geometry and the mold-filling process. Adds Pilla, "Modeling of these long fiber materials is difficult, because not much has been done on simulation." To gather the data needed, the team developed a manufacturing optimization loop. Generic part shapes for the door's inner frame and outer panel were generated with Dassault Systémes' (Waltham, MA, US) SolidWorks 3D design software; mold-filling simulations of those shapes were conducted to determine melt flow vectors with the aid of Moldex3D software from Moldex (Chupei City, Taiwan); melt flow dynamics and collusion were analyzed to determine fiber orientation via Digimat software from e-Xstream (Hautcharage, Luxembourg, a Hexagon company); and mapped fiber orientations were used to generate a stiffness matrix using finite element

> The best-performing material options following initial data evaluation underwent material modeling.

analysis (FEA) tools, including material cards supplied by Altair Engineering Inc.'s (Troy, MI, US) HyperWorks CAE solution. As part shapes were modified, and as materials were tested, the optimization loop was repeated multiple times.

Concurrently, other team members worked on actual door concept development, and eventually, tooling and manufacturing simulations. Starting with rough sketches and high-level material selection, a range of designs was created. Then, rough CAD models were generated, along with initial FEA simulations for simple static load cases. In the fall of 2016, says Pilla, a design workshop was held at CU-ICAR where the team narrowed the door concept options down to seven, for further work. "Our design philosophy from the start was to maximize functional integration of parts and materials, minimize part count, maximize effectiveness of materials utilized through optimization and simplify assembly," says Pilla.

At this point, detailed CAD models were generated and FEA simulations were performed for each concept to validate static performance in compliance with Honda's targets. Taking into account manufacturability and integration of subsystems, Concept 7 (a space frame approach) began to converge toward Concept 2 (a one-piece structural frame), so the team decided to continue with Concept 2, incorporating lessons learned from the space frame approach. That concept consists of four elements: the outer Class A panel, the door internals, an inner frame or panel, and the interior trim elements.

Multi-material inner, Class A outer

The team selected materials and manufacturing processes for the final door design in mid-2018, with a design freeze on Jan. 15, 2019; tooling manufacturing and prototyping has begun. Figure 2 shows the details for the 1.2-mm-thick inner frame and its components (the outer Class A panel is not shown). "Beltline" refers to a styling line formed by the lower edge of the window glass, where stiffeners have been placed to help support the molded composite panels. Pilla notes that the anti-intrusion beam, for passenger protection in the case of a side impact, had to remain in steel to keep overall door weight lower — a composite beam with the same performance would have been too heavy. One key element of the design is the fastening system for connecting the inner frame to the outer panel. Pilla explains: "The outer Class A panel will be attached to the door at the end of the assembly line, which will allow associates to easily install the door internals beforehand, and also prevent any damage to the Class A surface during assembly." Molded snap-fit features on the inner frame are adjustable, to accommodate manufacturing tolerances in the Y direction, he adds, while slotted holes for metallic fasteners help to compensate for manufacturing tolerances in the X and Z directions, during assembly.

To help with weight reduction, the current door design has no conventional interior trim panel. Instead, a few functional molded parts were designed, including an injection molded map pocket, »

FIG. 4 Collaboration is key

Team members, from left to right, include Dr. Gang Li (Clemson), Dr. Istemi Ozsoy (Clemson), John Tierney (University of Delaware), Dr. Shridhar Yarlagadda (University of Delaware), Dr. Srikanth Pilla (Clemson), Veera Aditya Yerra (Clemson), Pardhvi Shah (Clemson), Sai Aditya Pradeep (Clemson), Sarah Legatt (Honda), and Skye Malcolm (Honda).

Source | Honda

an arm rest of natural wood back-molded with ABS plastic, and some leather padding laminated with foam. Together, these parts weigh 1.34 kg, as compared to the baseline interior panel at 3.49 kg. Pilla says the team expects to save more weight with design optimization.

Currently, FEA analysis and optimization is underway, to model both static load cases and dynamic crash loads that the composite door will have to withstand. The static load cases alone are daunting, and include door sag, beltline stiffness, mirror mount rigidity, door handle pull rigidity and more. The dynamic load testing, says Pilla, for now consists of the Federal Motor Vehicle Safety Standard (FMVSS) 214 quasi-static pole test, in which a vehicle door is crushed inward by a pole (which misses the roof and body) for 18 inches while all minimum force requirements are maintained: "This case is the least computationally intensive in comparison to the other two crash tests [the 75° FMVSS 5th Percentile Female (AF5) Pole test and the Insurance Institute for Highway Safety Side Impact Criteria Evaluation (IIHS SICE) test].

This will enable us to conduct more design experiments and optimization loops."

Adds Gang Li: "The integration of the composite manufacturing process and structural performance simulations with optimization algorithms is both intriguing and challenging. While the challenge lies in the complexity of the system and the scale of the computations involved, such integration merges the structural, material and manufacturing process design spaces together and provides us more opportunities for lightweighting and enhanced performance." And, meeting this pole test load case means the door is close to meeting the other two pole and side impact tests, he adds.

"Our tests so far show that the composite door easily meets the federal requirements, but our baseline Acura door's comprehensive performance is much higher than those requirements," says Pilla. FEA results so far show that

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the lightweight composite door absorbs more energy than the baseline door (23.59 kJ vs.15.34 kJ) which Pilla attributes to composites' ability to absorb additional deformational energy after the initial yield point. But, simulations show that improvements can be made, both to the outer beltline stiffener and to the reinforcement architecture of the inner frame.

With one year remaining in the initial project timeline, the group is generating manufacturing simulations and tooling approaches; creating a mass production plan for scale-up and estimated costs of a production line; and producing prototype(s) for crash and mechanical performance testing, fit and finish tests, and accelerated aging.

Says Pilla, "The composite door is still not achieving the target, due to the panels' thicknesses, and it is not completely optimized. While we're much lighter than the steel baseline, we have not yet met our 42.5% weight reduction goal, but we're optimistic we can accomplish it." A prototype door for fit and functional testing will be ready soon. The project team believes that the materials and technologies developed for this door can easily be scalable to other automotive components (for example, bolt-on and body-in-white parts), and the relatively low infrastructure cost of the composites processes can enable new OEMs and suppliers to implement these technologies — a win for automotive composites. CW

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Energy storage in multifunctional carbon fiber composites

A need for lightweight energy storage technology is fueling the development of carbon fiber composite materials for car batteries and other electronics.

By Michael LeGault / Contributing Writer

A lighter electric car battery

Hyperbat Ltd. (Coventry, UK), a joint venture of Williams Advanced Engineering and Unipart Manufacturing Group, launched in September of last year as an independent vehicle battery manufacturer, will be supplying an 800V battery system for the Aston Martin *Rapide E*, with first deliveries scheduled for Q4 2019. The car's battery has an installed capacity of 65 kW-hr generated from more than 5,600 lithium-ion cylindrical cells and is the first battery-powered car that does not add any additional weight compared to the internal combustion engine.

Source | Williams Advanced Engineering

» Driven by an explosion of mobile and portable electronic devices, as well as the proliferation of drones and electric vehicles (EV), the research race is on to develop new lightweight materials for energy storage technology — specifically, materials with longer life and higher weight- and volumetric-based efficiencies. Carbon and composite materials have been integral components of energy storage systems for several decades, one notable example being graphitic carbon-comprising anodes in lithium-ion batteries. The anodes generally consist of a carbon fiber composite manufactured with metal or metal oxides, coupled with polymer coating, barrier layers and some type of cathode, creating an electrical potential that causes electrons to flow through the circuit. Carbon fiber/polymer-matrix composites filled with conductive materials have also been go-to materials for electromagnetic interference (EMI) shielding used in a host of applications including aerospace, automotive and consumer electronics.

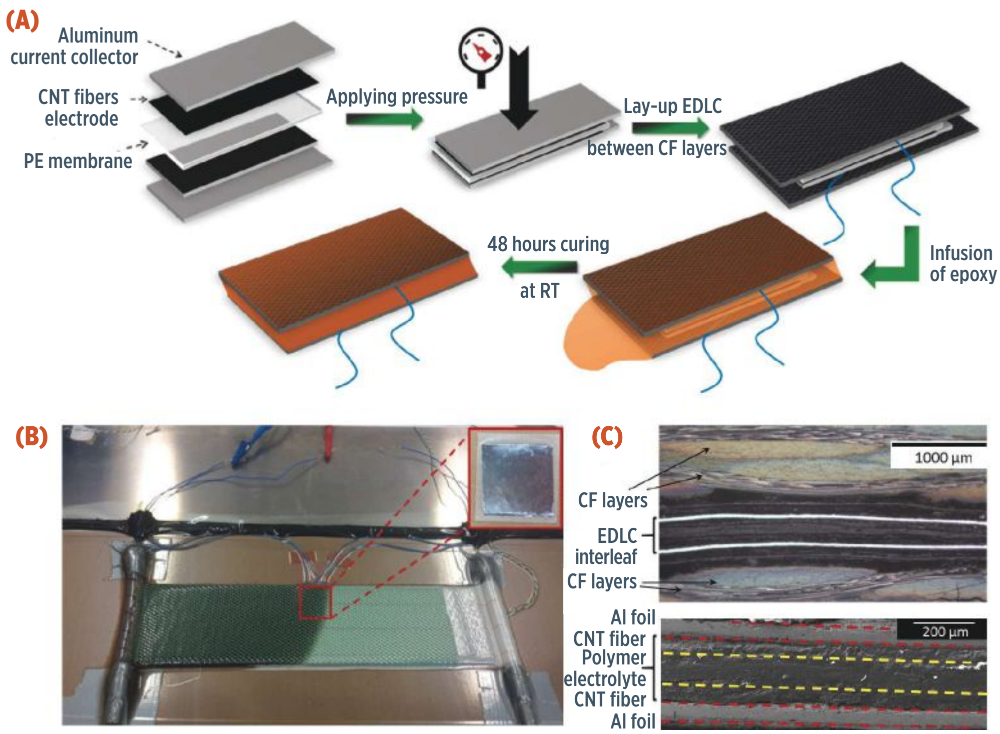
One emerging research approach in composites energy storage is minimization of the mass of batteries, fuel cells and capacitors via state-of-the-art materials, with the ultimate goal of increasing overall power densities. "One of the problems you have today is that about 50% of the weight of the battery can go to components that aren't producing energy," says Dr. Richard Collins, a senior technology analyst, IDTechEx (London, UK), which conducts independent market research on emerging technologies, including advanced materials.

In battery packs powering electric and hybrid vehicles, for example, one necessary component of a power system's overall mass is the battery casing. "High-voltage batteries, which can be upwards of 1,000V for performance EVs, generate a lot of radio frequency noise," says Simon Hiiemae, technical director at automotive heat management specialist Zircotec Group (Abingdon, UK). One way to protect the sensitive control electronics integrated into EVs, Hiiemae notes, is to place the batteries in a metal box, usually aluminum, which acts as a Farraday cage to absorb electromagnetic field or radio frequency interference, either from the battery itself or surrounding sources; however, this adds substantial weight. Replacing metal with lightweight carbon fiber composites removes the weight, but most composites are transparent to radio frequency noise and do not provide the required level of interference protection.

Zircotec Group has introduced a solution to this technological dilemma: a conductive two-part coating system that can be easily applied to battery casings manufactured from either carbon fiber- or glass fiber-filled composite materials. The coating's first layer, a thin aluminum alloy bond coat, is applied directly to the composite without any solvents or adhesives, and provides the conductivity required to shield the battery from interference. A second, ceramic layer is applied over the first metallic layer, protecting it from wear and corrosion; additionally, this ceramic layer can be modified to incorporate thermal-barrier protection, shielding the battery from external heat sources. Hiiemae reports that the coating is being tested by a number of vehicle manufacturers; he says the composite battery casing can save up to 4 kg/m² in weight compared to aluminum.

FIG. 1 Carbon nanotube EDLCs

A team of researchers at IMDEA Materials Institute has constructed an electric double-layer capacitor (EDLC) manufactured from thin sandwich structures. During manufacture, a layup constructed of a thin EDLC interleaf set between eight layers (4+4) of Hexcel HexForce high-strength carbon fabric is vacuum-infused with an epoxy vinyl ester resin (A). The final structural supercapacitor (SSC) (B) has a power density about three orders of magnitude higher than other SSCs studied thus far. The sandwich structures are interleaves made up of carbon nanotube (CNT) fiber veils and an ionic, liquid-based polymer electrolyte between carbon fiber plies infused with an epoxy resin (C). Source | IMDEA



Multifunctional materials

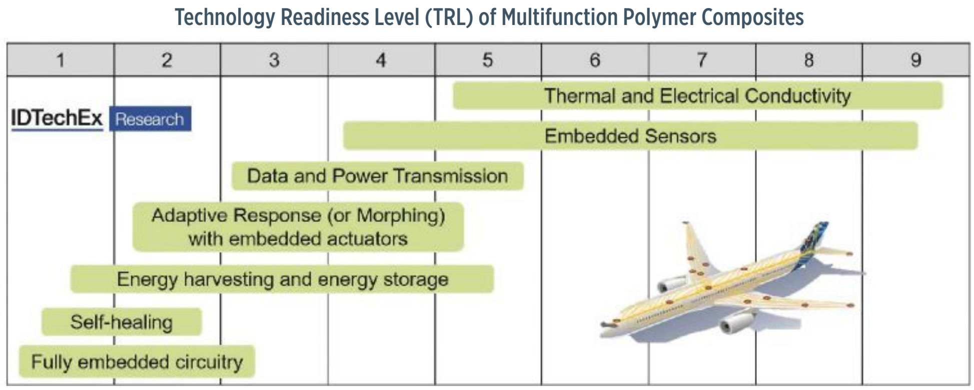
Also gaining traction in the energy storage industry is a structural laminate that can generate a current or store an electrical charge, an approach that attempts to *integrate* structural and electrical systems in power-consuming products. Such multifunctional materials, first proposed and explored in research largely targeting military and advanced aerospace applications more than 20 years ago, still face formidable technical challenges on the path to full commercialization. Nevertheless, over the last five to six years, tangible progress in the development of multifunctional materials has been reported on several fronts.

Composite structural supercapacitors (SSCs) show particular potential in the field, in part because of their relatively simple structure. An SSC stores energy via an electrostatic charge accumulation at the electrode/electrolyte interface, which is typically designed as a sandwich structure of two carbon, porous electrodes separated by a membrane and embedded in a liquid electrolyte with high ionic conductivity. Conventional commercial supercapacitors deliver high energy and power densities, long cycle life and reliable operation under a variety of temperatures and conditions. IDTechEx's Collins says that while SSCs could one day be used to power trains or cars, the earliest commercial SSC application will likely be in unmanned aerial vehicles (UAV) for military use. "SSCs integrated into UAVs could significantly extend range and operational time, a critical performance need," Collins says. "Also, the first commercial SSCs will be expensive to build, so they will likely be most appropriate for a military type of project."

An acceleration in the pace of multifunctional materials research is helping to push the technology toward commercialization. For example, an EU-funded project, SORCERER, is providing support for research into lightweight structural energy storage materials for electric and hybrid-electric aircraft. The project is aimed at developing advanced materials and technologies that can »

FIG. 2 Still in early development

IDTechEx's Technological Readiness Level (TRL) rating gives a technology a lower score if it entails mostly academic research and a higher rating the closer it is to full commercialization. The data mining suggests that multifunctional materials for energy storage and energy harvesting are still in a relatively early stage of development, shown here as slightly ahead of self-healing materials and fully embedded circuitry, but behind data and power transmission and embedded sensors. Source | IDTechEX



be used in both structural batteries and structural supercapacitors.

Another project involves the collaboration of a team of researchers at IMDEA Materials Institute (Getafe, Spain) with a number of aerospace partners from EU-funded programs like SORCERER, including Airbus. The team has demonstrated construction of a novel, electric double-layer capacitor (EDLC) manufactured from thin sandwich structures (see Fig. 1, p. 31). The structures are interleaves comprising carbon nanotube (CNT) fiber veils and an ionic, liquid-based polymer electrolyte between carbon fiber plies infused with an epoxy resin. Dr. Juan Jose Vilatela, head of the multifunctional nanocomposites group at IMDEA Materials,

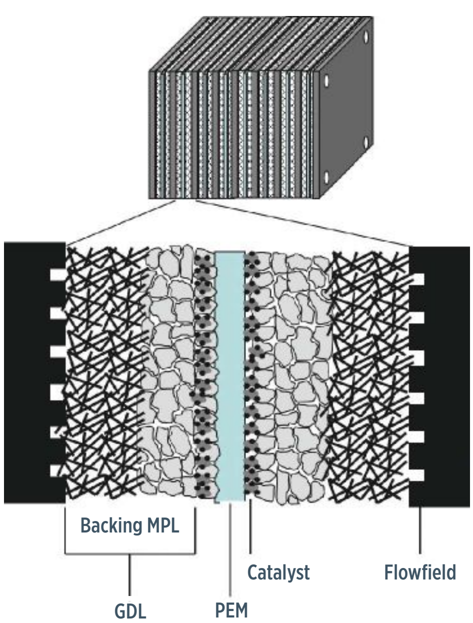


FIG. 3 Polymer-electrolyte membrane fuel cell

SGL Group's polymer-electrolyte membrane fuel cell (PEMFC), used to power Hyundai's zero-emission car *NEXO*, consists of two flowfields, comprising two gas diffusion layers (GDLs) and two carbon-supported noble metal catalyst layers, each separated by a proton exchange membrane. The GDLs are, in turn, a bilayer structure that consists of a macro-porous backing material (carbon fiber paper) and a micro-porous carbon-based layer. The membrane electrode assemblies are built as a layered laminate wherein one GDL acts as the anode and the other GDL layer performs as the cathode.

and one of the participants in the research, says the composites produced in the project are noteworthy for achieving high specific capacitance and power density of 88 mF/g and 30 Wh/kg respectively. This is one to three orders of magnitude higher than the best-performing structural materials. The material also has an energy density of 37.5 Wh/kg, currently one of the highest measured values of structural supercapacitors studied thus far.

Vilatela says CNTs come with the inherent advantage of a 1,000X greater surface area compared to carbon fiber fabrics. CNTs also have high electrochemical stability. To manufacture the EDLC composites, a layup constructed of a thin EDLC interleaf set between eight layers (4+4) of Hexcel (Stamford, CT, US) HexForce high-strength carbon fiber fabric, G0926, was vacuum infused with an epoxy vinyl ester resin, Derakane 8084, supplied by Ashland LLC (Columbus, OH, US), with full cure achieved in 48 hours at room temperature. The interleaf consists of a sandwich structure comprising, from the middle out, a polymer electrolyte membrane approximately 100-120μ thick, set between two CNT fiber sheets, both of which are affixed to thin aluminum current-collector plates (Fig. 1, p. 31). The carbon nanotube fibers were synthesized by a direct spinning method using iron and sulfur catalysts and butane as a carbon source (see Learn More).

Prior to being positioned between the outer layers of carbon fiber fabric, a small amount of pressure is applied to the interleaf to execute impregnation of the soft electrolyte membrane into the porous CNT fiber sheets. Samples of the EDLC produced for this study were approximately 4 cm^2 — the size of a typical laminate structural beam — although Vilatela says *self-supporting* EDLCs, which are made to be used without need for additional structural supports, can be produced in sizes as large as 100 cm^2. *In situ* electromechanical measurement of the EDLC samples during four-point bending tests show that electrochemical performance is retained up to the point of fracture. This test was a crucial performance validation of the material, given its application as both a structural and energy storage material.

The IMDEA group's use of unidirectional CNT fabrics to construct the SSC distinguishes the project from similar concurrent work employing a variety of "activated" carbon fiber fabrics as energy-storage materials. One such project, cited in Vilatela's, et al. paper published in *Scientific Reports* (February 2018), used an infusion technique to grow a high specific surface area carbon aerogel (CAG) around carbon fiber fabrics. Combined with an ethylene-glycol matrix containing 10% lithium ions, the technique produced a material with a calculated energy density of only 0.84 m Wh/kg, which is low compared to the energy density achieved with EDLC comprising CNT fibers. The technique, specifically when using the high specific surface area CAG, produced a composite with a shear modulus of 895 MPa, which is comparable to traditional structural composites. The CNT composites in the IMDEA study, by comparison, had a flexural modulus of 60 GPa and a flexural strength of 153 MPa, values on par with a typical unfilled polyimide and below the strength and stiffness properties required for composites used in primary structural applications.

The results of each of these projects demonstrate, in broad brushstrokes, one of the challenges facing the attempt to develop fully commercial, multifunctional materials suitable for a broad range of applications: namely, it is difficult to build composites with adequate electrical *and* structural properties.

Collins thinks the current tradeoff between structural and electrical properties will not be a major barrier to the adoption and commercialization of the technology. "I don't think the fall-off in structural properties in some of these new composite energy-storing materials will be a factor limiting their usefulness," he says, "because even if you have a slightly worse performing carbon fiber reinforcement, it will still have enough strength and stiffness to be useful in certain applications." A potentially bigger issue, he believes, is the question of how to design and mechanically integrate solid polymer electrodes and electrically insulating but ionically conductive separators. Additional challenges include cost-effective manufacturing and safety.

IDTechEx has researched and rated the technological readiness level (TRL) of various multifunctional polymer composites (Fig. 2, p. 32). The rating system is based on a range of criteria, including whether the research is still mostly academic (which produces a low rating),

SIDE STORY

Synthetic graphite now preferred

One of the trends in the design and production of fuel cells and lithium-ion batteries (LIB) is the preference of synthetic graphite over natural sources. Kevin Krauss, marketing, SGL Carbon, says there are both scientific and political aspects to the trend. Unlike natural graphite, which comes mainly from China, the raw materials for synthetic graphite (petroleum coke, pitch coke, carbon black, etc.) are widely available, and production therefore entails less geopolitical risk. Also, where the quality of natural graphite depends on metal impurities and other factors, synthetic graphite can be produced to a custom-made formula with isotropic properties, better cycle life and an energy density close to theoretical value.

whether the technology is being prototyped or tested (producing a higher rating), or if the technology is reaching commercialization (highest rating). The data mining reveals that multifunctional materials for energy storage and energy harvesting are, based on IDTechEx's criteria, still in a relatively early stage of development — slightly ahead of self-healing materials and fully embedded circuitry, but falling behind power transmission and embedded sensors. "When you look at the electrodes of SSCs, for example, one of the challenges is how to improve the surface area appropriately," Collins notes. "CNTs show promise, but there's still a ways to go to prove it commercially."

LEARN MORE

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

Read more about IMDEA's CNT fiber | short.compositesworld.com/aerocomp

Automotive energy technology leading the way

In automotive racing, however, the future in advanced materials energy storage is already here. Cars manufactured for the Formula E circuit, the first fully electric FIA racing series, running since 2014, are powered with advanced, multifunctional composite, 800V structural batteries. The battery technology was developed and manufactured by Williams Advanced Engineering (Grove, UK), the sole supplier of batteries for cars built for the Formula E grid. The typical Formula E car has about 250 hp (190 kW), can accelerate from 0 to 100 kmh (0 to 62 mph) in 3 seconds, and has a maximum speed of 225 kmh (140 mph). See *CW*'s November 2018 *Focus on Design* story, "Pushing EVs forward," for more information on Williams Advanced Engineering's structural battery systems for consumer vehicles such as the battery electric *FW-EVX*.

On another front, Hyundai Motor Group (Seoul, South Korea) is employing hydrogen fuel cell technology supplied by SGL Group (Wiesbaden, Germany) to manufacture its zero-emission car *NEXO*. The production car caps years of development work and cooperation between the car manufacturer and SGL, during which Hyundai optimized the hydrogen-powered drivetrain and other components on its *iX35* demonstration fuel-cell car. Since commencing production in March 2018, Hyundai has reported selling an average of about 45 units a month, a pace estimated to culminate with sales of more than 500 units in 2018, a new single-year sales record for a hydrogen fuel-cell car.

The core of the technology in the *NEXO* is the SIGRACET fuel cell, a polymer-electrolyte-membrane fuel cell (PEMFC) developed and sold by SGL. The PEMFC generates electrochemical power by converting hydrogen fuel into electricity, with heat and water as the only byproducts. A single PEMFC cell consists of two flowfields, comprising two gas diffusion layers (GDLs) and two carbon-supported noble metal catalyst layers, each separated by a proton exchange membrane (Fig. 3, p. 32). The GDLs are, in turn, a bilayer structure that consists of a macro-porous backing material (carbon fiber paper) and a micro-porous carbon fiber-based layer. The membrane electrode assemblies are built as a layered laminate wherein one GDL acts as the anode and the other GDL layer performs as the cathode. The PEMFC is sandwiched between two bipolar plates (BPP) made from graphite, coated steel or titanium. The BPPs form the structural components of the stack and are designed with channels to accommodate coolant flow and water outlet. Automotive PEMFC systems typically consist of stacks of up to 400 cells with a power output of around 80-120 kW.

Composites in energy storage are progressing, but making cleaner, lighter energy sources a large-scale reality will depend on working out the details in advanced technologies such as fuel cells, structural batteries and structural supercapacitors. CW

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Withstanding fire without the weight

New composites meet stringent fire requirements while lightweighting ships, rail cars and battery boxes.

By **Ginger Gardiner** / Senior Editor

FR materials for a range of resin-infused structures

SAERcore LEO comprises chopped glass fiber mat and FR-treated PP foam core to deliver drapability and resin flow for complex shapes (top) while SAERTEX LEO COATED FABRIC (bottom) meets even exterior burn-through requirements for rail floors via an intumescent material that creates an insulating foam when exposed to fire. Source | SAERTEX

The list of mechanical functions that composite materials are expected to provide is well known and long: Strength, stiffness, toughness, durability, weatherability, corrosion resistance, impact resistance, fire resistance. This last requirement is one that composites have been addressing for many years. However, the industry is seeing an uptick in demand for fire performance, driven by the development of electric vehicles (EVs) — both on the ground and in the air — and increased penetration, finally, into the fire-conscious rail, marine and construction markets.

Material suppliers are responding to that market pull, but the industry cannot rely only on traditional fire-resistance solutions to meet the demands of this market. For example, furan and phenolic resins have long been solutions for fire-resistant composites. They are, however, crosslinked via condensation reactions, which makes processing more difficult, often creating porosity that requires multiple operations to achieve a good surface finish. They also tend to be brittle. Meanwhile, fire retardants such as aluminum trihydroxide (ATH), added to resins to provide fire resistance, typically require a loading of 20% by volume, which can adversely affect processing, mechanical properties and surface finish. Halogenated flame retardants, once an attractive alternative, are now banned by pan-European regulations including REACH and RoHS. Thus, the composites industry continues to research and develop new solutions.

Fire-resistant materials must also provide sufficient time and protection for occupants to escape in case of fire. In the most stringent applications, this means not only preventing the spread of flames, the release of heat, the transmission of temperature and the formation of toxic smoke, but also maintaining load-carrying capability in the composite material for as long as 60 minutes.

FR methods and measures

Generally, inorganic fibers (e.g., glass, carbon, basalt, ceramic) and inorganic matrix materials (e.g., ceramic/carbon, metals, polysialate/geopolymers) do not burn, and many can withstand high temperatures. However, most *organic* fibers and polymer matrices will decompose when exposed to high temperatures and fire and may also release flammable gases and toxic smoke. KEVLAR para-aramid and NOMEX meta-aramid

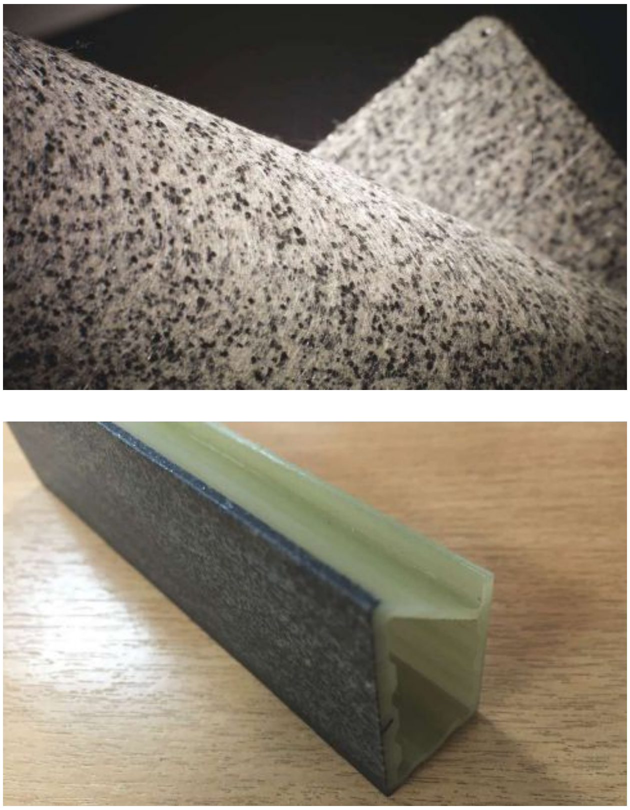

FIG. 1 One intumescent veil, many versions

Technical Fibre Products' Tecnofire fiber and particle composition are tailored for each application — more than 100 versions have been developed to date (see above photos). They are well-suited for pultrusion, RTM and resin infusion processes. Source | TFP

FIG. 2 Light RTM rail floors

SMT is using SAERTEX LEO SYSTEM and a light RTM process to produce 25,000 m^2 of composite railcar floors to replace plywood in Deutsche Bahn's ICE Version 3 high-speed trains. Source | Deutsche Bahn

organic fibers are notable exceptions, being organic fibers with inherently flame-resistant chemical structures.

A composite's fire performance is measured by a variety of characteristics, including ignition, ability to self-extinguish, flame spread, burn-through, heat release, smoke generation and smoke toxicity. Another frequently cited requirement is limiting oxygen index (LOI), which measures the minimum oxygen concentration (in percent volume) necessary for combustion; thus, higher LOI means higher flame resistance. The standard tests for these performance measurements vary by industry and range in test sample size from small coupons to full-scale constructions representative of in-service use (see Learn More).

There are two main approaches for improving fire performance in composites: Increase the flame resistance of the matrix and/or reinforcing fibers, or provide a protective coating.

Fibers can be treated with flame retardants (FR) such as borax/boric acid mixtures and ammonium salts of strong acids. Flame retardance in *matrix resins* can be improved by three basic methods: incorporating an FR compound into the polymeric backbone; mixing FR compounds, particulates and/or nanomaterials into the resin; or adding an intumescent to the matrix. Intumescents are substances that are activated by heat to expand and form a porous, carbonaceous char that thermally insulates the underlying composite and inhibits production of flammable volatiles. Coatings may use FR additives or intumescents.

FR additives may exploit multiple mechanisms to slow composite decomposition, heat release and flame spread. For example, additives may decompose via an endothermic reaction, cooling the composite. This decomposition may also produce water and noncombustible gases that dilute the concentration of flammable gases. Additives may also char and/or produce a gaseous layer that excludes oxygen and suffocates the fire. Often, two or more FR agents are combined synergistically to increase and broaden a composite's fire performance — for example, one FR compound may reduce heat release, while the next reduces smoke and the third produces char.

FR options for infusion

A systems approach is exactly what materials supplier SAERTEX (Saerbeck, Germany) has pursued with its LEO series of FR products, which include the company's noncrimp fabric (NCF) reinforcements as well as FR foam cores and ATH-filled or intumescent coatings. The series' first product, LEO SYSTEM, which was launched in 2013, combines FR-treated SAERTEX fabrics with FR resins and FR or intumescent gelcoats. "We wanted to close the gap between fire performance and mechanical performance," »

FIG. 3 Bio-based PFA prepreg replaces phenolic in rail components

TRB Lightweight Structures unveiled its CFRP rail car door leaf in June 2018, using bio-based PFA prepreg to cut weight by 35% vs. bonded aluminum. Barcella's cantilever rail car seat support also uses carbon fiber/PFA prepreg, supplied by Composites Evolution.

Source | TRB Lightweight Structures and Composites Evolution

explains Jörg Bünker, SAERTEX head of R&D/application service for LEO. "With LEO SYSTEM, it is possible to get high fiber content *and* high fire performance. We started with a modified fabric and vinyl ester infusion resin that does not use ATH or other fillers, but instead is treated with liquid fire retardants. It also avoids all halogens and bromides, so no toxic materials, which means no toxic smoke or fumes."

The SAERTEX LEO SYSTEM is being used in the floors of 66 ICE Version 3 high-speed trains in Germany, cutting weight by 50% versus previous plywood panels (Fig. 2). The composite panels average 2.4 by 1.2m in size and comprise SAERfoam core, glass fiber NCF skins, LEO infusion vinyl ester resin and a LEO protection layer in the finish. Using vacuum infusion with reusable silicone membranes from Alan Harper Composites (Cornwall, UK), the floor panels are made by SMT Montagetechnik (Forst, Germany), the exclusive supplier to Deutsche Bahn, producing 25,000 m^2 of panels for the 66 eight-carriage trains.

Bünker says LEO SYSTEM has been well-received, "but some customers wanted to use epoxy, polyester or thermoplastic resins, so we developed LEO COATED FABRIC." SAERTEX applies the intumescent coating after fabric manufacture. "It impregnates the fibers a bit, enabling a good connection to the composite," he explains. "It cannot wear or scrape off like some paints. In a fire situation, the intumescent coating creates a foam, insulating the composite from flame and thermal energy. It provides fire resistance for load-bearing structures without smoke or toxic fumes, meeting the highest requirements." LEO COATED FABRIC is supplied in rolls and used like any other infusion fabric. "The only thing to watch," Bünker cautions, "is if you use it as an inside skin, placed beneath the vacuum bag during infusion, because you cannot impregnate through this layer to any laminate layers underneath."

The third product, SAERcore LEO, "is a micro sandwich material comprising chopped strand mat (glass fiber) on both sides of a specially FR-modified polypropylene (PP) core," says Bünker. "This material combination is easy to drape and provides good resin flow during infusion." SAERcore LEO is placed into a molding tool with a countermold in a light resin transfer molding (light RTM) process. "You can adjust the part thickness via the cavity between the mold and countermold," he notes, "and can calculate how much resin content you want up front." It is available in a range of densities and thicknesses, and can be used with vinyl ester, epoxy and polyester resins. "You can add ATH to the resin if you want to combine FR methods," says Bünker. "The material has been used most often with polyester RTM applications."

SIDE STORY

Lightweight FR for bridge and bus structures

Source | *CW* and TFP

"Buses often require extra fire protection in vulnerable areas," explains TFP business development associate Scott Klopfer. North American Bus Industries (NABI, acquired by New Flyer, Toronto, Canada in 2013) chose TFP's Tecnofire intumescent nonwoven veil to protect the resin-infused vinyl ester composite doors and wheel wells of its CompoBus. Such parts comprise a gel coat or paint as the outer surface, followed by Tecnofire with a resin matrix, an outer skin using glass or other fiber, a core material and then an inner skin. Tecnofire has also been used in trains and people movers, including the BART and MARTA systems in San Francisco, CA, and Atlanta, GA, respectively.

Another application was in wind fairings (see white curved panels along left side of pictured bridge deck) for the Whitestone Bridge (the Bronx, NY, US) where replacing steel with composites reduced load on the bridge by 6,000 MT. "Traditional materials have been entrenched for so many years," says Klopfer, "but now there is a movement to reduce weight and expand design freedom." Klopfer is also seeing an uptick in other architectural applications of Tecnofire. Go to **short.compositesworld.com/TecnoFR** for more.

All three SAERTEX LEO products have passed the European rail applications standard EN 45545, including the most stringent HL3 class for underground and high-speed trains. SAERcore LEO is being used by global rail products supplier BARAT Group (Saint Aignan, France) to produce access doors for Stadler's (Bussnang, Switzerland) SMILE high-speed trains. The doors feature complex molded areas, made in a single piece using RTM with FR resins.

SAERTEX LEO products have also passed ASTM E84 for building applications, and were used by Carbures Civil Works Spain (Puerto de Santa Maria, Cadiz) to infuse cored panels for the lightweight roof of the Pavilion of Inspirations in the Norman Foster Foundation headquarters (Madrid, Spain).

Intumescent veils

Another fire-resistant solution for use in composites is intumescent veils. Tecnofire is a family of intumescent nonwoven products made by Technical Fibre Products (TFP, Burneside Mills, UK and Schenectady, NY, US) using a wet-lay process (Fig. 1). Made in roll form, the products range from 0.4-10 mm in thickness (0.5-2.0 mm is the most common). Its maximum width is 50 inches and it can be slit into tapes as narrow as 0.25 inch wide. Tecnofire can be used with pultrusion, RTM and vacuum infusion processes with a range of resins including epoxy, vinyl ester, unsaturated polyester, thermoplastics and FR-modified systems from Ashland (Columbus, OH, US) and Polynt (Carpentersville, IL, US).

"When Tecnofire materials reach 190°C, they activate and expand unidirectionally in the z direction up to 35 times their original thickness," explains TFP business development associate Scott Klopfer. "That expansion, which is irreversible, forms an insulative char layer. Tecnofire is typically used at a part's surface, where it would be exposed to heat and flame during a fire." Tecnofire has been specially designed to be stable during a fire and protect underlying structures.

"We have a lot of freedom in what we can put into this material, including different types of fibers and particles," Klopfer explains. "We tailor the composition for each application. For example, we can add ATH as a powder during the Tecnofire manufacturing process and disperse it evenly throughout the material." He contrasts this with the traditional process of adding ATH to the matrix resin, which can cause increased viscosity. "The ATH can also migrate or filter unevenly during the molding process," Klopfer says. "Tecnofire avoids these problems."

TFP has created more than 100 versions since Tecnofire's inception in 2005, with 10-15 grades commercially in use. One has epoxy resin already infused into it, available in 4-by-8-ft sheets, like plywood. "This was created for an industry where they needed a veneer type of material," he explains. "It is one of the highest expanders. We also have a version that is electrically activated using metal-coated fibers for a conductive, fire-resistant composite."

Applications include continuous profiles with built-in fire protection for use in roof systems, window and door frames, steel beam coverings and modular composite housing kits. "It is also »

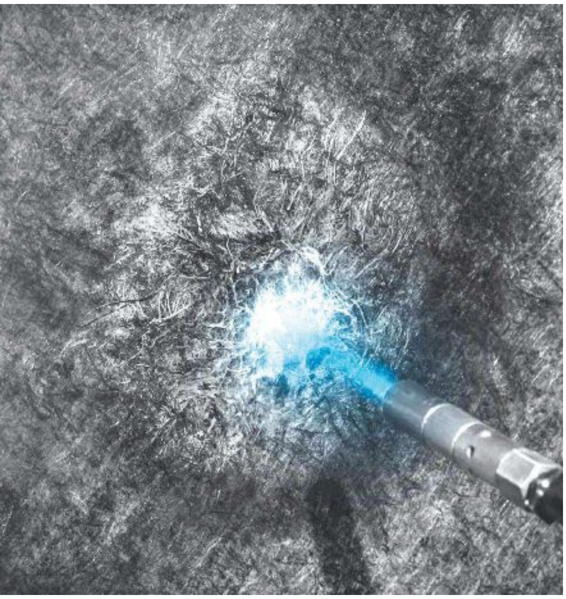

FIG. 4 Two hours at 1200°C, no burn-through

CFP Composites combines chopped carbon fiber and inorganic resin to produce its FR.10 materials, which have withstood direct flame and 1200°C for 2 hours with no burn-through and sufficient thermal insulation to place a bare hand on the back side. Source | CFP Composites

used for 45- and 90-minute rated doors, providing a solution to pass the UL 10C Positive Pressure Tests of Door Assemblies," Klopfer says. "This standard ensures that doors remain intact to prevent spread of flame and hot gases between rooms. At the end of the test, the door has to withstand a high-pressure water fire hose and still have integrity to stay in place."

Bio-based FR prepregs

Polyfurfuryl alcohol (PFA) is a thermoset resin that meets phenolic performance with better surface processing and sustainability. Its manufacture begins with hemicellulose derived from biomass — corn cobs, rice and oat hulls or sugar cane waste (bagasse) — which is converted to the furan-based furfuryl alcohol and then polymerized (via acid catalysts or temperature) into PFA. "Glass/phenolic has been the go-to material for such a long time, but if you want to accelerate weight reduction, you look at carbon fiber and PFA," says Gareth Davies, commercial manager at prepreg supplier Composites Evolution (Chesterfield, UK). Its Evopreg PFC prepregs combine PFA resin and reinforcements such as flax, glass, aramid, basalt or carbon fiber, and have passed FAR 25.583 flame, smoke and toxicity (FST) tests for aircraft interiors as well as EN 45545 class HL3 for rail.

Another company offering PFA prepregs is SHD Composites (Sleaford, Lincolnshire, UK). The company was founded in 2010 by Steve Doughty, a 20-year process development engineer with Advanced Composites Group. SHD Composites has grown significantly, adding factories in Slovenia and Mooresville, NC, US. It offers two PFA-based phenolic resin products: FR308 and PS200.

Developed as a phenolic replacement for aircraft interiors, FR308 passes all aircraft FST requirements as well as EN 45545 HL3 for rail. PS200, which meets fire protection requirements for aircraft batteries mandated by the European Aviation

Safety Agency (EASA), is already in use at manufacturers of general aviation aircraft. In a lab test recreating thermal runaway conditions for lithium-ion batteries, a prototype battery box made using PS200 proved its performance. "Though the inside temperature reached 1100°C, the outside never exceeded 250°C and the box never burned or decomposed," says SHD Composites technical director Nick Smith. The company is now working with several electric vehicle engineering companies on battery boxes for cars.

Both PS200 and FR308 are formulated to handle like an epoxy, typically curing at 120-130°C in one hour. Both also pass BS 476, the British material specification for building interiors, which Smith sees as a sizable emerging market.

Smith highlights rail as another market for PFA materials that is developing rapidly. "We are bidding on quite large projects," he adds. Davies agrees, citing several exhibits at the 2018 InnoTrans International Trade Fair for Transport Technology in Berlin, including the CETROVO metro train by the world's largest rolling stock manufacturer, China Railway Rolling Stock Corp. (CRRC, Beijing), which features a carbon fiber composite car body, bogie frame and driver's cab equipment cabinets. Meanwhile, Composites Evolution has worked with composite structures manufacturer Bercella (Varano de Melegari, Italy) to develop a lightweight composite support for rail seats (Fig. 3, p. 38). "It is quite a chunky, heavy part in metal," says Davies. The 1m-long part made from carbon fiber Evopreg, however, weighs less than 5 kg. "Multiply the weight savings by the number of seat supports per rail car, and the composite redesign reduces the axle load substantially."

Bio-based PFA prepreg is also featured in a carbon fiber reinforced plastic (CFRP) sandwich panel door leaf developed by TRB Lightweight Structures (Huntingdon, UK). Compared to bonded aluminum door leaves, this sustainable CFRP alternative, featuring a 100% recycled foam core, cuts weight by 35% — from 40 to 26 kg — at a comparable part cost. TRB's lightweight door leaf meets EN 45545 HL3 with an expected 40-year service life, offering fatigue resistance and lower maintenance costs vs. aluminum, as well as a lighter-duty door operating system for further weight and energy benefits.

Though both Composites Evolution and SHD Composites also offer FR epoxies, Davies says that in terms of test data, "they cannot provide the full FST performance provided by PFA-based resins, and they are more expensive." Smith notes that FR epoxies still have higher toughness, "but PFA resins have better toughness than phenolics, and we are working on formulations to further improve that. Also, the fire retardants in FST epoxies slow down the effects of fire, but they will still burn and give off toxic fumes. When PFA burns, it's only releasing CO_2 — no toxic gas is produced."

PFAs also can outperform traditional phenolics in surface finish. "This is a big issue in aircraft interiors," he explains. "Manufacturers want better part quality the first time without the need for rework. Historically, FR composites have been harder to process, requiring multiple rounds of surface prep due to porosity. PFA systems offer an improved surface finish with increased glossiness. This is confirmed by the Horizon 2020 project IntAir, which showed » that directly substituting PFA prepreg for phenolic reduced molding cycle time by 34%, manual finishing by 70% and cost of final interior components by 58%.

Eliminating organic materials

There are also new composite technologies that achieve fire resistance by foregoing organic materials completely, relying solely on inorganic fibers and polymers. Traditionally, inorganic polymers have tended to be expensive and/or difficult to process. Some are also brittle and/or sensitive to notching and impact damage. However, polysiloxane, polysilane and polysialate/geopolymer can be blended into a resin or synthesized into the backbone of organic polymers, as can the base inorganic monomers. This approach has been used successfully in FR development work with polypropylene, polyethylene, epoxy, polyvinyl, polyester, polyamide and polyurethane resins. Geopolymers, especially, seem to offer potential in current research.

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CFP Composites (Solihull, UK) combines chopped carbon fibers and inorganic resin to produce what it calls FR.10, which has passed seven-hour fire resistance tests at 1500°C while emitting almost no smoke or gas (Fig. 4, p. 40). The materials offer a cost-effective, structural alternative to metal that is lightweight — 2-mm-thick FR.10 weighs less than 3 kg/m^2 and 5-mm-thick is less than 6 kg/m^2. FR.10 has also passed structural tests under load, withstanding direct flame at 1200°C for two hours, with no burn-through while providing enough thermal insulation to place a bare hand in full contact on the back side. It is available in 1.3 by 0.8-m sheets in thicknesses up to 20 mm and can be easily joined or bonded using conventional fasteners or adhesives.

The process used to make FR.10 combines the chopped fiber and inorganic resin in a water-filled mix. This mix is then released, producing fully resin-infused flat and net-shaped preforms with x-, y- and z-direction fiber structure in seconds. These are then transferred to a 1,000-MT press and compression molded to form flat sheets or shaped parts. "We can produce lightweight parts very quickly, with no waste," says CFP Composites managing director Simon Price. Patented globally, this process enables lower cost versus conventional composites, while the inorganic composition delivers higher fire performance. "The two key hurdles for composites adoption in building/construction, heavy ships and oil and gas are cost and fire regulations," says Price. "We are opening new applications for composites, replacing metals or ceramics."

Another new solution is fi:resist for pultruded non-flammable profiles. It was developed by FISCO GmbH (Zusmarshausen, Germany), a joint venture founded in 2015 between German fastening specialist Fischer (Waldachtal) and in-vehicle equipment producer Sortimo (Zusmarshausen). At the 2018 European network for lightweight applications at sea (E-LASS) Seminar Day (June 26, Pornichet, France), Fisco product manager David Thull described fi:resist as using 100% inorganic materials that produce no fumes when exposed to flame. In addition, the matrix and glass fibers reportedly maintain their strength up to 1000°C and 600°C, respectively. The material also provides high thermal insulation and reportedly meets DIN 4102-1 and EN 13501-1 requirements for the most stringent Class A1 construction materials.

Thull describes using fi:resist for fire-resistant cable ducts, enabling larger spans with fewer supports thanks to the material's high structural performance. He says future applications could expand to the automotive and aerospace industries.

Continued development

Nanoclays are another area of significant development, showing potential for high FR performance at low cost. They promote formation of char, and because of their small particulate size and ability to disperse at a sub-micron scale, smaller amounts of nanoclays are needed compared to macro-scale additives. When uniformly dispersed in a resin system, nanoclay amounts of 5-10% by weight can reduce peak heat release by 70%. Initial work on graphene nanoplatelets (GNPs) and carbon nanotubes (CNTs) have also shown positive results.

While EU-funded development programs such as MAT4RAIL and FIBRESHIP pursue significant milestones in new FR materials and improved composite performance, there are numerous other high-potential initiatives. For example:

- US Navy program to replace PMR-15 with a sustainable resveratrol-based phthalonitrile resin;
- Hybrid polymer/inorganic foams developed in India that, without FR additives, are self-extinguishing, do not drip or collapse from flame and show a 75% lower peak heat release rate than commercially available fire-retardant polyurethanes made using ice scaffolding and water as the solvent/porogen;
- MAI Sandwich aircraft interiors comprising foam core and CFRP laminates, all made using Ultrason E polyethersulfone from BASF (Ludwigshafen, Germany), processed into 1-3m^2 panels in less than 5 minutes via automated thermoforming and overmolding.

"Our goal is that by providing a variety of high-performing materials, fire retardance becomes not the main issue for the customer, who instead can focus on meeting the needs of the project overall," says Bünker at SAERTEX. The composites industry as a whole is well on its way to that end. CW

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Plant tour: Meggitt San Diego, CA, US

This aerospace and defense fabricator upgrades to a larger facility and gets, in the process, a chance to rethink and optimize material, people and process flow.

By Jeff Sloan / Editor-in-Chief

New, bigger facility

Meggitt Polymers & Composites' new facility in San Diego, CA, US, provides 93,000 ft^2 of manufacturing space and 120,000 ft^2 of total space.

Source | Meggitt

» Rare is the composites manufacturing engineer, operations director or plant manager who has looked at his or her facility and not wished for the opportunity to do things differently — to improve material flow, optimize processes and replace waste with efficiency. Most of the time, such improvements are done in-situ, working with existing space. Occasionally, however, such improvements are done with a blank slate in a new, purpose-built plant that allows for a complete reconsideration of manufacturing operations.

Such was the case for San Diego-based Meggitt when it was given the opportunity to not only move out of the smaller, older space, but to create a new manufacturing space designed specifically for the materials and processes it uses. Along the way, the company learned much about itself, as well as about how people, resins, fibers and machinery can and should be organized to make parts now and in the future.

Meggitt San Diego is a composites fabricator within the larger, global Meggitt PLC aerospace group that, in addition to composites manufacturing, provides technology and solutions for avionics, braking systems, engine systems, fuel systems, fire protection, sensors, thermal management and more. The company has locations in

North America, South America, Europe, Asia and Australia. The former San Diego facility, which *CW* toured and reported on in early 2015, was previously owned and operated by Cobham and acquired by Meggitt in late 2015.

San Diego operations were previously located in two buildings, with a total space of about 75,000 ft^2. As with many composites fabricators, Meggitt San Diego's business simply outgrew the old space. The company was given the opportunity to consolidate operations under one larger roof, also in San Diego, which it did in 2018. The new building is an expansive 120,000 ft^2, with 93,000 ft^2 of that devoted to manufacturing.

Designing the space

Meggitt San Diego operates 14 discrete "value streams," or lines, that produce products. These products include, among others, munitions housings for flares for the F-35 fighter, cylinder sections for the *Javelin* anti-tank missile, spinner caps and spinner assemblies for Pratt & Whitney turbofan engines, and stators, guide vanes and exhaust flaps for the F-135 engine, which powers the F-35. Materials are exclusively hand-laid prepreg; processes are mostly compression molding, including the unusual multi-axis compression molding process, which is described below.

As Meggitt engineers looked at the new space and considered how best to organize it, the first step was to evaluate product and work flow at the old facility. Where were the inefficiencies and how could they be either minimized or eliminated? Meggitt subscribes to the lean-based 3P philosophy, which focuses on production, preparation and process.

Because Meggitt produces discrete and unique products, each product manufacturing line has autonomy and could be evaluated individually. Looking at each manufacturing line through the 3P lens, Meggitt assessed product, material and personnel flow at its old facility. The company discovered that parts flow, in the old facility, from start of manufacture to finish, could be as long as 1 mile, which created time and effort waste, and introduced the opportunity for error. "Obviously we wanted to optimize this number," says Dylan Mendoza, value stream manager at Meggitt San Diego.

Dana Forseth, director of operations at the San Diego facility, leads us out to the production floor of the new building. He says the vast and empty space that greeted Meggitt just a »

Designing a "highway"

With a chance to rethink how materials, processes and people are organized, Meggitt employs a "highway" through which the facilities' primary manufacturing cells are accessed (on left). Equipment storage, freezers and cutting/kitting rooms are on the right. Source | Meggitt

U-shaped manufacturing cells

Each product line at Meggitt is fabricated in a U-shaped manufacturing cell that features a prepreg layup room (background) and primary manufacturing equipment. This shows the cell for the F-35 flare munitions housings, which are made with carbon fiber/phenolic and compression molded in Carver presses. Source | Meggitt

Multi-axis compression molding

A hallmark of Meggitt's operations are the multi-axis compression molding machines used to fabricate F-135 engine stators. TMP, A Division of French, builds the machines, which were designed by Meggitt.

Source | Meggitt

few months previously allowed engineers to completely rethink the physical layout of the manufacturing lines. Mendoza says Meggitt settled quickly on a U-shaped production line for each value stream, with raw material entering one end of the U and finished product exiting the other end. In between would be all of the people and equipment necessary for manufacturing, including ply layup in a cleanroom, compression molding, machining/finishing, inspection and quality control.

Forseth says that once the U-shaped lines were decided on, cross-functional teams created cardboard cutouts of the footprint of every piece of equipment that would be moved into the new facility — cutting tables, compression molding machines, CNC machines, inspection equipment, metrology equipment. These cutouts were laid in a variety of configurations to assess use of space, product travel distance, personnel travel distance and more. Forseth says 60 layouts were considered using this method.

Parallel to this effort, Meggitt engineers also considered how these U-shaped manufacturing cells would be positioned inside the facility relative to other equipment and operations, including prepreg freezers, cutting and kitting, material receiving, product shipping and administration/management. The overall design Meggitt settled on employs geographical/map concepts. The entire production floor is bisected down the middle by a "highway," a 20-ft-wide throughway running the length of the building that accommodates personnel. On one side of the highway is a cutting and kitting clean room, as well as a large walk-in freezer for prepreg storage. On the other side of the highway are the U-shaped manufacturing cells, each one identified by a sign (Stator 1, Javelin, etc.) over the layup room door associated with the cell. Behind the U-shaped manufacturing cells is the "alley," through which Meggitt delivers materials needed for each cell (see floorplan, p. 49, for details).

Immediately adjacent to the manufacturing area, separated by a wall of glass, the administration/management space employs an open concept, with several long desks and computer workstations for engineers and support personnel. Conference and meeting rooms surround this space. Clustered against the glass wall, and looking directly onto the manufacturing floor, are the open work spaces for the facility's top managers, including Forseth, who are visible from almost anywhere in the plant. In short, *all* employees are easily seen and accessed. "We now have parts flow and we have line-of-site leadership, so everyone is where you need them to be," he says.

Evolving composites manufacturing

The product lines that engendered the most growth at Meggitt San Diego are the stators and the munitions housings for the flares, both of which are associated with the ramp-up of F-35 production. The munitions housings, about 12 inches long and 1 inch in diameter, are made up of a carbon fiber/phenolic prepreg and compression molded in four Carver Inc. (Wabash, IN, US) compression molding machines. They are finished on two Haas Automation (Oxnard, CA, US) CNC machines, followed by post-cure in three ovens. Subsequent quality control and metrology is done »

Cutting and kitting

Although Meggitt operates one American GFM cutting table, two more will be added. All cutting and kitting at Meggitt is done in a cleanroom environment, with manual kit sorting aided by FARO Technologies laser projectors. Source | Meggitt

■ **Daily layered accountability**

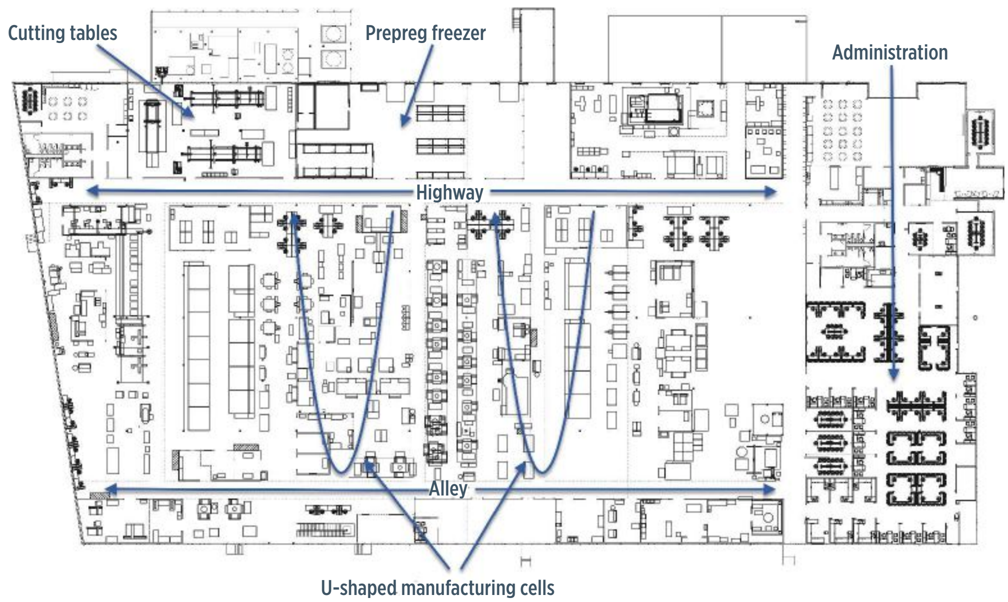
Manufacturing operations are monitored and tracked using daily layered accountability (DLA). Every day at the plant starts with a stand-up meeting where managers discuss material, production, quality and safety defects/challenges, which are categorized by severity. Source | Meggitt

■ **Open-office concept**

Leadership personnel at Meggitt work in an open-concept office environment that provides a clear view of the manufacturing floor. Conversely, manufacturing personnel have a clear view of management staff. Source | Meggitt

by a Hexagon Manufacturing Intelligence (North Kingstown, RI, US) CMM system. Forseth says current throughput in this cell is 128 flares per day, and capacity can be easily increased; there is room for four to six more presses and one more CNC machine. The product flow of the flares is the one that, in the old facility, was a mile long. Here, in the new plant, it's just 1,000 ft.

The most intriguing manufacturing process at Meggitt San Diego's composites site, and the calling card of the facility, is the multi-axis compression molding used to fabricate the F-135 stators. These complex parts are manufactured with a carbon fiber/polyimide prepreg in complex multi-part molds that, when closed, are cube-shaped (or, six-sided). These molds are placed into one of eight (with five more coming) multi-axis compression molding machines, designed by Meggitt and manufactured by TMP, a Division of French (Piqua, OH, US). What makes the machines unusual is that they provide compression and heat to all *six* sides of the mold.



Facility floorplan

This floorplan of Meggitt San Diego shows the "highway" relative to cutting, kitting, freezers and the U-shaped manufacturing cells, two of which are identified here. Source | Meggitt

The new TMP machines are the latest iteration of the multi-axis technology installed in the old facility. The new units, says Forseth, feature easier mold loading, are safer, have upgraded hydraulics, offer better temperature regulation and provide better process control. The updates result in tighter tolerances, higher yields and better product quality. After molding, the stators are demolded, sandblasted and then deflashed by hand. Meggitt is evaluating automated deflashing systems to reduce touch labor on the products.

Freezing, cutting, kitting, QC and Mexico

Prepreg storage at Meggitt San Diego is provided by two walk-in freezers. The largest is used to store full rolls of prepreg and is managed manually on a first-in/first-out (FIFO) basis. The second, smaller, freezer is used to store prepreg kits.

Prepreg cutting and kitting at Meggitt San Diego is performed in a two-room enclosure adjacent to the freezers. It houses one 30-ft American GFM (Chesapeake, VA, US) cutting table, with two » more to be installed soon. The table features an ultrasonic cutter that can cut three to five plies at once, has five spools for prepreg feeding, and is integrated with a FARO Technologies (Lake Mary, FL, US) laser projection system to aid manual ply sorting. Forseth says the waste rate on the table is 15-18%; it operates almost 24/7, particularly for the stators, which require 400 plies per part.

> As the new building becomes fully operational, Meggitt is well positioned to accommodate growth.

Operations management at Meggitt San Diego relies on daily layered accountability (DLA), a paper- and bulletin board-based system located on the manufacturing floor at the end of the highway. It is designed to give floor employees and managers easy access to manufacturing performance metrics. Under this system, managers start each day with a stand-up meeting at the DLA boards where performance metrics are reviewed, assessed and prioritized. Under the DLA system, material, production, quality and safety defects/challenges are categorized by severity (DLA1, DLA2, DLA3, DLA4), with specific actions and remedies prescribed for each level. Forseth says the DLA system provides a great tool for everyone at Meggitt to easily and quickly see and assess what the manufacturing challenges are. "We walk the safety talk here," he says.

Just prior to Meggitt acquiring the San Diego facility from Cobham, Meggitt also acquired EDAC, a composites fabricator with locations in Erlanger, KY, US, Cincinnati, OH, US, and Saltillo, Mexico. Those sites are now being aligned with Meggitt San Diego for *commercial* composites fabrication work. For all commercial composites manufacturing projects, says Forseth, the San Diego and Erlanger facilities will focus on new product integration and low-rate production, with full-rate production provided by a 125,000-ft^2 facility in Saltillo. One of the old San Diego buildings will be retained for new business expansion.

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As the new building becomes fully operational, Meggitt is well positioned to accommodate growth with highly organized, efficient operations. Says Forseth: "The structured approach emphasizing a data-driven decision-making process has Meggitt poised to be a player in the highly competitive composites manufacturing industry." CW

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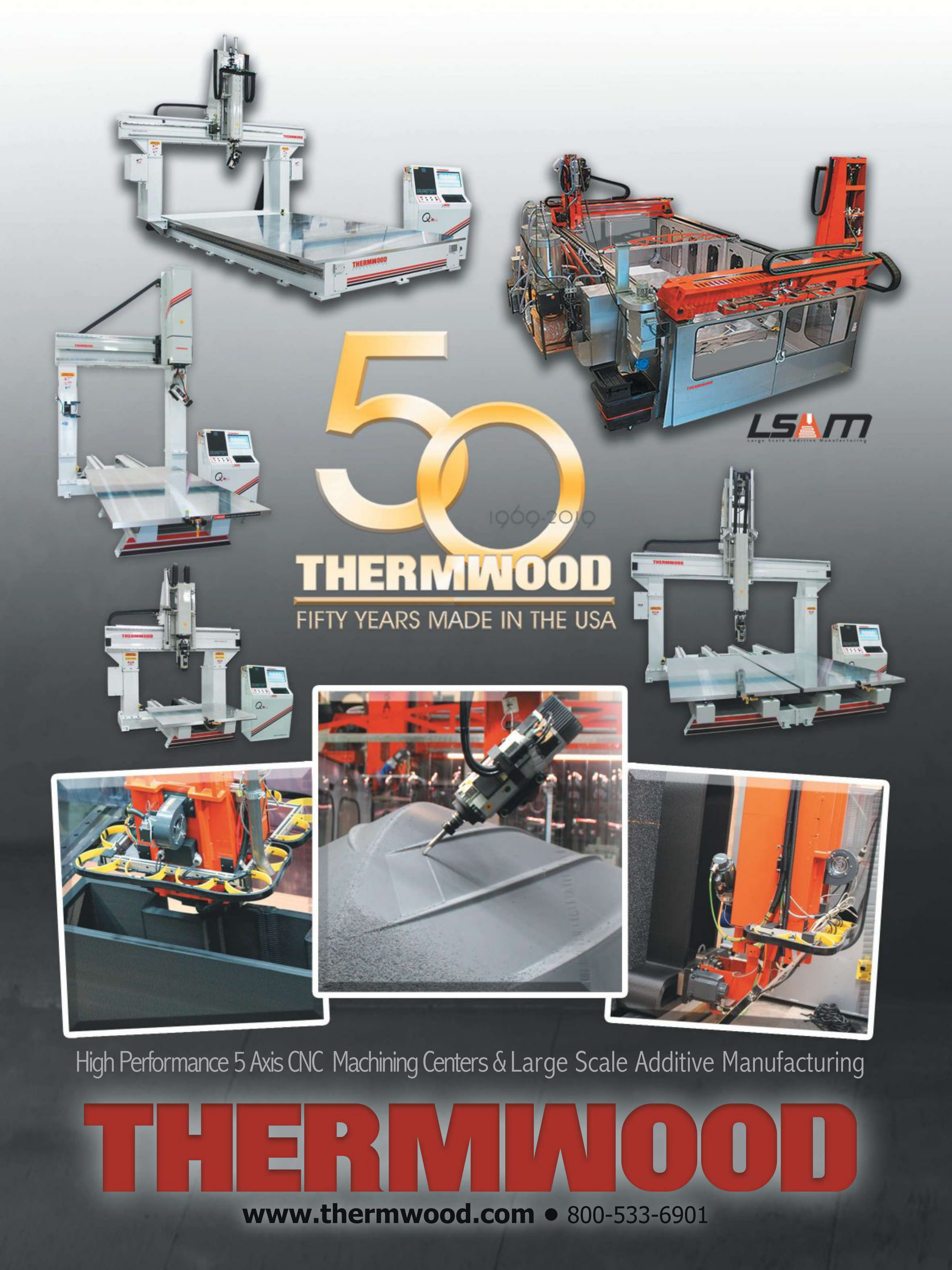
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FOILING MOTORYACHT IMPRESSES IN CARBON FIBER/EPOXY

A project is underway to build a faster, lighter, hybrid-electric motorboat with foils and hull fabricated from carbon fiber and epoxy.

› ENATA Industries (Dubai, UAE), founded by Sylvain Vieujot with offices in Singapore, France and Switzerland, was, says the company, born from a passion for applying high-tech engineering to sailing, flying and architecture, underpinned by access to advanced composites technology. In 2016, ENATA acquired the small Swiss company Hydros to add to its marine group. As an America's Cup consultant and holder of numerous marine speed records, Hydros had begun a project in 2010 called *FOILER*, aimed at creating a foiling powerboat. A small-scale prototype with a hybrid propulsion system, dubbed *HY-X*, was unveiled by Hydros in 2015, and it won the Union Internationale Motonautique (International Powerboat Association) Environmental Award. ENATA began design and production planning for a full-scale boat, called *FOILER*, in 2016, to be built at the company's Sharjah, UAE, boatyard and shop.

Foils, or hydrofoils, work like an airplane wing — instead of enabling liftoff of a plane, though, the hydrofoil creates sufficient lift to raise the boat hull above the surface of the water, greatly decreasing drag and, as a result, enabling much increased speed. The ENATA *FOILER*'s four patented foils enable the hull to "fly" 1.5m above the water at speeds up to 46 mph. The foils are fully retractable and do not intrude into or impact the hull space. The propulsion system (supplied by Mecachrome, Amboise, France) comprises twin 300-HP diesel/electric hybrid engines powering two generators that drive two custom electric torpedoes, with the torpedoes mounted adjacent to the rear foils.

ENATA opted for carbon fiber infusion to fabricate the foils and hull — rather than the fiberglass used in most marine composite structures — to achieve high strength and stiffness and the low weight required to achieve lift, given the hybrid electric drive. Sicomin Epoxy Systems (Châteauneuf les Martigues, France) had worked with ENATA since 2016 and was brought into the project to supply epoxy resins compatible with carbon fiber fabrics. ENATA chose Sicomin's SR8100 epoxy system for the infusion, because the resin is formulated with low viscosity at ambient temperature and is compatible with a range of hardeners for small or large parts, enabling fast demolding. SR8100 has Germanischer Lloyd certification approval.

"We have worked with Sicomin on various projects over the last few years and have every confidence in their products," says Vieujot. "We know we can work with them to develop custom products when needed. *FOILER*'s performance wouldn't have been possible with a heavier E-glass structure." CW

Composites Events

Feb. 19-20, 2019 — Charleston, SC, US
SPE 2019 Thermoset Topical Conference – TOPCON
spethermosets.org

Feb. 26-27, 2019 — Los Angeles, CA, US
SAMPE Hands-on Tooling Technologies for Composites Manufacturing Workshop
nasampe.org

Feb. 26-28, 2019 — Raleigh, NC, US
Techtextil North America 2019
techtextil-north-america.us.messefrankfurt.com

March 4-5, 2019 — Detroit, MI, US
Graphene Automotive 2019
usa.graphene-automotive-conference.com

March 6-8, 2019 — Rome, Italy
5th Annual World Congress of Smart Materials: 2019
bitcongress.com

March 12-14, 2019 — Paris, France
JEC World 2019
jeccomposites.com

March 21, 2019 — Belfast, UK
Joining of Composites Conference
ktn-uk.co.uk/events

March 24-28, 2019 — Nashville, TN, US
NACE Corrosion 2019
nacecorrosion.org

April 7-10, 2019 — Charleston, SC, US
TRFA Annual Meeting
trfa.org/meeting

April 8-10, 2019 — Rosemont, IL, US
North American Pultrusion Conference
s1.goeshow.com/acma/2017PultrusionConference/ereg419088.cfm

April 8-11, 2019 — Colorado Springs, CO, US
35th Space Symposium
spacesymposium.org

April 9-11, 2019 — Detroit, MI, US
SAE 2019 World Congress & Exhibition
10times.com/sae-world-congress

April 10-11, 2019 — Amsterdam, The Netherlands
CompIC 2019
compositesinconstruction.com

April 23-25, 2019 — Moscow, Russia
Composite-Expo-2019
composite-expo.com

April 29-May 2, 2019 — Long Beach, CA, US
AeroDef 2019
aerodefevent.com

April 29-May 2, 2019 — Chicago, IL, US
AUVSI XPONENTIAL 2019
xponential.org

May 6-8, 2019 — Beijing, China
SAMPE China 2019
sampechina.org

May 20-23, 2019 — Houston, TX, US
AWEA WINDPOWER Conference 2019
windpowerexpo.org

May 20-23, 2019 — Charlotte, NC, US
SAMPE 2019 Technical Conference and Exhibition
nasampe.org

June 12-13, 2019 — Stade, Germany
CFK-Valley Stade Convention 2019
CFK-Valley.com

June 19-20, 2019 — Chicago, IL, US
JEC Chicago 2019
jec-chicago.events

July 3, 2019 — Vigo, Spain
MATCOMP19
matcomp19.com

July 22, 2019 — Kelowna, British Columbia, Canada
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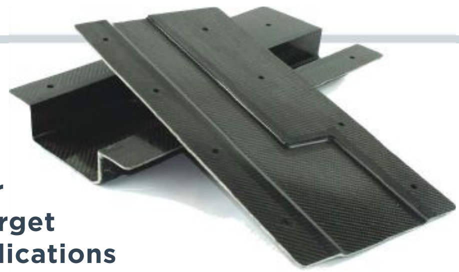


» PREPREG MATERIALS

Hybrid fiber prepregs target tooling applications

Composites Evolution Ltd. (Chesterfield, UK), in collaboration with with molder **KS Composites** (Melton Mowbray, UK), has developed a new tooling prepreg system based on a hybrid combination of carbon fiber and flax fiber reinforcements, aimed at reducing the cost of carbon fiber tools. In the new hybrid tooling system, several of the carbon bulking plies are replaced with flax fiber. Composites Evolution says this is possible because the thermal expansion properties of flax fibers are sufficiently similar to those of carbon fibers. The result, says the company, is a hybrid carbon fiber/flax fiber tool in which the material costs are reduced by up to 15% compared to an all-carbon fiber tool. Secondary benefits include a reduction in tool weight of up to 15% and reduced environmental impact from the use of sustainable flax. In trials performed by KS Composites, a hybrid carbon fiber/flax fiber tool has successfully completed more 400 thermal cycles. A mold manufactured with the material is now used in production.
compositesevolution.com

» THERMOSET RESINS & ADHESIVE SYSTEMS

PEEK polymer designed for cryogenic temperatures

Victrex (Thornton Cleveleys, UK) has introduced VICTREX CT 200, a high-performance polyetheretherketone (PEEK) polymer designed for dynamic sealing applications where gases such as liquefied natural gas (LNG) are stored and transported at cryogenic temperatures (-150°C/-238°F to -200°C/-328°F). According to Victrex, its 200 grade series polymers exhibit improved sealing over a wider range of temperatures when compared to commonly used materials such as PCTFE. The resin reportedly does so at low temperatures because of its good ductility, and at high temperatures due to its good creep resistance. VICTREX CT polymers are said to maintain better dimensional stability, with a lower coefficient of thermal expansion, than incumbent material. The higher thermal conductivity of these polymers is said to enable a fast response to temperature changes and ensure the material is engaged with the counter-surface at all times. According to Victrex, laboratory testing indicates that the polymers also may require less torque to actuate since they have a lower static and dynamic coefficient of friction compared to PCTFE, resulting in less wear and higher performance. **victrex.com**

» TESTING, MEASUREMENT & INSPECTION SYSTEMS

Automated, high-volume part inspection system

The **L.S. Starrett Co.** (Athol, MA, US), global manufacturer of measuring tools, gages and metrology systems, has introduced its AV450 Automatic Vision System. The new 3-axis vision system is designed for high-volume, repetitive applications and routine quality assurance. The AV450 has a 18-by-14-by-8-inch (457-by-356-by-203-mm) measurement envelope, high-resolution video zoom optics and can be pre-programmed for repetitive part inspection or driven manually via a trackball for individual measurements. Either QC5000 or MetLogix M3 software controls video edge detection and multiple-channel fiber optic or LED illumination. Computer-controlled Quadrant (LED) ring lighting, sub-stage lighting and optional through-the-lens lighting provides illumination.

The reported accuracy of the system is 2.5 + 5L/1000; reading resolution is 4 in (0.1m). Magnification on a 24-inch monitor at 1:1 pixel setting is 37-240x with 6.5:1 zoom, and 25-300x with 12:1 zoom. The system has a 1.3-megapixel color digital video camera and a granite base. The AV450 has an external motion control unit and includes a Windows-based operating system with an operator interface via a desktop PC with a 24-inch touchscreen monitor, as well as wireless network connectivity. CAD files can be imported and exported and reports can be generated and archived. M3 metrology software supports 3-axis measurements and 2D geometric constructs (such as points, lines, angles, rectangles and slots) and corrections for level, skew and datum origin. Options for the AV450 include a Renishaw touch-probe kit; an Optimet laser probe; 0.5x, 1.5x and 2.0x auxiliary lenses; an LED dark-field quadrant illuminator; and a DXF/field-of-view option for automatic comparison to CAD files. Other options include a CNC rotary axis fixture, touch probe change rack, calibration standards, part fixtures and workholding devices. **starrett.com**

» CUTTING & KITTING

Waterjet system enables precise, non-thermal cutting

Finepart Sweden AB's (Bollebygd, Sweden) new Finecut micro abrasive waterjet system has a reported positioning accuracy of ±2.5 microns and the ability to cut precise, complex parts with diameters as small as 200 microns and as large as 500 mm. The system's particle erosion process adapts to the material and cuts complex shapes out of most materials, including composites, reportedly without causing thermal or mechanical damage. According to Finepart, the system is used in applications such as prototyping, fine mechanics and tooling, medical devices, aerospace, watchmaking and luxury goods. The machine can be used with the company's customized solutions for fixturing and handling, and new machinery options are retrofittable to older models. Additional features include the ability to pierce and cut in one setup, high cutting speeds, no need for recast layers and the ability to cut nonconductive materials. **finepart.com**

» PREPREG MATERIALS

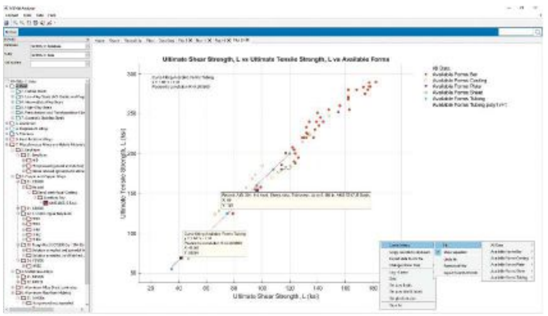
Fast-cure prepreg targets automotive mass production

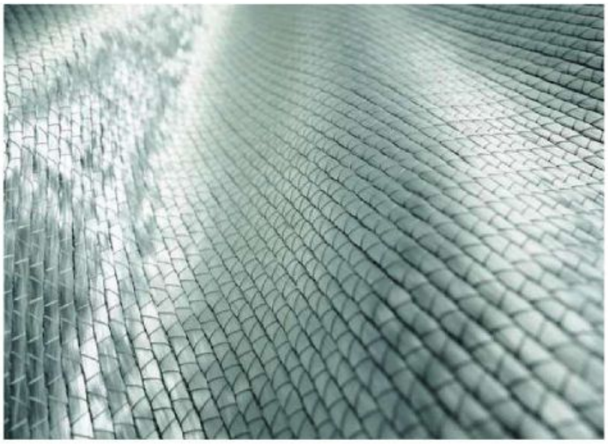
Kordsa (Istanbul,Turkey) has introduced CM14, a new fast-cure prepreg system for use in press-molding and designed for manufacturing large-volume, low-cost, high-quality composite parts. Kordsa says CM14 eliminates waterspot and whitespot problems, reportedly providing high visual clarity. The new resin, says the company, was designed to provide high-grade part surface quality with a visible carbon fiber look. It is said to enable prepreg use in automotive mass production. **kordsa.com**

» PROCESS CONTROL SYSTEMS & SOFTWARE

Materials information management software updated

Granta Design (Cambridge, UK) has announced the release of GRANTA MI Version 12, the latest version of its materials information management software. The company says GRANTA MI Version 12 brings the materials-enabled digital twin — a virtual representation of real products — closer, with new capabilities to manage vital materials data, ensure traceability, and apply it in design and simulation. The new capabilities are said to be useful for emerging material and process technologies like additive manufacturing (AM). The latest release also is designed to help users assess and ensure regulatory compliance, while enhanced integration with CAE, CAD and PLM technologies reportedly enable the fast interaction needed to empower an effective digital twin. **grantadesign.com**





» UNIDIRECTIONAL FIBER FABRICS

Unidirectional glass fiber fabrics target leaf springs

SAERTEX (Saerbeck, Germany) has introduced Ultra Fatigue UD, a unidirectional, non-crimp, glass fiber fabric designed specifically for the manufacture of leaf springs in trucks and passenger vehicles. The fiber is reportedly 50% lighter than steel and offers longer operational life and improved fatigue properties. Ultra Fatigue UD is designed to be processed via resin transfer molding (RTM) and is said to be most compatible with epoxy and polyurethane (PU) resin systems.
saertex.com

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Proving performance in EV powertrains

Simulation-driven development replaces aluminum with thermoplastic composites in gearbox housing.

By Ginger Gardiner / Senior Editor

Reducing weight while maintaining performance

ARRK/P+Z Engineering, ARRK Shapers and ARRK LCO Protomoules brought together powertrain, metals and composites expertise to redesign and prototype this EV gearbox housing using continuous carbon fiber-reinforced PA6 organosheet overmolded with short glass fiber-reinforced PA6 molding compound. The simulation-driven approach produced a design that saved weight while maintaining a rigid, efficient and quiet transmission housing. Source for all images | ARRK Group

» Weight reduction continues to be a goal for electric vehicles (EV), improving performance and extending range. To that end, designers and manufacturers are exploring the use of composites in battery enclosures, body panels, chassis structures and suspension components. However, one project has set its sights on the powertrain *beyond batteries* to the gearbox housing, replacing cast aluminum with a hybrid carbon fiber- and glass fiber-reinforced thermoplastic composite to cut weight by 30%.

This project was engineered by multiple companies within the ARRK Group (Osaka, Japan). Founded in 1948, the group comprises 20 companies in 15 countries, with more than 3,500 employees, and provides product development services including design, prototyping, tooling and low-volume production to multiple industries. Since early 2018, ARRK Corp. has been a subsidiary of Mitsui Chemicals Group (Tokyo, Japan), which produces long fiber-reinforced thermoplastic compounds and unidirectional (UD) carbon fiber/polypropylene (CF/PP) tapes. ARRK has established composites as one of its 14 centers of competence, joining the German industry associations Carbon Composites e.V. and MAI Carbon in 2012 and Composites UK in 2015.

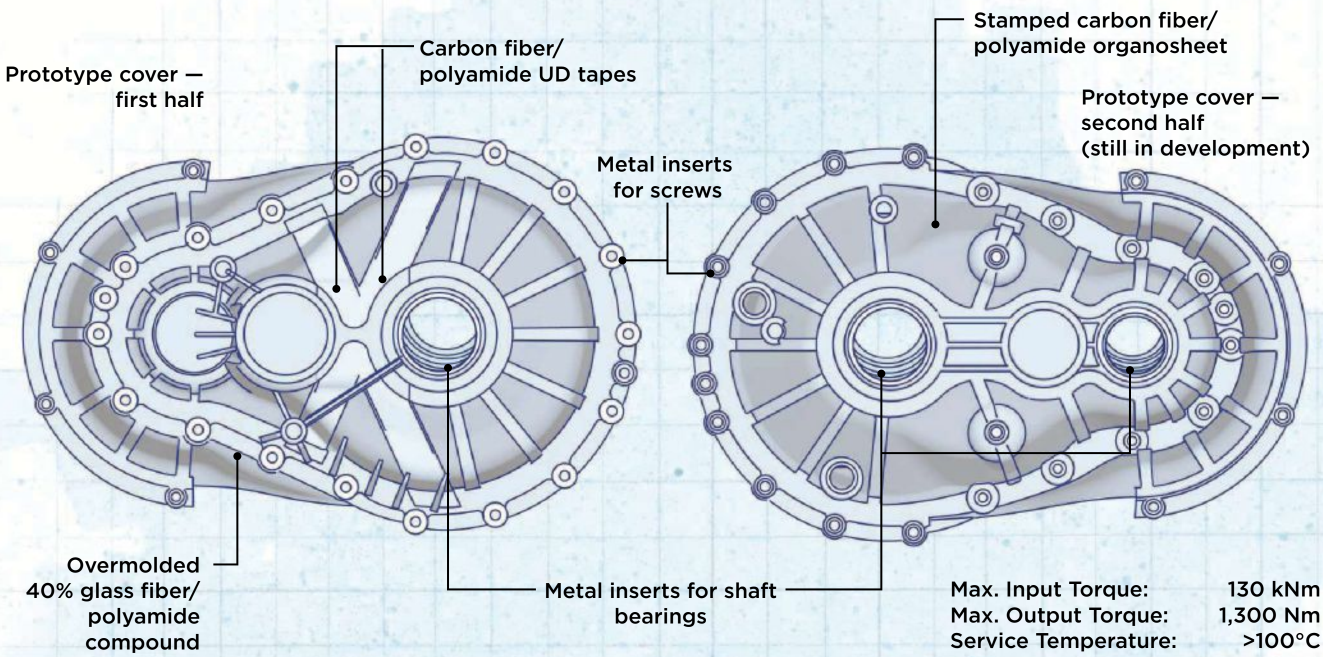
For this gearbox housing project, engineering was completed by ARRK/P+Z Engineering GmbH (Munich, Germany) with support from ARRK Shapers' France (La Séguinière and Aigrefeuille-sur-Maine, France) for the production process as well as stamping and molding tools, while prototyping was led by ARRK LCO Protomoules (Alby sur Chéran, France). "The aim was to demonstrate the light weight and stiffness that fiber-reinforced thermoplastics can provide for electric vehicle engine and transmission components typically cast from aluminum," explains ARRK Engineering project leader Raik Rademacher.

The gearbox used as the basis for this project is made by Getrag (Untergruppenbach, Germany) for the Smart *Fortwo* electric city car. Only the housing was redesigned, with all interior parts reused and operating without change. The re-engineering approach employed a variety of simulations — finite element model (FEM), topology optimization and simulation of preform stamping and injection overmolding processes. It also proved out a process for converting a metal design to composite using multiple partners with diverse materials, process and structures expertise.

Defining targets, loads and materials

This EV gearbox housing comprises two halves mechanically fastened around the vehicle's transmission gears and shafts. The concept phase began by defining design targets. The first step was to reverse-engineer a finite element model by 3D scanning a disassembled *Fortwo* gearbox, including the internal components, shafts and gears. Maximum input and output torque, the gear ratio and torque on the input and output shafts were derived from manufacturer's data. An FEM simulation was then used to calculate torque on the gearbox housing for vehicle drive and coast loads, as well as gravity loads up to 60G to simulate crash situations.

The gearbox housing must handle these loads without exceeding allowable deformation; otherwise, there may be significant



DESIGN RESULTS | **ARRK Engineering Hybrid Composite Gearbox Housing**

- Composite housing reduces weight 30% vs. cast aluminum baseline
- UD tapes reduce organosheet thickness from 5 mm to 4 mm and help meet design-critical stiffness
- Overmolded ribs boost stiffness, provide galvanic corrosion isolation and integrate metal inserts for screws and shaft bearings
- Composite part maintains process time of ≈ 2 minutes

Illustration / **Karl Reque**

deflections in the gear shafts, causing inaccurate contact in the gears. "Such contact will damage the gears and, in the worst case, lead to failure," says Rademacher. "Transmission errors due to inaccurate gear alignment also lead to unwanted acoustic behavior in the gearbox," he adds. "They call it 'whining.' Because EVs are so quiet, it is important that this composite gearbox be really calm and silent." Thus, stiffness is a critical performance target, and must match or exceed that of the aluminum baseline.

Identified early on as candidate materials for this redesign, woven glass fiber and carbon fiber-reinforced polyamide 6 (PA6) organosheets from TenCate (Nijverdal, The Netherlands) were tested for mechanical properties. Because the glass fiber composite showed only 50% of the stiffness of the carbon fiber organosheet, the latter was selected. "The material is TenCate CETEX TC912 using 12K fiber in a 2-by-2 twill fabric," says Rademacher. "We specified a tailored organosheet made using nine plies in a quasi-isotropic stacking sequence (0°/90°/45°/-45°/90°/-45°/45°/90°/0°)".

Concept and design phases

Five gearbox housing concepts were developed, but only two offered adequate potential for weight and cost savings, along with low cycle time. Feasibility checks revealed that only one concept permitted sufficient stiffness, by using metal bearing seats. "Seats are the direct connection between the bearings for the gearshafts and the gearbox housing," Rademacher explains. "We looked at simply injection molding these, but instead chose an overmolded aluminum insert to increase the stiffness." This concept was thus chosen for development.

Topology optimization to minimize strain energy was performed in the subsequent design phase. From this analysis, gearbox housing geometry was refined, including minimum radii for molded curvatures. This geometry was used to build a simulation model for the detailed design. The organosheet laminate was then further optimized, revealing that the +45°/-45° layers should be the thickest. This correlated well with the fact that torsion in the housing is the main source of deformation that must be resisted.

Housing stiffness was still found to be insufficient, thus crossed UD tapes and overmolded ribs were introduced into the housing geometry. For overmolding, the team selected a 40% glass fiber/PA6 (GF/PA6) compound from EMS-Grivory (Domat/Ems, Switzerland).

Detail phase and manufacturing

Functional fixing points and connections for the two gearbox housing halves were detailed in this third phase of the redesign. The halves would be mechanically fastened, so aluminum inserts were added to the design to transmit bearing loads from the fasteners. Other »

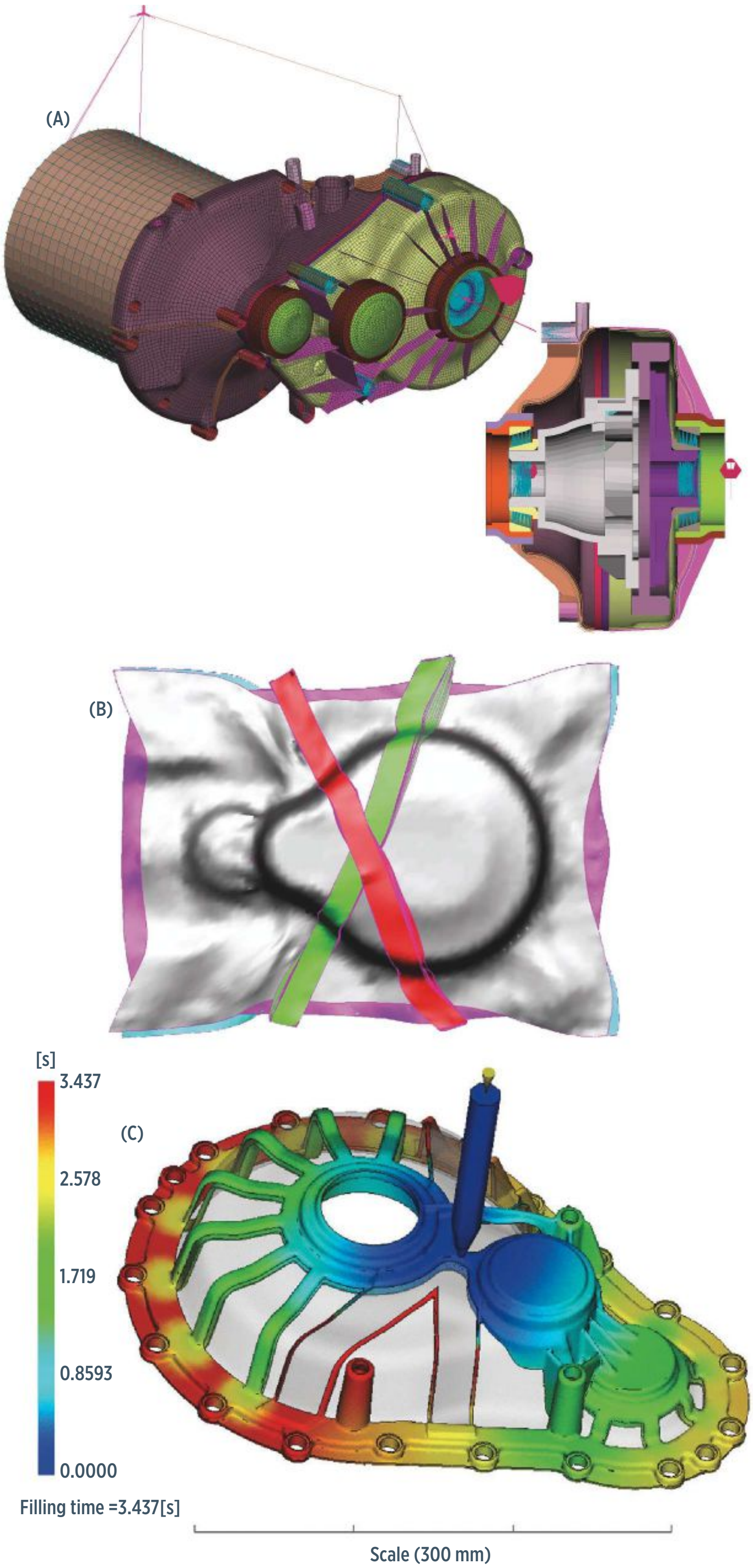


FIG. 1 Simulation-driven development

ARRK Engineering used multiple simulations to develop this hybrid fiber-reinforced thermoplastic composite gearbox housing including FEM for dimensioning and evaluation of concepts (A), stamping (B) and overmolding simulation (C).

features were then detailed, including the overmolded flange containing these inserts and the ribs and other functional geometry overmolded onto the housing exterior.

A stamping process was selected for preforming the organosheet prior to overmolding. A stamping simulation was completed (Fig. 1) by partner ESI Group (Paris, France) using its PAM-FORM software to anticipate any problems during preforming and to derive a starting cut for the raw organosheet.

"The simulation showed bending deformation due to the high thickness of organosheet and tight radii in the housing geometry, causing wrinkles in the preform," says Rademacher. "So, we modified the design radii and reduced the organosheet thickness to 4 mm. This was when we showed that thicker 45° plies should be used, but we couldn't get such an organosheet from a supplier. We decided to keep the quasi-isotropic stack but apply 45° UDs on top to enable the thickness reduction, while maintaining stiffness."

The team used 12 plies of 25.4-mm-wide and 0.16-mm-thick CETEX TC910 carbon fiber/PA6 tape and reran stamping simulations. These showed that the crossed UD tapes were sliding out of place during stamping. To address this, slots were designed in the stamping tool to lock the UD tapes in position.

The overmolding process was also simulated, performed by Shapers using Autodesk's (San Rafael, CA, US) MoldFlow software, and also Moldex3D software from CoreTech System Co. Ltd. (Chupei City, Taiwan). One benefit to overmolding was the prevention of galvanic corrosion. The short glass fiber-reinforced molding compound provided isolation between the aluminum fasteners and the carbon fiber in the organosheet. Thus, no additional adhesive, sealant or coating was required.

After completing these simulations, the manufacturing process was finalized as follows (see Fig. 2, p. 63):

1. Organosheet is cut and stacked into quasi-isotropic layup;
2. Laminate stack and UD tapes are placed into a frame that maintains tape positioning;
3. Infrared heater heats thermoplastic matrix to 240-260°C;
4. Frame with preform materials is transferred to stamping press and tool (preheated to 90-110°C);
5. Preform is stamped (5-sec. cycle time);
6. Consolidated preform is trimmed to final shape using a waterjet cutting system;
7. Shaft bearings and screw inserts are placed into the overmolding tool while trimmed preform is again preheated;
8. Preform and inserts are overmolded (2-min. cycle time including manual placement and removal);
9. Final part flanges and bearing seats are milled to required tolerances.

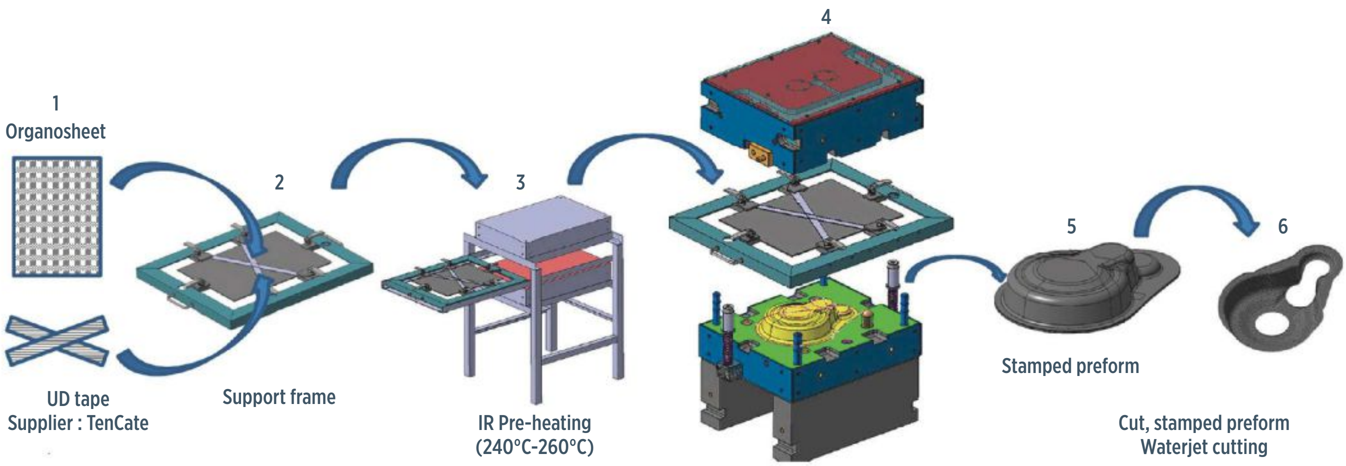


FIG. 2 Finalized process for first prototype

The first half of ARRK Engineering's redesigned composite gearbox housing was produced using the process steps shown above, followed by overmolding and final milling of part flanges and bearing seats.

Prototype and process success

The first half of the prototype composite gearbox housing was produced and displayed at JEC World 2017. It was then tested to validate the FEM simulations. The prototype showed good mechanical properties, while reducing weight to 4 kg from 5.8 kg for the aluminum baseline, a weight savings of about 30%. The cost of this first half prototype cover is estimated at €50-80, with the organosheet being the most expensive component.

This project also succeeded in prototyping how this collection of companies works together to deliver a composites redesign. "Our background at ARRK Engineering was in simulation for small composite parts but not in using organosheet," Rademacher recalls. Shapers had extensive experience with injection molding and development of molding tools, but also no organosheet background. The ARRK team working on organosheet simulation were experts in composites simulation, but their previous work had been in aerospace. "We had discussions with the team every week," Rademacher says. "I am from the powertrain department, so more on the metals side, but as the project leader, I had to combine these metals and composites worlds. We metal guys think, 'Why do it in composites?' while the composites guys think, 'this is easy to do in composites.' We are too skeptical, and they are too optimistic, so it was good to work together. We learned a lot and have developed a design process which is very efficient." He compares the ARRK process with the more common method of developing one design, using less simulation and then trying to optimize through building iterative prototypes. "We see that it's more efficient to start with multiple designs and down-select from these using simulation, and then further optimize the design before prototyping. It takes time in the beginning to do this modeling, but less time during prototyping, so it's less expensive." Rademacher points out that due to the time and cost of producing new tooling, "it's always more costly to produce ten prototype parts vs. ten simulation models."

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Challenges and next steps

The team also overcame significant manufacturing challenges. "The UD tapes in combination with the nine-ply organosheet laminate had areas where it was not consolidated," Rademacher notes. "This was partly due to air between the tapes and the organosheet and also affected their attachment after molding. The other contributor was a non-homogeneous temperature distribution across the organosheet. It looked good in our measurements, but was a little colder at the outer edges, which caused small areas of matrix failures in the outer structure. So, we have learned a lot about both the modeling and actual molding of organosheet parts."

The next step in the project is to prototype the second half of the gearbox housing and validate the stiffness of the complete assembly. The team is also working to remove the waterjet cutting step so that the preform stack may be immediately overmolded after stamping. "Because we have changed the process, we are still working on the second cover," says Rademacher. "The biggest challenge for us now is reaching an acceptable price for the client. We are looking at glass fiber and a polyphenylene amide (PPA) matrix, the latter enabling higher performance at high temperatures while further reducing organosheet thickness. We won't use woven fabric but maybe stacked tapes to help meet the required stiffness." 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.
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