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Breaking the Inspection Bottleneck: AUTOMATION UNLEASHED

FEBRUARY 2018

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VOL 4 № 2

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CLOSED MOLD REINFORCEMENTS

SAERcore: This patented **SAERTEX** product consists of one or two layers of chopped strand mats (CSM) and an intelligent flow media. Facilitates flow in high speed resin injection.

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1. First the resin flows into the core material (the resin flow zone) – horizontal injection
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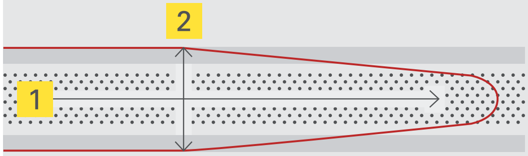
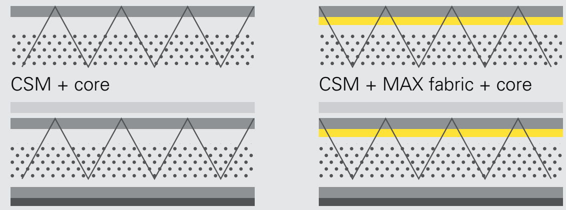


Can be individually designed and combined

Examples:



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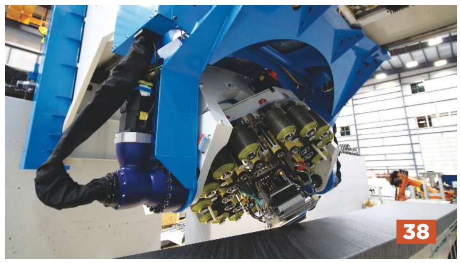
COLUMNS



DEPARTMENTS

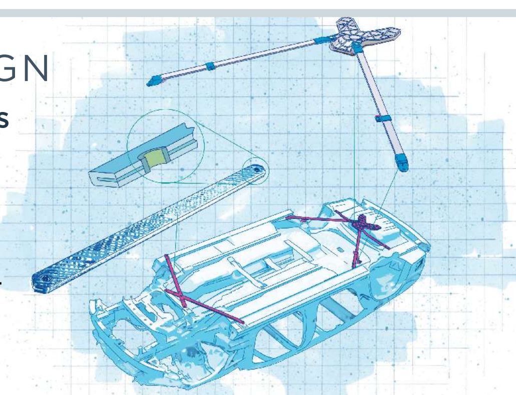
FEATURES

ON THE COVER

CNC equipment supplier Electroimpact's (Mukilteo, WA, US) automated fiber placement (AFP) head is shown here during production trials for The Boeing Co.'s (Chicago, IL, US) 777X commercial passenger plane's carbon fiber composite wing spar. An onboard, on-the-fly, automated inspection system is expected to help ensure Boeing's production processes produce much more cost-effective finished parts.

Source / Electroimpact

FOCUS ON DESIGN



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My first plant tour as a business journalist was in February 1997. I was, at the time, a senior editor at *Injection Molding* magazine and traveled up to northern Wisconsin to visit a custom injection molder there. I was traveling with John Bozzelli, who, at the time, had just launched a consultancy, espousing the virtues of "scientific molding." He had been called to this Wisconsin molding facility to help the company increase its operational efficiency.

Math, science, data and the composites industry's future.

Scientific molding, as the phrase implies, is the application of scientific and mathematical principles to the injection molding process, and is designed to increase molding process consistency, reduce waste and increase finished part quality (sound familiar?).

I remember thinking at the time that such principles certainly could/should have been applied many years previously. But, in fact, the molding industry's efforts to meet production goals were still beset by dependence on human operators. That is, there were, in many plants, certain people who "knew" how to make certain injection molding machines operate properly. Indeed, I once had a plant manager point to an idle molding machine and tell me, "Only Mike on third shift can make this machine and mold produce good parts."

John's mission, early on, was to move molders away from this dependency by helping operators and plant managers to better understand the physics governing the injection molding process. The ultimate goal was to help molders build robust, repeatable molding processes that produce quality parts with little or no human intervention.

The first step in this transformation was a machine audit, and that's what I witnessed in frigid Wisconsin — watching and learning as John assessed this molder's machines. Much of this work was basic math, verifying that what the machine's controls *said* the machine was doing was reflected in reality (often it was not), and then working to align those controls with reality. It was, basically, data collection, calculation, assessment and adjustment. If we are in or on the cusp of Industry 4.0 today, then what John and I were doing in 1997 must have been Industry Beta.

Of course, getting molders to do simple math was not the highest hurdle John had to clear. The biggest barrier, more often than not, was not mathematical but sociological: Getting the company and its employees to change the way they think about manufacturing, to change the company management and shop floor *culture* — top to bottom — to embrace the concept of science-centric manufacturing.

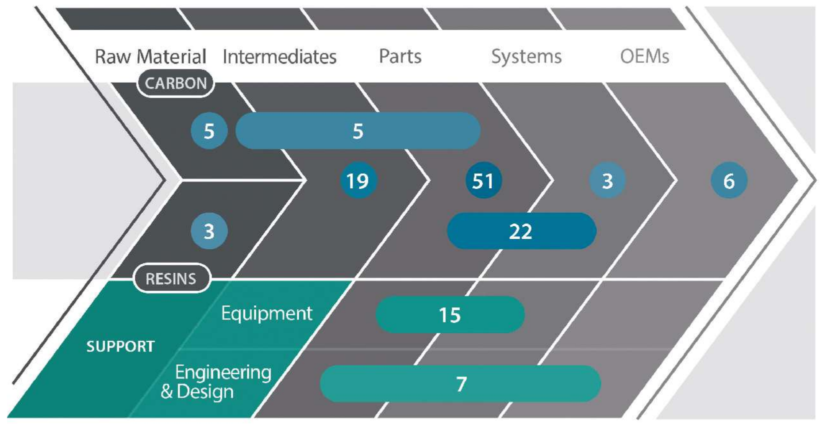
Fast forward to 2018 and suddenly what was old is new again. Science- or math-based manufacturing is now known as the Industrial Internet of Things (IIoT), or the aforementioned Industry 4.0. And while the overarching goals are the same — systematic, disciplined, data-based processing — the tools available to us are much more sophisticated. Raw computing power, cloud-based data storage, remote sensing and artificial intelligence, unimaginable in 1997, now simplify and streamline the effort to harness the power and precision of data-based manufacturing. And when implemented well, the results can be impressive, increasing efficiencies, reducing cycle times and waste, and ensuring the consistency and repeatability of composites manufacturing processes.

What has not changed, however, is cultural intransigence, the built-in institutional reluctance in a composites fabricator's facility to *seek out and apply* new technologies. The myriad (understandable) reasons for this include lack of resources, lack of time, fear of change, uncertainty of results. What is certain, however, is that the entire composites industry, just as the injection molding industry did more than 20 years ago, must begin to embrace the systematic use of data, particularly if it expects to deliver the process control, production speed and product quality sufficient to establish composites as *the* advanced materials of the 21st Century.

JEFF SLOAN — Editor-In-Chief

Composites bucking the market trend in M&A

SUPPLY CHAIN ANALYSIS



The 2015-2017 M&A deal count shows that the fragmented center of the carbon fiber composites supply chain — those who (left to right) sell carbon fiber/resin intermediates, such as prepreg (19), and mold parts from carbon fiber and resin (51) plus those who supply resin (22) and equipment (15) to those who mold parts or assemble systems — were the most acquisitive. Source | *PitchBook*, FMG M&A Database

» During 2015 and 2016, the composites industry saw such impressive activity in mergers and acquisitions, it was perhaps to be expected that, in 2017, we would see a dip in transaction levels, especially given the global regulatory uncertainty and the impact that might have on larger, more complex deals. What we have seen this year, however, is a high level of dealmaking within the specialty materials and advanced composites sectors, because robust growth rates, substantial value propositions and sustainable margins remain attractive incentives for strategic buyers and financial investors.

Overall, business M&A transaction levels declined in the first half of 2017 in the historical centers of composites M&A activity — Europe and North America. Key median multiples of enterprise value/earnings before interest, tax, depreciation and amortization (EV/EBITDA) for all M&A transactions decreased slightly in both territories in H1 2017, with Europe down to 8.1x (8.3x in 2016) and North America proving a little more durable at around 10x for the past 18 months.[1] Our research, in late 2017, with a focus on the advanced composites sector, saw that transactions there were not subject to this activity and margin decline. There was, in fact, a pick-up in dealmaking through 2017 that (when 2017's final tally is evaluated) might well get very close to 2015 levels by year's end.

Private equity (PE) investors, with their elevated levels of deployable cash, are now taking a larger share of the overall M&A pie than ever before. However, this is less apparent in the composites market, and they're still the minority player to the large strategic acquirers, with their strong balance sheets and investment cash reserves.

M&A activity in speciality materials this year included highlights, such as Evonik's early 2017 confirmation of its acquisition of Air Products' speciality additives business, along with its US$630 million purchase of JM Huber's silica business. In this column, we have chosen to look in greater depth at the advanced composites M&A transactions in the past 12 months, certain key transactions and sectors and some important industry trends that have appeared.

Consolidation in aerospace supply chains

Aerospace composites M&A transactions continue to lead the way financially, with probably the two largest deals completed in 2017 coming from the aero interiors segment. Zodiac Aerospace (US$8.2 billion announced value acquisition by Safran) and B/E Aerospace (US$8.6 billion announced value acquisition by Rockwell Collins) were both market leaders in interior components and systems, and although their acquisitions have been publicly portrayed as adding diversity to the customer mix and product portfolio[2], it also seems likely the OEMs have been, to some extent, encouraging consolidation, with the expectation that the resulting larger, more robust and increasingly agile players can provide a more cost-effective supply chain to support the OEMs' challenges, such as increased growth rates and moves into newer markets.

Vertical integration and a focus on components

In contrast to aerocomposites, the automotive composites space is in a relatively early stage, with a more diversified supply chain. It was interesting to note that several key composites players, historically strong in automotive, added further component production, engineering and design capabilities to their market offerings in the past 12 months.

Altair formed Altair Engineering Finland with the purchase of Componeering, the Helsinki-based structural analysis specialist and developer of the composite design and analysis tool ESAComp, in September 2017.

Mitsubishi Rayon Co. Ltd. (MRC), currently the leading global producer of carbon fiber sheet molding compound, acquired all shares of Seattle-based Gemini Composites in March 2017 via its California subsidiary Mitsubishi Rayon Carbon Fiber and Composites Inc. Adding Gemini's breakthrough product development approach, design skills and expertise with forged composites parts were confirmed as the main drivers for MRC's strategic acquisition.

In the crowded parts-and-systems field, we have highlighted two recent deals that illustrate the strategic importance of this area and its diversity in terms of processes and scale. January's US$825 million acquisition of Continental Structural Plastics Holdings »

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Corp. (CSP) by Teijin Ltd. gave the Japanese fiber and raw materials producer a large boost toward its 2030 automotive composites annual sales target of US$2 billion[3]. Just as interesting was LG Hausys' US$43 million acquisition of a majority holding in c2i, the Slovakian composite part manufacturer that supplies BMW, Porsche, Bentley, Jaguar Land Rover and a number of aerospace and industrial applications. LG Hausys is clearly looking to take its materials and composite solutions through to finished parts, in support of the parent LG Group's strategic growth targets in the automotive parts sector.

Given the current surge in automotive composites development and the focus on electric vehicles, it's perhaps odd that we have seen so few major investments in composites technology from China — the biggest global EV market. And certainly, we have seen nothing on the scale of ChemChina's US$1 billion takeover of resin transfer molding and injection molding machinery specialist KrausMaffei in 2016. We speculate that this lack could be due, in part, to regulatory controls within China. That country could be seeking more control over overseas M&A transactions in a bid to stem vast capital outflows that are putting pressure on foreign exchange reserves and the renminbi itself.

Despite the additional scrutiny, Chinese buyers did show some appetite for Western firms: Advanced materials manufacturer Qingdao GON Technology, for example, acquired a majority stake in Compositence GmbH, a German firm specializing in rapid production of tailored preforms with carbon, glass and other fiber types for high-volume production applications in transport, aerospace and wind energy.

It's been an intriguing year for M&A activity, delivering some highly significant industry deals. Private equity investors and strategic purchasers have found the advanced composites sector attractive and an incentive to overcome "wait and see" market uncertainties. They have brought their large available capital reserves to the sector in 2017. We expect this trend to continue into 2018, with significant M&A activity driven by a variety of motivations, such as the need to acquire innovative technology or growth capital, to further consolidate the fragmented value chain or simply to satisfy the desire to create a position in an attractive advanced composites market. CW

REFERENCES:

[1] FMG research and *PitchBook*.
[2] Rockwell Collins release, 04/13/2017.
[3] Teijin press release, 01/05/2017.

ABOUT THE AUTHOR

David Schofield, co-founder and managing director of Future Materials Group (Cambridge, UK), a leading independent strategic advisory firm, has 25 years' experience in the specialty chemicals/advanced materials sector on a global level, with a focus on the areas of strategy and business development. Schofield previously held senior positions within Ciba-Geigy, Huntsman and Gurit AG.

And suddenly the inventor appeared

» Perusing my bookshelves recently, I came upon a book I'd read more than 20 years ago, titled *And Suddenly the Inventor Appeared*, by Genrich Altschuller, a Russian inventor. It's a treatise on TRIZ, the theory of inventive problem solving. Its premise is that any invention is ultimately the result of the application of physics, although the path to the solution is not always the obvious one.

The world is full of famous inventors (and inventions), going back, at least, to Archimedes, with his conveying screw, and his use of buoyancy to derive material densities (per legend, an idea he conjured while bathing). Inventions change things. Some inventions change everything. Johannes Gutenberg, who introduced moveable type for printing presses, and Leonardo da Vinci's numerous inventions ushered in the modern period of human history. The creation of the patent system provided legal protection to inventors that afforded them the time and opportunity to monetize their ideas.

> Inventors and their inventions are essential to keeping the composites industry vibrant and ever improving.

The industrial revolution gave us Watt, Whitney, Deere, Benz, Daimler, Ford, Tesla, Bell, Firestone and perhaps the world's most famous inventor, Thomas Edison. Referring to his deliberate method of discovery, Edison famously claimed, "Genius is 1% inspiration and 99% perspiration," to dispel the notion that inventions are mainly the result of accidents or are stumbled upon by those pursing other goals. In 1947, William Shockley's invention of the transistor and the commercialization effort that followed in California is believed to be the genesis of today's Silicon Valley.

The composites world is not short of well-known inventors, starting with Leo Baekeland, the creator of the first synthetic resin, phenolic. Trademarked as Bakelite, thermosetting phenolics quickly found numerous uses in neat form, but also as a binder for mineral and fibrous fillers, both discontinuous and continuous. Phenolic composites are used extensively today, in aircraft interiors, oil and gas applications, fire-resistant building and train panels, and high-voltage electrical components.

The first patent for resin transfer molding (RTM), issued in 1950, is often referred to as the Marco Process, assigned to Marco Chemicals in New Jersey by the lesser known inventor Irving Muscat. The process and patent are often cited in later patents for all sorts of resin infusion techniques, including variations of vacuum-assisted RTM (VARTM), such as the Seeman Composite Resin Infusion Process (SCRIMP), patented by Bill Seeman. Robert Morrison, founder of Morrison Molded Fiber Glass, has been involved in many innovations, none more famous than the press-molded composite body panels for the pioneering 1953 *Chevrolet Corvette*.

The most lauded inventor in the composites industry is probably the late Brandt Goldsworthy, who was granted well over 50 patents for composites processes, including straight and curved pultrusions, CNC filament winding and tape placement, among others. From his inventions, and the companies he founded or helped found, has sprung a robust composites industry built on lower cost, automated manufacturing.

I've been fortunate during my career in composites to come across numerous inventors. Some are itinerant tinkerers, working out of a garage or shed — like the founders of Hewlett Packard and Apple. Others have the advantage of tinkering inside corporate laboratories. Some employ deliberate methodologies that would make Edison proud. Others simply reach out experimentally, relying on the random epiphany for that "Eureka!" moment. For example, the inventor of the Quickstep curing process, a floating, balanced pressure, liquid heating and cooling process, claims to have come up with the idea while sitting in his bathtub — his own Archimedes moment!

My favorites have been the serial inventors, those with multiple ideas that have reached various states of commercialization. One friend of mine in the US has come up with novel ways to recycle thermosets, developed metals that heat and cool molds rapidly, resins for infusing (and improving the strength of) 3D printed powder structures, and very high-temperature and fire-resistant thermoset resins, among other creations. A friend in the UK, whom I consider one of the best I've met at thinking outside the box, has developed a number of lightweight vehicle platforms, a patented method of metalizing carbon composites, and low-cost methods for fabricating large, structural sandwich panels, using a mix of virgin and recycled carbon fibers. Not only are both serial inventors, they are also serial entrepreneurs. I know many others just like them, who open my eyes to what is possible.

What they, and others like them are doing, is essential to keeping the composites industry vibrant and ever improving. Not every invention or innovation is a commercial smash, but that should not limit us from encouraging novel ideas, no matter how they are conceived or how improbable they might seem. CW

ABOUT THE AUTHOR

Dale Brosius is the chief commercialization officer for the Institute for Advanced Composites Manufacturing Innovation (IACMI, Knoxville, TN, US), a US Department of Energy (DoE)-sponsored public/private partnership targeting high-volume applications of composites in energy-related industries. He also is the head of his own consulting company, and 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 has 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.

The Composites Fabricating Index closes 2017 on an up note

December 2017 – 55.8

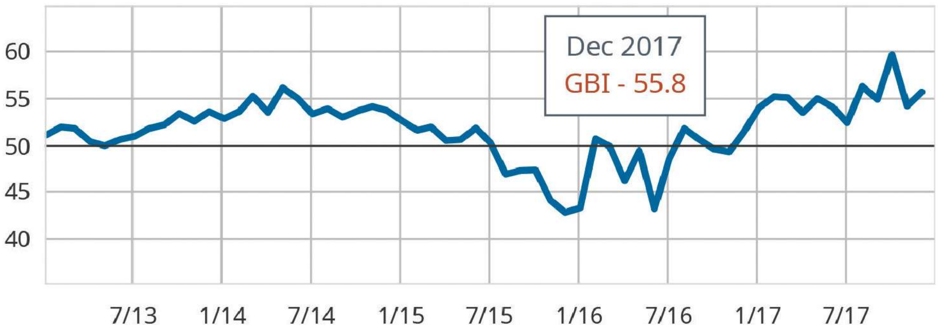
» Registering 55.8 in December, the Gardner Business Index (GBI): Composites Fabricating ended the month above its 2017 average of 55.1. The fourth quarter's readings were the year's highest and were well above the readings recorded during the same quarter a year earlier. Compared to December 2016, the Index this past December had increased approximately 8%. The Gardner Intelligence review of the underlying data for the month indicates that New Orders, Production and Employment lifted the Business Index higher while Exports, Supplier Deliveries and Backlogs held it back. However, only the reading for Backlogs indicated actual contraction (registering less than 50.0) during the month.

Throughout most of the year, Production and New orders were the major drivers of overall Index performance. During two of the three months in the fourth quarter, the readings for New Orders exceeded those for Production. Past examination of Gardner data suggests that when New Orders growth exceeds Production, manufacturers can expect continued industry growth. In addition, such instances typically result in a near immediate improvement in Backlogs, Exports or both. This has been proven out by both the sharp expansion in the Backlogs reading in November and the Exports reading in December. CW

ABOUT THE AUTHOR

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

GBI: Composites Fabricating

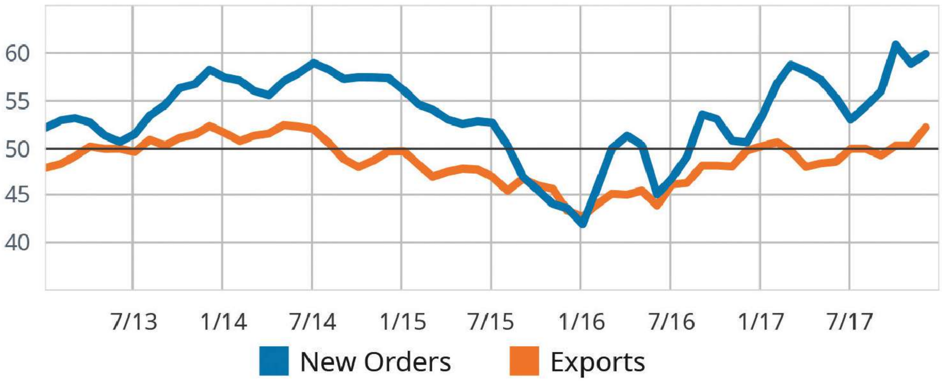


■ The 2017 surge will give 2018 a strong start

The Composites Fabricating Index's December reading, up from November's, exceeded the calendar year average of 55.1. Trends within the data suggest that the composites fabricating industry will start off 2018 strongly.

GBI: Composites Fabrication - New Orders and Exports

(3-month moving average)



■ Strong demand indicated by key high readings

Strong expansionary readings in the New Orders and Exports components of the Index suggest that export and domestic demand grew in the fourth quarter, pushing up Backlogs.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An excerpt from the *CW Talks* interview with Avner Ben-Bassat about making a big difference using Big Data, plus *CW*'s report on December's info-rich Carbon Fiber conference, and news of another supersonic aircraft, this time in the business jet sector.

Source | Plataine Technologies

Q&A: Avner Ben-Bassat, president and CEO, Plataine Technologies

Editor's note: As composites move increasingly into higher volume, automated manufacturing environments, the need for good process and data control also increases. CW Talks: The Composites Podcast *offered its forum to Ben-Bassat, who spoke about Industry 4.0, the digital thread and how to get started managing, and making sense of, manufacturing data. Excerpts follow. To listen to the entire conversation, search for CW Talks on iTunes or Google Play, or visit* www.compositesworld.com/podcast.

***CW*: How does your software collect data and how is it used?**

ABB: A lot of companies collect data, which is very intuitive and makes sense. But the key is, what do you do with the data? We look at this from a practical, problem-centric point of view. …. We want to know what is actually happening. Here, we use sensors, to tell us what is going on, where are the materials, where are the parts, what's their condition, what's the situation? And we get data off machines as well. …. And yes, some of the data needs to be received from the operators, so we give them an application. But the point is that the data is digital data. If it is on paper, it really is useless for us. So, we want data, want data in digital format and we want data in real time. Now, once we have the data, we want to put it in context, and context is fundamentally the key here. If we're tracking a material and material number one is at station number two, is this a good thing or is this a bad thing? It's great if it's supposed to be there, but it's horrible if it needs to be in the freezer because it's about to expire. So, for example, we can raise an alert and I can tell you that material 123 is going to expire. It's prepreg, it has 20 hours to live, and I will tell you that it's going to expire. … But what if tell you that you have a problem, or about to have a problem, but what if I also tell you the solution?. …. So there is a major leap here — a revolution — of how we can run the production floor by digitizing the process and then elevating it to helping production floor staff make better decisions.

***CW*: You are creating a digital thread, are you not?**

ABB: A digital thread, in plain language, is the history of the making of the part. … As we move down the production line, we are capturing that information. We use a lot the parent-child analogy. The materials are the parents and the part is the child. When this child is born, two very important things happen. One, we have a new entity to track and optimize, because the materials will go back in the freezer and the part will go on to the autoclave or beyond. But the other thing that happened is that the part inherited a lot of the parents' DNA. It inherited the material number, the batch number, the remaining shelf life. …. And we have captured all of that history. …. The implications for quality and operations are huge. …. Let's say that you're in production and suddenly a part fails a quality check, and you run it to the lab and you realize that it had used a bad batch of material. So, now you need to disqualify the part, but what you also need to do is find all the other parts that had used the same material. So, you need to go back and find the source of material and then find all the other children of that material. In today's environment, this can take hours or days. The bigger problem is that during these days, you continue making bad parts. …. And the worst is that at the end of all that, you're not sure you found everything. In our world, with a real digital thread, it's a done deal in a matter of seconds. …. So, this is a very powerful data structure.

***CW*: How does automation fit in with the digital thread and your software?**

ABB: I would say the industry today, and certainly the leaders, understand that they must automate and they must digitize to stay competitive, to grow or to simply meet rate. …. Automation is really the only path forward. …. But nobody is buying anything because it's cool. We see some amazingly cool robotics, and I think our stuff is cool. … We are engaged with our customers in a very professional, very technical, very practical discussion to evaluate the technology, to evaluate the software, to evaluate the benefits. …. It's not technology for technology, but technology for value. So, why do you automate? Because, you want higher throughput, because you want better control of quality, because you want to reduce scrap.

CW: What are some things a company can do to get on the road to higher efficiency and higher rate production?

ABB: When someone approaches us like that, we obviously ask some more questions. What's going on? Where are your challenges? Where are your pain points? In most cases, the root cause for all of this is a production environment that grew more challenging either by complexity or by volume. And, for whatever reason, the investment did not keep up with that. And so the systems and processes are just not suitable to deal with that level of complexity or volume. .... And if you throw more people and more paper at it, it only makes things worse. .... We start by solving the most elementary need to digitize the process. How do we integrate the data? How do we automate data collection? And there we would introduce sensors, for example, we put RFID or any other sensor — could be Bluetooth — on every material, every tool, every part that moves around. Now we are working with customers on temperature sensing. What about humidity sensing? But this is a lot of data that did not exist, or existed in paperwork somewhere. .... The pain points in composites are in tracking, managing the materials — not just the raw materials but the work in progress .... As we develop a dialog, we pilot a system, and eventually deploy it. And deployments can be very quick.

Source | *CW*

Catching up with CAMX 2017

CAMX 2017 was originally scheduled for September 2017 in Orlando, FL, US, but Hurricane Irma blew it off course and into December. The postponed show was no worse for the wear and proved, again, the dynamism of the composites industry's largest market. *CompositesWorld* was there, and you can see our reporting online in several places, including summaries from senior editors Ginger Gardiner (**short.gardnerweb.com/CAMX17GG**) and Sara Black (**short.compositesworld.com/CAMX17SB**) and editor-in-chief Jeff Sloan (**short.gardnerweb.com/CAMX17JS**). And if video is more your speed, see the show here: **short.gardnerweb.com/CAMX17V.**

AEROSPACE

Lockheed Martin and Aerion to co-develop supersonic business jet

Source | Aerion Corp.

Aerion Corp. (Reno, NV, US) and Lockheed Martin (Bethesda, MD, US) announced a Memorandum of Understanding (MoU) on Dec. 15, 2017 to define a formal, gated process to explore the feasibility of joint development of what would be the world's first supersonic business jet, the *Aerion AS2.* During the next 12 months, the companies will develop a framework for all program phases, including engineering, certification and production. The MoU is the result of extensive discussions between Aerion and Lockheed Martin's Skunk Works Advanced Development Programs team.

Lockheed Martin, key to development of the F-16, F-35 and F-22 supersonic combat aircraft, is committed to fostering innovation. For close to 75 years, its Skunk Works has existed to "create revolutionary aircraft" that "push the boundaries of what is possible." Aerion chairman Robert M. Bass agrees, "This relationship is absolutely key to creating a supersonic renaissance. When it comes to supersonic know-how, Lockheed Martin's capabilities are legendary. We share with Lockheed Martin a commitment to the long-term development of efficient civil supersonic aircraft."

"We are excited to work with Aerion on their development of the next-generation, efficient supersonic jet that will potentially serve as a platform for pioneering future supersonic aircraft," says Orlando Carvalho, executive VP, Lockheed Martin Aeronautics. "Following our initial review of Aerion's aerodynamic technology, our conclusion is that the *Aerion AS2* concept warrants the further investment of our time and resources."

During the past two-and-a-half years, Aerion advanced the aerodynamics and structural design of the *AS2* through a previous engineering collaboration agreement with Airbus (Toulouse, France). That effort resulted in a preliminary design for wing and airframe structures, a systems layout, and preliminary concepts for a fly-by-wire flight-control system. "We are grateful for Airbus' contribution to the program," says Brian Barents, Aerion executive chairman. "We could not have moved the program to this stage without their support."

In May 2017, GE Aviation announced an agreement with Aerion to define a supersonic engine for the *AS2*. With this latest announcement, Aerion joins Boom Supersonic (Denver, CO, US), which intends to field a supersonic commercial passenger *(continued on p. 20)*


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(continued from p. 18)

transport aircraft (see *CW*'s coverage at **short.compositesworld.com/BoomJet**) and others in the nascent sector of civil supersonic aviation.

Aerion Corp. was formed in 2003 and has demonstrated advanced wing technology with NASA and other leading aeronautical institutions. This research led to breakthrough work in supersonic natural laminar flow, the key enabler behind the 12-passenger *AS2's* maximum speed of Mach 1.4. The aircraft is expected to achieve long range (LA to Paris) and efficiency at supersonic and subsonic speeds. Once fielded, it will reduce transatlantic trips by as much as three hours, enabling business leaders to fly roundtrip between New York and London in a day. In November 2015, Aerion announced an order from fractional aircraft fleet operator Flexjet for 20 *AS2* aircraft. Aerion expects the *AS2's* first flight in 2023 and certification in 2025.

BIZ BRIEFS

Qee-Composites Inc. (Gyeonggido, South Korea), a global developer and supplier of custom, high-volume composites manufacturing equipment, announced in early November its relocation to the Purdue Research Park (West Lafayette, IN, US). The move places Qee-Composites in close proximity to Purdue students, professors and researchers giving the company access to skilled labor, and the option of laboratory space within the Park, which is managed by the Purdue Research Foundation and is the largest university-affiliated business incubation complex in the US. A key element in the Qee-Tech production is the patented Qee-Tech Cell, a thermoplastic preform technology developed and sold by sister company **Qeestar Co. Ltd.**, which enables cost-effective production of 3D shaped composite parts using continuous carbon or glass fiber. "Our Qee-Tech Cell enables the production of lightweight, structural thermoplastic composite parts at a high rate, often one minute," says Queein Manson, CEO and founder of Qee-Composites. "This is possible by a faster transformation from fiber and polymer to a finished 3D shaped part." Targeted applications include demanding structural parts for automotive, such as bumper beams, seat structures and front-end model carriers (Read *CW's* previous Qee-Tech coverage | **short.compositesworld.com/QT-3DTPC**).

Wisconsin Oven Corp. (East Troy, WI, US) reports that it has recently acquired a neighboring facility in East Troy that adds 130,000 ft^2 to its existing facilities. The new plant space doubles the company's manufacturing floor space and also adds substantial new office space that will help support the company's continuing growth. In addition to using the new facility in East Troy, Wisconsin Oven continues to ramp up production with Baker Furnace at its new 40,000-ft^2 plant in Brea, CA, US, which serves its West Coast customers with a local manufacturing and service presence. Wisconsin Oven is owned by Thermal Product Solutions LLC (TPS, White Deer, PA, US).

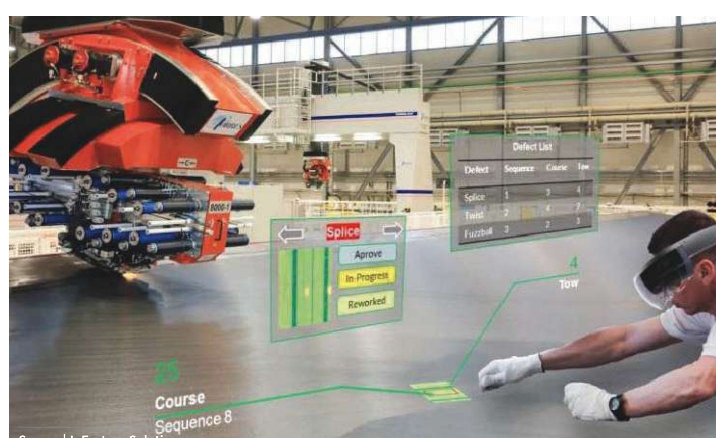
AEROSPACE

Conference Highlights: Carbon Fiber 2017

Source | Boeing

CompositesWorld's annual Carbon Fiber conference, held this year in Charleston, SC, US (Nov. 28-30), began with a tour of conference co-sponsor The Boeing Co.'s (Chicago, IL US) South Carolina facility, the only site where all three versions of the *Dreamliner* — the 787-8, 787-9 and the newest and at 68.3m, the longest, the 787-10, are built. Although assembly of the -8 and -9 versions are completed in Charleston and at Boeing's Everett, WA, US assembly facilities, the 787-10 rolls out only from Boeing South Carolina.

Following the morning's tour, Chris Red of Composites Forecasts and Consulting LLC (Mesa, AZ, US) opened up the conference by presenting his *2017 Carbon Fiber Global Outlook*. Global growth in the US$75 billion carbon fiber industry, he said, will average 10% year-over-year during the next decade, with carbon fiber demand increasing from 102,000 MT in 2016 to 182,000



Source | InFactory Solutions

MT in 2021 and peaking at 262,000 MT in 2025. Red noted that principal demand continues to come from industrial applications, which represent 75% of the market vs. 14% for aerospace and 11% for consumer goods. Major segments within industrial include automotive, wind, rail, pressure vessels and other energy (oil & gas, energy storage, tidal and wave power). He projected that ground transportation — including automotive, bus, truck and rail — will consume nearly 30,000 MT of carbon fiber by 2025, but pointed out that pressure vessels will command the highest segment volume by 2025, exceeding 53,000 MT of carbon fiber.

Automation was a strong conference theme this year. Airbus Group Innovations' Rainer Rauh discussed the development of automated, inline inspection of automated fiber placement (AFP), using laser sensors and digital tools, by Airbus subsidiary InFactory Solutions (Taufkirchen, Germany). Rauh revealed that 32% of AFP machine production time is consumed with manual inspection and rework (see photo). The sensor systems and data analysis tools in qualification for aircraft production by InFactory, however, reportedly can reduce inspection time by 95% and rework time by 73% — resulting in a 48% drop in the overall part processing time.

Several sessions focused on *additive manufacturing.* A highlight was Cole Nielsen, CEO of Orbital Composites (San Jose, CA, US), who presented a vision of the future for 3D-printed, continuous fiber-reinforced composites, based on his company's patented co-extrusion head, which allows not only the printing of thermoplastics, but also *thermosets*. A modified version of the system mixes and maintains temperature of two-component epoxies — and even metal or ceramic matrices — to completely surround continuous fibers and copper wires with good matrix-fiber distribution in the deposited plies. Wires? *Yes.* For integrated printed circuits *(continued on p. 24)*

(continued from p. 23)

with the power capacity required for applications like spacecraft and electric aircraft. Nielsen suggests wires could and should become part of the structural reinforcement for future spacecraft and unmanned aerial vehicles (UAVs), but can also provide multifunctionality in automotive parts and even wind blades.

Keynote address. The challenges of expanding carbon fiber into new automotive applications was the focus of Carbon Fiber 2017's keynoter Mark Voss, General Motors (Detroit, MI, US) engineering group manager, body structures advanced composites. From his experience implementing carbon fiber panels for several vehicles in the *Corvette* series, Voss' primary admonition was to "limit the 'news'" in new applications — that is, restrict the number of technologies and processes that are new to the automotive industry.

Voss also emphasized how crucial joining technologies are to the introduction of carbon components, which must be integrated with dissimilar materials in automotive structures. Finally, to make carbon composites cost-competitive despite their higher material cost, Voss suggested that scrap costs be considered early in the development cycle.

Anthony Vicari of Lux Research (Boston, MA, US) followed the keynote with a study of growth opportunities and challenges for carbon fiber composites. He began with a forecast for carbon fiber (CF) nameplate capacity (total announced by the manufacturer) of 151,000 MT/yr by 2020. Actual yield is forecast to be roughly 10-20% less. Demand for CF was estimated to reach 228,000 MT/yr by 2025, with the most growth in wind and aerospace. Vicari believes, however, that CF penetration into automotive will not move beyond luxury models in higher-volume mainstream vehicles before 2025, if indeed this happens at all.

He does see potential for growth, however, through large opportunities in rail transit, construction repair and large marine vessels. In rail, CFRP bogies that replace steel can reduce the weight of a rail car by almost 1 MT and also provide corrosion resistance that will improve the car's maintenance and service life. Vicari also sees a large market in bridge repair, which is a very mature technology using CFRP, but cautions that the infrastructure marketplace has not yet been "sold" on this approach. Expansion here depends on the promise of near-term, low-cost carbon fiber, such as that being developed by LeMond Composites (Oak Ridge, TN, US) and Oak Ridge National Lab (ORNL, Oak Ridge, TN, US), among others; OEM pull; and improved repair techniques, under development by innovators such as FARO Technologies (Lake Mary, FL, US) and Oxford Performance Materials (Windsor, CT, US).

And that's just a sampling. For a full report on the eventful CF 2017 conference, read the following posts at the *CW Blog* | short.gardnerweb.com/CF17live and short.gardnerweb.com/CF17final

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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**

John Hopkins named permanent CEO of IACMI
Hopkins had been serving as interim CEO since September 2017. The "interim" tag was removed at the IACMI winter membership meeting on Jan. 16.
01/16/18 | short.compositesworld.com/IACMI-CEO

CPIC develops family of unique fiberglass products
A flat rather than round cross-section facilitates higher fiber loading levels and better mechanical properties in injection molded thermoplastic composites.
01/15/18 | short.compositesworld.com/CPICnew

Siemens Gamesa to supply French offshore project
It will supply its new 8-MW offshore wind turbine, the SG 8.0-167 DD, to the 500 MW Saint Brieuc offshore wind project off France's Bretagne coast.
01/15/18 | short.compositesworld.com/SGRE-8MW

Maine regulators delay UMaine floating wind farm project
A *Press Herald* story reports that Maine officials have delayed a power contract for the University of Maine's Aqua Ventus floating offshore wind turbine.
01/11/18 | short.compositesworld.com/UMainehalt

Chocolate Factory replaces metal parts with Stratasys 3D printed composite
The 3D-printed replacement machine part, produced in Stratasys' FDM Nylon 12CF thermoplastic, contains 35% chopped carbon fiber.
01/11/18 | short.compositesworld.com/ChocFactPt

Solvay, deBotech announced as USA Bobsled and Skeleton technology partners
Solvay and deBotech will provide custom-designed, high-quality carbon fiber composite equipment.
01/11/18 | short.compositesworld.com/USAsled

MIT nanofibers offer strength, toughness
MIT researchers have used gel electrospinning to produce ultrafine polyethylene fibers that offer excellent strength and toughness properties.
01/08/18 | short.gardnerweb.com/MITnano

Airbus rolls out first A321neo ACF
The A321neo ACF is powered by CFM LEAP-1 engines and seats up to 240 passengers.
01/08/18 | short.compositesworld.com/A321roll

ELG's new CARBISO product on display in Japan
The company introduced its trademarked CARBISO range of recycled carbon fiber products at the Automotive World Show in Tokyo, Jan. 17-19, 2018.
01/08/18 | short.compositesworld.com/Carbiso

Plasan to manufacture composite ramps for Amtrak
Plasan Carbon Composites meets stringent weight and strength requirements for Amtrak's Acela rail service.
01/08/18 | short.compositesworld.com/Amtrakramp

BIZ BRIEFS

Wabash MPI and **Carver Inc.,** co-located in Wabash, IN, US, have completed their recent expansion to their Wabash facility in response to continued growth. This 5,000-ft^2 expansion includes new warehouse and service areas that allow for re-organization of the current space for new offices, increased manufacturing capacities and greater efficiency for Wabash and Carver hydraulic and pneumatic presses.

Wabash MPI is an international supplier of standard and custom presses to the medical, aerospace, recreation, automotive, education and energy markets. Carver Inc. offers two-column and four-column benchtop, manual and automatic hydraulic laboratory presses with clamping capacities from 12-48 tons.

SGL Carbon SE (Wiesbaden, Germany) has sold its 51% share in the **SGL Kümpers GmbH & Co. KG** joint venture to **Kümpers GmbH** and **Franz-Jürgen Kümpers**, both of Rheine, Germany. SGL Group will continue to supply carbon fiber and will maintain its existing business relationship with Kümpers. The parties to the contract have agreed to keep the financial details confidential. The joint venture was founded in early 2007 for the production of high-performance materials, such as fabrics and braids based on carbon and glass fibers.

SGL Group's Composites – Fibers & Materials (CFM) business unit will now operate five sites in Germany and Austria — three German sites in Meitingen, Wackersdorf (both in Bavaria), and Willich (North Rhine-Westphalia), plus Ried and Ort in Austria's Innkreis region.

AEROSPACE

Market prediction: Strong growth in aerospace

MarketsandMarkets (Pune, India) has released a new report, titled *Aerospace Composites Market by Fiber Type (Carbon, Glass, Ceramic), Resin Type (Epoxy, Phenolic, Polyester, Polyimides, Thermoplastics, Ceramic and Metal Matrix), Aircraft Type, Manufacturing Process, Application, Region – Global Forecast to 2022.* In it, the aerospace composites market is projected to reach US$42.97 billion by 2022, up from the US$26.87 billion estimated in 2017, representing a healthy compound annual growth rate (CAGR) of 9.85%. The major factors fueling the growth across the globe are the increasing use of aerospace composites in commercial and military aircraft, say the report's authors.

Composites use in commercial aircraft, they show, has gained momentum during the past few decades (~53% of the Airbus A350 XWB, for example, now comprises composite materials) primarily for their weight reduction and corrosion resistance benefits. Moreover, the authors claim that maintenance costs for composites-intensive aircraft are lower when compared to traditional aluminum construction.

Carbon fiber accounts for more than 70% of the reinforcements used to manufacture aerospace composites, and demand is increasing, the authors say, in both commercial and defense aircraft. As the demand for carbon fiber composites continues to rise, the number of carbon fiber manufacturing plants, too, will grow in North America and Europe.

In terms of market demand, North America is the largest consumer of aerospace composites, and use of composites is projected to grow there at the highest CAGR in terms of both value and volume during the forecast period. More information about the report is available here | short.compositesworld.com/MandMACMFT

CORRECTION

In the January 2018 issue of *CW*, we reported, on p. 20, that BMW AG (Munich, Germany) has launched its own line of organosheets and acquired BENTELER's (Salzburg, Austria) share of the BENTELER-SGL (Ort im Innkreis, Austria) joint venture. This was incorrect. It was, in fact, SGL Group (Wiesbaden, Germany) that launched its own line of organosheets and acquired BENTELER's share of the BENTELER-SGL joint venture. *CW* regrets the error.

AEROSPACE

Major aircraft OEMs celebrate 2017

The reports are in, and the two major commercial airframers are noting newsworthy numbers, as they tally totals from 2017. Airbus' (Toulouse, France) Commercial Aircraft deliveries in 2017 were up for the 15th year in a row, for a new company record of 718 aircraft delivered to 85 customers. Deliveries were >4% higher than the previous record of 688 set in 2016. The 2017 total comprises 558 single-aisle A320 Family (of which 181 were A320neo, an increase of 166% over 2016); 67 A330s; 78 A350 XWBs (up by nearly 60% from 2016) and 15 A380s. In addition, Airbus achieved 1,109 net orders from 44 customers. At the end of 2017, Airbus' overall backlog stood at 7,265 aircraft, valued at US$1.059 trillion at list prices.

This year capped 15 consecutive years of Airbus production increases. From its four A320 plants in Hamburg, Tianjin, Mobile and Toulouse, Airbus is said to be on track to achieve a rate of 60 per month on single-aisles by mid-2019.

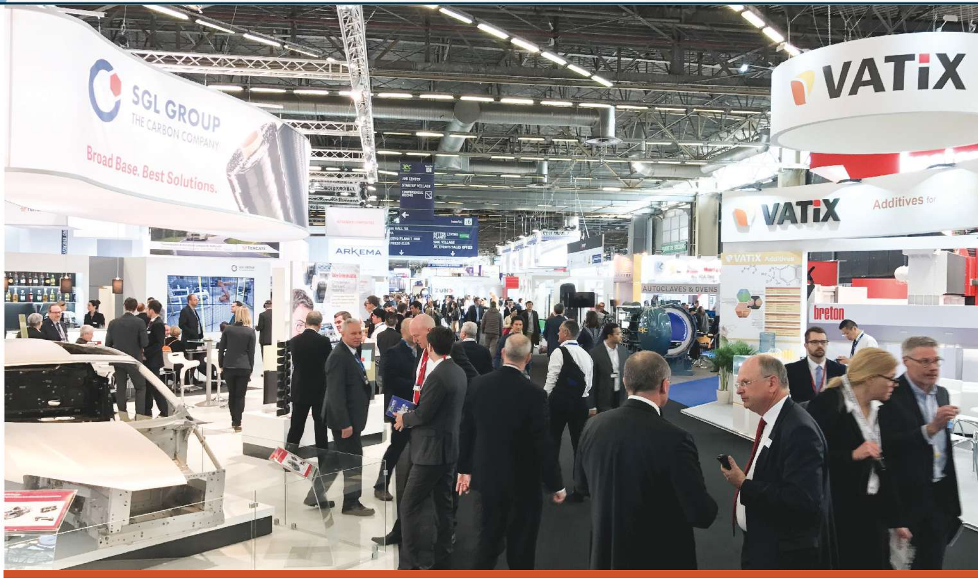
Industrial milestones achieved by Airbus Commercial Aircraft in 2017 included delivery of the 100th A350 XWB; the delivery of the 50th A320 Family aircraft from its facility in Mobile; the first flight of the A330neo; certification of the A350-1000; inauguration of the new A330 Completion and Delivery Centre in Tianjin, China, with two first deliveries; and structural completion of the first Beluga XL.

The Boeing Co. (Chicago, IL, US) reportedly set an industry record with 763 deliveries in 2017, driven by high output of its 737 and 787 jets. At the same time, the company grew its backlog, with 912 net orders, reflecting healthy demand for its single-aisle and twin-aisle airplanes.

Boeing reached a new high on the 737 program as it raised production to 47 airplanes a month during 2017 and began delivering the new 737 MAX, contributing to a record 529 737 deliveries, including 74 of the MAX variety. On the 787 *Dreamliner* program, Boeing continued building at a high production rate for a twin-aisle jet, leading to 136 deliveries for the year.

On the orders front, 71 customers placed the 912 net orders, valued at US$134.8 billion at list prices. The total extended Boeing's backlog to a record 5,864 airplanes, reportedly equal to about seven years of production.

In 2017, the 787 *Dreamliner* family racked up nearly 100 net orders and the 777 family captured 60 net orders. Other milestones include the first flights of the 737 MAX 9 and the 787-10 *Dreamliner*, and the start of production of the 737 MAX 7 and the new 777X.



International reach

Although 52% of show attendees live and work in Europe, show organizers expect visitors this year from as many as 113 countries. Of total expected attendance, 18% will come from the Asia-Pacific region, 15% from North and South America, 10% from the Middle East and 5% from Africa.

Source | CW / Photo | Jeff Sloan

JEC World 2018 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, near Charles de Gaulle airport, outside Paris, France. Taking place this year March 6-8, the event's exhibitors — JEC predicts as many as 1,300 — will showcase many new technologies in the composites world, which continues to be one of the most technologically creative and innovative sectors within the wider world of manufacturing.

JEC will offer its three-day conference program, including 30 expert presentations that provide competitive intelligence, technical innovations and benchmarking for the composites industry. Also on the bill will be the JEC Innovation Awards, held each year to recognize the latest trends in R&D (a wide range of categories will include the likes of Biomaterials, Raw Materials, Processes, Transportation, etc.).

Unique to the Paris event, however, are several other features in JEC's show repertoire:

- *B2B Meetings*: JEC offers an online service designed to help attendees organize targeted meetings while in Paris. The JEC team claims that, this year, more than 2,000 B2B meetings will take place in junction with the JEC proceedings.
- *Startup Booster*: This program is designed to support entrepreneurship by offering a forum for startups to present themselves and their technologies to the industry. Supported by aircraft OEM Airbus (Toulose, France) and automaker Daimler (Stuttgart, Germany) in 2017 as well as other industrial partners, the program reportedly highlights the industry's latest significant innovations.
- *Leadership Circle:* This is JEC's networking event for composites industy management personnel.

Previews of the latest technology

RIBA Composites (Faenza, Italy) featured this highly engineered carbon fiber composite motorcycle structure at its stand during JEC World 2017.

Source | *CW* / Photo | Jeff Sloan

JEC also has taken to advertising its Parisian event as "end-user oriented." Contending that the composites sector is "young, complex and heterogeneous," JEC explains, "the sector's customers and potential customers can find it difficult to understand what is or can be done with composites for their own market, so they might not be aware of the valuable benefits of their usage." Since 2016, JEC's Innovation Planets — specialized showcase areas — have served to offer the end-users among JEC attendees an opportunity to view already successful composites applications in automotive and land transportation, aerospace, construction and "better living" sectors (sports and leisure, energy and sustainability, medical and other markets). The Planets each focus in on specific markets, giving the end-user a clearer view of how composites can impact product development and manufacturing in each. CW

For more about JEC World 2018, visit www.jec-world.events

Carbon/glass spar cap enables world's longest wind blade

LM Wind Power goes long with a resin-infused hybrid carbon composite strategy.

By Donna Dawson / Senior Writer Emeritus

FIG. 1 LM Wind Power's 88m blades, installed

One set of 3 LM 88.4 P blades, installed by Adwen and running in Bremerhaven, Germany, on this single wind turbine, are said to be capable of powering around 10,000 homes — a small town. Ten similar turbines might power a city.

Source (all photos) | LM Wind Power

» LM Wind Power's (LM, Kolding, Denmark) sole product is wind turbine blades. From 1978 through 2016, the company had produced more than 195,000 blades. Recently, LM stretched its skills to produce its first 88.4m wind turbine blades (Fig. 1, above). Almost as long as a 100-yd American football field, they are the longest blades yet built by any manufacturer. The swept area of a turbine rotor fitted with 88.4m wind blades is large enough to cover three soccer fields and power a small town.

The blade in question, designated LM 88.4 P, is nearly 15m longer than LM's previously longest blade, the LM 73.5 P, but only 6 MT greater in mass (see Fig. 2, p. 33). This was accomplished by introducing the lightweight strength and stiffness of carbon fiber into the spar cap laminate.

Other wind blade manufacturers have leveraged the benefits of carbon fiber for more than a decade — primarily through pultruded and carbon/epoxy prepreg spar caps — justifying its higher price through realized performance benefits that enabled competitive levelized cost of energy (LCoE) per megawatt hour. LM, however, is now taking a different approach, embedding a hybrid carbon/glass fiber main spar cap along the length of its standard glass fiber base shell laminate. Saving time and money, the blade shell and spar cap are built in the same tool, with the shell serving as the mold for the hybrid-carbon spar cap. "The LM 88.4 P is the first hybrid blade to be built in this way, using a dry hybrid-carbon layup with a vacuum-assisted resin transfer molding (VARTM) infusion process," says LM's Michael Lund-Laverick, director composite technology projects. This hybrid design enabled LM to stretch its core competence to a 88.4m blade within its existing resin-infusion process, without adding another manufacturing process. This strategy met LM's customer's design specifications within established cost and schedule targets. "We chose the solution that was closest to the concept we usually apply, thereby reducing risk and enabling faster development for the customer," Lund-Laverick says.

The design process for the 88.4m started with the question LM's engineers ask first on every project: *How windy will it be?* Customers select one of four wind classes established by the International Electrotechnical Commission (IEC, Geneva, Switzerland), based on the destination wind farm site and on calculated loads (Fig. 3, p. 33). LM's customer for the 88.4m blade, Adwen (Bremerhaven, Germany, now part of Siemens Gamesa Renewable Energy, Zamudio, Spain), specified Wind Class I (high wind) for offshore sites. LM, accordingly, designed the blade for 50 m/sec (112 mph) Reference Wind Speed and other Class 1 requirements.

FIG. 2 Blade comparison

Statistics comparison, LM 73.5 P (glass/polyester construction) with LM 88.4 P (featuring the hybrid carbon spar), for IEC Wind Class 1.

Model	Length (m)	Rotor dia(m)	Swept area (m^2)	Blade mass (MT)	Bolt circle dia. (m)	Maximum Chord (m)	Projected Blade area (m^2)	Nominal power output (MW)
LM88.4 P	88.4	181	25,734	34	4.2	5.9	333	8
LM73.5 P	73.5	151	17,910	28	3.2	4.2	188	6
Percentage Difference	120%	120%	144%	121%	131%	140%	177%	133%

IEC Wind Classes				
	I (High Wind)	II (Medium Wind)	III (Low Wind) IV	(Very Low Wind)
Reference Wind Speed (max.)	50 m/s	42.5 m/s	37.5 m/s	30 m/s
Annual Average Wind Speed (max.)	10 m/s	8.5 m/s	7.5 m/s	6 m/s
50-year Return Gust	70m/s	59.5 m/s	52.5 m/s	42 m/s
1-year Return Gust	52.5 m/s	44.6 m/s	39.4 m/s	31.5 m/s

FIG. 3 IEC Wind Classes

LM built the LM 88.4 P blades for Wind Class 1, according to the class system established by the International Electrotechnical Commission (IEC, Geneva, Switzerland).

Design drivers for new products: uncertainties and risk

Next, the design was driven by LM's uncertainty management strategy. "This approach tackles the highest uncertainties first — the worst failures that can be conceived," explains Lund-Laverick. It starts with LM's failure modes effects analyses (FMEAs). An FMEA is a formal analysis tool for evaluating the risk for a design (dFMEA) or a process (pFMEA). This consists, first, of engineers verbally brainstorming possible risks before turning to computer assistance. "In this way, we manage new projects by managing their risks, relying on the company's deep engineering knowledge, experience and communication to define the key showstoppers. Our engineers think about all the doom-and-gloom things that could possibly happen, and then think of tests and engineered solutions to ensure those things do not happen," Lund-Laverick explains.

The discoveries of these FMEA sessions determine what real tests and trials need to be conducted — actual sample parts are made and tested to verify design limits and failure modes before computer modeling and analysis begins. "The computer models are then based on a kind of reality," Lund-Laverick says, instead of preliminary theory — no matter how astute that theory may be.

After wind class, design limits and failure modes were established, engineers used LM Blades, the company's suite of design programs and 3D modeling software, to bring the big blade within established limits for static and dynamic fatigue load Markov Matrices (for variations over time); buckling of the large aero panels; Puck fracture criteria for strength of unidirectional fiber/matrix (Alfred Puck, Immenhausen, Germany); and other mechanical/strength and chemical/environmental requirements.

Hybrid carbon/glass fiber, the best of both worlds

LM's hybrid technology consists of the company's standard glass fiber/polyester base shell laminate strengthened by a hybrid carbon/glass fiber main spar cap. Glass fabrics for the shell are woven to LM's specifications by a variety of glass and fabric suppliers, typically including H-glass fiber, supplied by Owens Corning (Toledo, OH, US). The shell laminate is a structural sandwich with a balsa wood core, infused with LM's standard polyester resin. »

SIDE STORY

LM Wind Power now part of General Electric

On April 20, 2017, General Electric announced final acquisition of Kolding, Denmark-based LM Wind Power. Although LM will continue to operate as an independent blade manufacturer, Jérôme Pécresse, president and CEO of GE Renewable Energy (Fairfield, CT, US), says, "The completion of the LM Wind Power acquisition provides us with the operational efficiencies necessary to support the growth of our wind turbine business, which is the fastest growing segment of power generation. With LM's technology and blade engineering, we are now able to improve the overall performance of our wind turbines, lowering the cost of electricity and increasing the value for our customers. Together, we are set to capitalize on the expansion of renewable energy and be a growth engine for GE." To date, GE has installed more than 30,000 wind turbines worldwide, using blades supplied by LM and other blade manufacturers.

FIG. 4 In-mold finishing

Workers spray gel coat onto mold in preparation for fiberglass base shell layup, eliminating the need for a post-mold painting step.

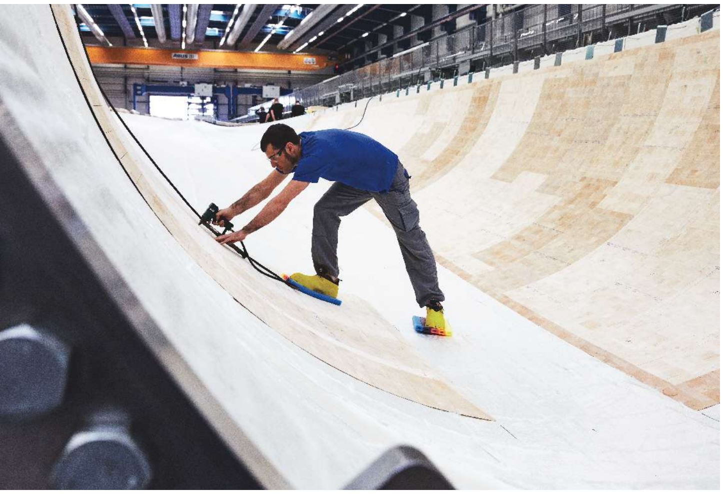


FIG. 5 Core placement

The balsa core is fixed in place by workers.

FIG. 6 Dry fabric layup

A semi-automated machine lays lengths of dry fabric along flat center of the mold. The hybrid carbon layup is shown in this photo.

For the spar cap, uniaxial carbon/H-glass hybrid fabric is manufactured by Devold AMT AS (Langevaag, Norway), a subsidiary of SAERTEX GmbH & Co. KG (Saerbeck, Germany), which received LM's Most Innovative Partner 2017 award for this fabric. Fiber architecture for both the base shell and the spar cap consists of a mixture of ±45° biaxial fabric, 0°, ±45° combination fabrics, and 0° unidirectional (UD) fabrics in differing areal weights. Developed with the LM team, this fabric was used for the first time in the 88.4m blade, infused with an unidentified, but proven LM resin to achieve target blade properties. The proprietary resin system used for spar cap infusion is based on the chemical backbone of other systems that have shown excellent chemical attachment and adhesion to the polyester resin used in the shell structure, Lund-Laverick says.

Hybrid carbon manufacturing strategy

The blade is constructed in two halves — an upwind (upper) half and a downwind (lower) half — which are mated after cure. Each blade half carries a hybrid spar cap. The manufacturing strategy for the hybrid carbon development consists of a two-stage infusion process, based on VARTM:

In the first stage, the shell, which includes all elements of the blade except the spar cap, is built up in the following sequence:

- Gel coat applied to 88.4m mold (Fig. 4, above).
- External biaxial fiberglass shell coverage layers are arranged.
- Root and edge reinforcements are applied, primarily UD materials.
- Balsa core is positioned in place for sandwich panel construction and retained with small fasteners (Fig. 5, above).
- Internal biaxial layers are added (Fig. 6, above).
- Vacuum bag is attached and standard LM polyester resin is infused via VARTM process.

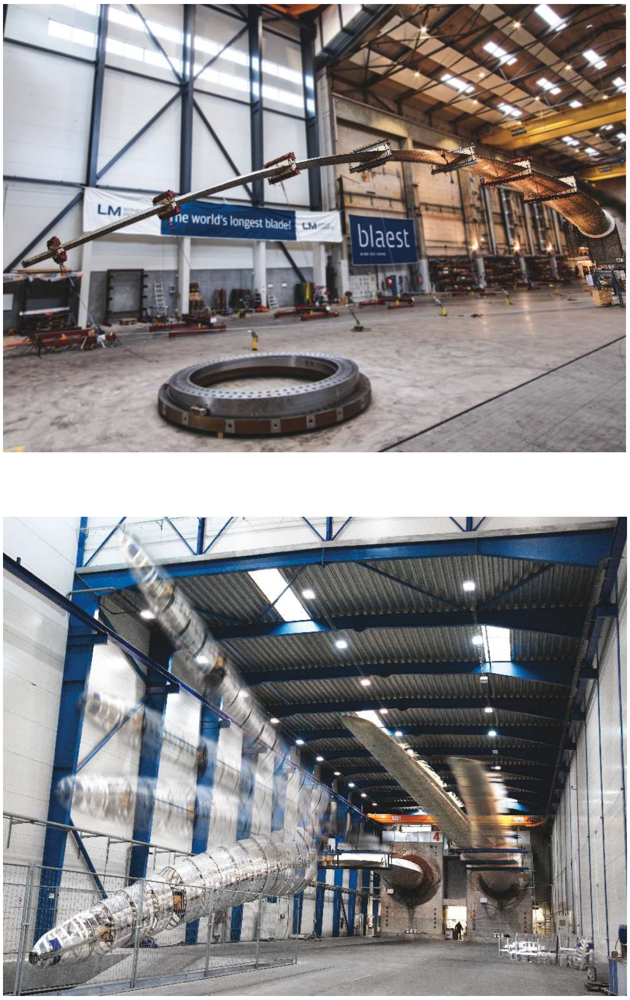


FIG. 7 Static and fatigue testing

Static (top photo) and fatigue (bottom photo) full-scale testing confirms design loads. Flapwise and edgewise loads were generated on the blade using a mechanical exciter, the same principle used during all other LM tests. But in the case of the LM 88.4 P blade, the test regime was beyond what LM had ever attempted in the past. Its lab first had to scale up the test equipment and review and confirm the standard test procedures for the big blade.

FIG. 8 Transport by truck and barge

The blades' massive size presented some significant challenges in terms of transportation. Movement was limited to after heavy road traffic hours. Each 60-ton blade made the 218-km trek through Denmark late at night by truck to Aalborg, Denmark (top photo). From there, they were carried by barge (bottom photo) to their final destination in Bremerhaven, Germany.

- Part is cured at room temperature, according to proprietary LM specifications.
- After cure, the base shell is de-bagged and inspected to prepare it for the next stage.

In the second stage, the hybrid main spar cap is then built up on top of the cured base shell, using the cured shell as a mold:

- Hybrid UD carbon/glass fabric layers are applied directly over the base shell, starting 4m from the root.
- LM-designed lightning protection components are added.
- Standard ±45° biaxial fiberglass coverage layers are arranged.
- Vacuum bag and VARTM infusion, carefully controlled to infuse only the carbon layup with a specially developed resin system.
- Part is cured at room temperature, according to proprietary LM specifications.

"We were able to scale-up our standard manufacturing process for our increasingly long blades," Lund-Laverick says. On these huge blade halves, the sides curve up but the center of the structure is essentially flat," he adds, "with only a gentle curve in the length direction due to pre-bending of the blade." For the flat sections of the blade halves, LM's in-house-designed, computer-controlled, semi-automated machine lays down wide sheets of dry fabric in programmed layers to meet strength requirements. »

The curved sides, however, present more complex geometries that generally must be layered by hand.

The machine was used for both the base shell and the hybrid spar cap. "For the hybrid carbon fabric, which is more sensitive than normal glass," Lund-Laverick says, "we developed a hands-off layup process to avoid wrinkles and other potential defects from manual handling."

The spar web is a fiberglass/foam sandwich structure made using primarily biaxial layers and infused with the standard polyester resin.

For quality control, LM employs the Six Sigma (Austin, TX, US) methodology. "During production, there is a strict suite of quality-control documents and procedures," including continual visual inspection of the blade, Lund-Laverick says. After cure, ultrasonic and visual inspection ensure the quality of the laminate. Following these inspections the blade halves were adhesively bonded in conventional fashion.

Closure and post-cure operations

After blade halves were adhesively joined, LM added its vortex generators, which compensate for the fact that large blades demonstrate relatively poor aerodynamic performance near the root. Designed for individual blade geometry and resembling small fins, they are injection molded and then adhered to the outer blade surface on the downwind shell, typically from about 5m from the root to about the middle of the blade during final blade assembly, using VHB tape, supplied by 3M Advanced Materials Div. (St. Paul, MN, US). These reduce flow separation (air separating from the blade before reaching the trailing edge) and improve lift and energy output. Additionally, LM installs proprietary, custom-designed spoilers on the inboard blade section, near the root, to further increase lift. These are made by reaction injection molding (RIM).

LEARN MORE

Read this article online | short.compositesworld.com/LM88mBlade

Destiny to be determined

The LM 88.4 P blade passed static and fatigue full-scale tests at LM's facility and at the independent Blaest Blade Test Center in Aalborg, Denmark (Fig. 7, p. 35). The blade subsequently was certified by DNV GL AS (Oslo, Norway). The first commercial LM 88.4 P blades were destined for installation in Adwen's next-generation AD 8-180 wind turbine, with 8 MW nominal capacity and a 180m rotor diameter. LM manufactured three blades, which were transported by truck and barge (Fig. 8, p. 35), installed by Adwen, and are running on one grid-connected turbine in Bremerhaven, Germany (opening photo, p. 32). LM "delivered the required blades and completed the DNV certification according to the original time plan," says Lund-Laverick. The overall project, however, became a casualty of industry consolidation: Adwen was acquired by Gamesa, which subsequently merged with Siemens, followed by Siemens Gamesa Renewable Energy's (Zamudio, Spain) cancellation of the AD 8-180 platform, for which the LM 88.4 P had been developed.

Lund-Laverick says LM Wind Power continues to drive hybrid carbon fiber spar platform development and is now delivering it on 69.3m blades for Siemens Gamesa. This onshore turbine blade design — for the world's largest onshore rotor — uses the same design, material and manufacturing principles developed for the 88.4m blade and continues to leverage the hybrid carbon and resin system technology benefits to drive the LCoE ever lower. He adds that future hybrid blade construction depends on customer requirements, but says as blades grow longer, LM expects an increasing number will be built using the hybrid technology. CW

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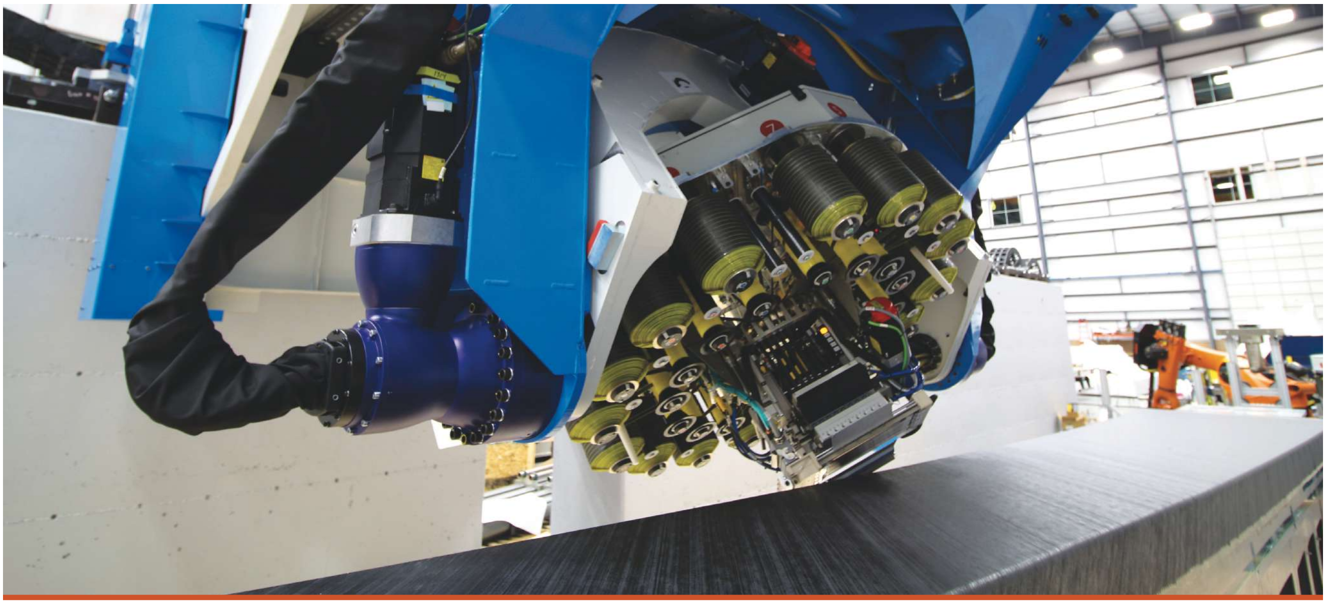
Improving composites processing with automated inspection

Automated, in-situ inspection bypasses the bottleneck of manual inspection.

By Sara Black / Senior Editor



Breaking the inspection bottleneck

Electroimpact's automated fiber placement (AFP) head is shown here during production trials for the Boeing 777X carbon composite wing spar. On-the-fly inspection is expected to help production processes keep up with today's AFP/ATL systems.

Source | Electroimpact

» It's no secret to anyone involved in aerospace composites that production rates in commercial aircraft assembly lines anchored by advanced layup processes — automated fiber placement (AFP) and automated tape laying (ATL) — have been constrained by the necessity of careful visual inspection and verification after each ply placement. Often, rework also must be done, by trained specialists, to meet quality assurance requirements. For a fuselage barrel or other large composite part that requires hundreds of plies, the impact of inspection and rework is significant.

In a paper presented several years ago by Robert Harper of Fives Cincinnati (Hebron, KY, US) and Allen Halbritter of The Boeing Co. (Chicago, IL, US), based on data from a generic fuselage barrel laid up using an optimized AFP process, inspection and rework accounted for more than *60%* of the total part production time. More recently, Todd Rudberg, senior engineer at Electroimpact Inc. (Mukilteo, WA, US), says manual inspection/repair activities typically constitute more than 30% of the time distribution for a part build.

Over the past several years, much research and development has been devoted to finding a path to *automated* inspection using digital methods, to permit the overall aircraft production process to keep pace with the efficiency of today's AFP and ATL processes. Toward that end, aerospace composite parts are now being made by ATL and AFP machines equipped with onboard, automated inspection systems. ATL/AFP machine suppliers have developed, and continue to refine, systems capable of

Automated, in-process inspection

A preproduction trial of a 777-X wingskin segment is shown at ElectroImpact's facility. Note the second gantry above the part (top, center), on which three Aligned Vision LASERVISION projectors are mounted, for automated in-process inspection of the wingskin layup. Source | Electroimpact

inspecting layups and alerting technical staff to anomalies *on the fly*. In the first of a series of articles on this topic, *CW* takes a look at automated, in-situ inspection equipment developed for Electroimpact's AFP machines.

Eliminating manual inspection

Electroimpact got its start in 1986, when founder Peter Zieve commercialized his first low-voltage electromagnetic riveting machines for aluminum aircraft assembly, which offered safer, less expensive and less noisy technology than existing riveting machines used by aerospace OEMs. Since then, the company has thrived by expanding its focus to provide a range of automated production solutions for metals and composites. Customers include not only Boeing but other aerospace OEMs, including Airbus (Toulouse, France), Bombardier (Montreal, QC, Canada), Spirit AeroSystems (Wichita, KS, US) and many more.

"We've been developing automated, in-process inspection over the past three years. Ours is currently the only automated inspection system that is fully certified by an OEM for composite part production," says Rudberg, who was on the team that developed Electroimpact's first AFP machine and its control software. Indeed, the company's AFP machines are producing the first-article wing panels and wing spars for Boeing's first 777X test aircraft, and automated inspection has been implemented for the wing panel parts. These are fabricated in two Electroimpact-designed, automated workcells at Boeing's new Composite Wing Center (CWC) in Everett, WA, US, built specifically to handle fabrication and production of the 777X's composite wings, the world's largest. Notably, the aircraft's massive 72m wingspan will be reduced, on the ground, via folding wingtips, each 3.5m long, to enable the plane's crew to access the same airport gates as today's 777. The 777X wingtips and folding hardware will be made at Boeing's facility in St. Louis, MO, US. Two more Electroimpact workcells have been installed at the CWC to produce the one-piece, composite wing spars (more on those below).

The wing panels are made in two halves (upper and lower) via AFP in low-curvature, male molds positioned inside each workcell's gantry work envelope, explains Josh Cemenska, controls engineer at Electroimpact. The main gantry, on which an Electroimpact AFP head is mounted, travels along the length of the 30m wing panel tool, and a bit beyond, while the head itself can move 7.5m across the gantry, to access the entire 9m width of the tool at its widest point; the head's z-direction travel is about 2m. The material is 34-mm/1.5-inch wide carbon/epoxy prepreg tape, supplied by Toray Composite Materials America (Tacoma, WA, US).

"For the 777X panels, automated inspection was a necessity," asserts Rudberg. "The parts are so large, you really can't do manual inspection. Our automated inspection system was really an enabling technology for this next-generation wing." Cemenska explains that in a manual process, inspectors verify tow end accuracy by visually comparing the layup to a laser outline projected onto the tool surface, then painstakingly scan the surface for other flaws such as gaps, overlaps or missing tows, using hand-held magnifiers.

Replacing this, the Electroimpact wing panel cells integrate three 20.5-kg LASERVISION projector box units, each equipped »

Boeing 777X: Technology advance beneficiary

The 777X aircraft from Boeing has an all-composite wing with a 71.75m wingspan. Electroimpact machines with automated inspection capability will be used to make the wingskins and internal spars. Source | Boeing with a high-resolution camera in addition to a laser projector. Supplied by Aligned Vision (Chelmsford, MA, US), the units each work together with a laser profilometer — essentially a small laser that projects a line onto the work surface — which is mounted on the head. All three elements (laser, camera, profilometer) feed data to a user interface supported by computer software algorithms.

The Aligned Vision projector box units are mounted in a row on a second gantry beam that operates independently of the head gantry, but typically follows behind it. Rudberg says the configuration minimizes the distance between the lasers and the part, and reduces the angle of incidence. Explains Aligned Vision's COO Matt Zmijewski, "The 777X wing panels and spars are the launch applications for LASERVISION, which delivers two key functions. From one aperture, a laser is projected, positioned by a set of two steerable mirrors. From a second aperture, a high-resolution digital camera with a 300-mm lens is also steered by two mirrors to capture pictures of the in-process material deposition."

The high-definition images are precisely located in three dimensions, because the camera and the laser work within the same coordinate system, "transformed" or registered to the tool and head locations in space. The 3D location of each camera pixel is identified by the user interface. Image sets are conjoined to create a complete image of each ply over the entire part. Image resolution is high enough that ply boundary locations can be measured automatically from that image. Electroimpact says that camera images of ply boundaries have been qualified to be within ±0.060 inch/±1.5 mm of the true position in a mobile (i.e., gantry-mounted) setup.

+ *LEARN MORE*

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

This short Boeing video, taken at the CWC, shows pre-production versions of the 777X composite spar and wingskins | short.compositesworld.com/777XYTvid

Read more about a "Real-time automated ply inspection (RTAPI) system: *CW's* series on automated inspection methods" | short.compositesworld.com/MaassBlog

This Electroimpact video shows the layup of a prototype wing spar shape | short.compositesworld.com/EI-WSvid

Leveraging big data

Meanwhile, the laser profilometer projects a line onto the part surface during material laydown, and its built-in detector array measures the height of more than 1,000 discrete positions along that laser line, says Cemenska. Thus, it detects a 2D profile of the surface. As the profilometer rides along with the head during material deposition, it creates, in effect, a 3D surface profile.

As explained in two recent white papers authored by Cemenska, Rudberg and colleagues Michael Henscheid, Andrew Lauletta and Bradley Davis, the profilometer's laser line spans the seams between tows, measuring the width of any overlaps and gaps as layup proceeds. These profilometer data are integrated with the data from the camera and the part programs, as well as operator input, within the inspection user interface; the interface builds a ply-by-ply 3D model of the part as production progresses.

Recognition software measures the locations of features from the vast amount of camera image data, as well as the raw data array generated by the profilometer, to see tow ends (or ply boundaries), tow overlaps and gaps and identify defects such as puckering and bridging. It then displays these on the 3D model. The user interface and algorithms required to crunch the collected data were developed in-house by Electroimpact software engineers, says Rudberg. (A foreign object detection system not developed by Electroimpact is coming, according to Boeing.)

The Electroimpact automated ply boundary inspection system can correctly identify and measure 92% of tow ends on a standard ply, with a mean error smaller than ±0.005 inch and a standard deviation of ±0.020 inch. Rudberg says that overlap/gap measurements made with the profilometer, which happen in parallel with material laydown, can be accomplished significantly faster than manual inspection. In case a question about a tow end or a gap/overlap arises, select images are forwarded to an inspector for assessment on a computer screen in the workcell. Says Cemenska, "We've *almost* eliminated any manual inspection. If we find that rare case of an error, like a dropped tow, that area is displayed by the LASERVISION's laser lines, and the bad tows are pulled off, if necessary. The machine head is then reprogrammed to conduct the repair." Cemenska adds that in the case of the wing panel parts, many tow ends can be eliminated from inspection, because part edges are subsequently trimmed, which saves additional time.

Inspection speed depends on ply complexity, and it decreases as the number of tow ends increases, which is why the inspection system for the wing panels was a higher priority than for the spars, says Rudberg: "Because of the part size and flat shape, and because Boeing didn't want inspectors walking on the layups, it was a priority to get the automated inspection system on the panel part up and running, so we focused our efforts there. With regard to the wing spars, the layup and lamination were the major hurdles, so we worked on that aspect first."

Cemenska reports that the inspection system can measure 15 tow ends per second; on the wing panel part with up to 2,000 inspected tow ends, it takes a few minutes for the following cameras to take the photos and the software to assemble the ply image. Overall, says Rudberg, complex plies take from 3-5 minutes to image and process: "At this time, we're aiming for 100% inspection, so the 8% of tow ends we don't identify are currently being located 'semi-automatically,' with human eyes, so that adds about 10 minutes." He adds that this semi-automatic step can be accelerated by making the software system faster. Eventually, the need to find that 8% could be eliminated altogether if statistics show that the 92% of identified tow ends accurately represent the *entire* part. "These are early days, and there is still room for improvement — as confidence in the system grows, the human double-check can be reduced to nearly zero, going forward."

The system was validated by Electroimpact in partnership with Boeing by performing a series of rigorous pre-acceptance tests: "Test panels were laid up with a range of intentional mistakes, and we ran the automatic inspection system during all the layups. Then, those panels were inspected manually, and the manual results were compared to the automated system results," say Rudberg and Cemenska. Those results convinced Boeing of the system's reliability, resulting in its adoption for the 777X parts. In-process inspection of the one-piece spars — the largest ever produced, says Boeing (see Learn More) — was scheduled for implementation early this year.

Concludes Rudberg, "This is a smart use of big data. We're measuring every tow relative to the ply boundaries and creating a digital record of the results. These data improve part quality, and allow the client to make more informed decisions. Because we can prove part quality digitally, it ultimately will allow use of less restrictive design allowables."

The time has certainly come for a sorely needed technology that allows automated composites fabricating machines to operate at the speeds for which they were designed. No doubt, it will be applied to additional parts. *CW* will continue to follow developments — stay tuned. CW

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I want to say two words to you: "Thermoplastic tapes"

Thermoplastic tapes are not new to composites, but they soon will join the primary aerostructures material palette and could be their future.

By **Jeff Sloan** / Editor-in-Chief

"I want to say one word to you. Just one word . . . *plastics*."

In the 1967 movie, *The Graduate,* college graduate Benjamin (Dustin Hoffman) is offered by his father's friend Mr. McGuire this advice in what is now one of the most famous lines in cinematic history.

By plastics, of course, he meant unreinforced thermoplastics, and in 1967, they were being injection molded, extruded and blowmolded. And he was right. That year, this segment of the plastics manufacturing industry was on the verge of a decades-long expansion that continues to this day.

What Mr. McGuire did *not* reference in that oft-quoted line was thermoplastic *composites*, and he definitely did not envision unidirectional (UD) thermoplastic tapes. *But he could have.* In the late 1960s and through the 1970s and 1980s, thermoplastic tapes were being used to manufacture a variety of composite parts and structures, particularly in military and defense applications.

Thermoplastic tape: The once and future aeromaterial?

Thermoplastic tape, here, shown as it is wound onto a spool following prepregging, enjoyed use in composites manufacturing, notably in military aircraft applications, back in the 1970s and 1980s. But a subsequent lull in their application delayed material development, putting them behind thermoset tapes. However, the appeal of thermoplastics, particularly for potential out-of-autoclave aerospace applications, has re-ignited interest and product development. Source | Barrday Composite Solutions

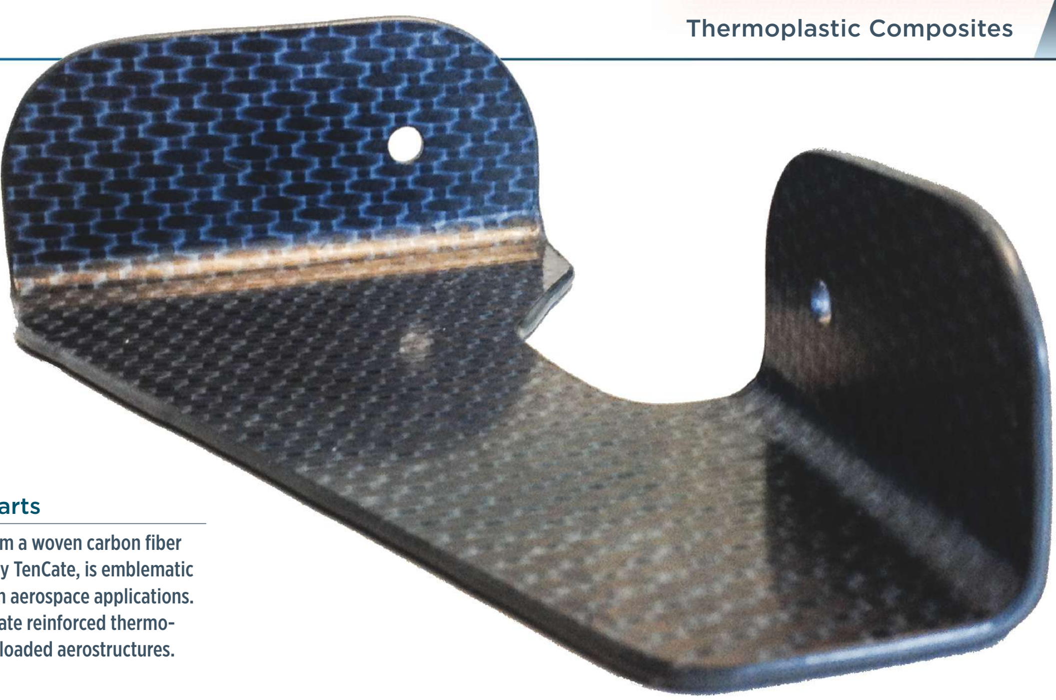


FIG. 1 CFRTP: From brackets to big parts

This clip, compression molded from a woven carbon fiber thermoplastic material supplied by TenCate, is emblematic of the potential the material has in aerospace applications. Efforts are underway now to migrate reinforced thermoplastics into use on large, heavily loaded aerostructures.

Source | TenCate Advanced Composites

The appeal of thermoplastic tapes was not hard to see. Being UD, they could be applied to meet almost any mechanical force. They were melt-processible and could be consolidated easily and quickly via stampforming (that is, out of the autoclave) or compression molding (Fig. 1, above and Fig. 2, p. 44). They offered toughness properties that could not be matched by thermosets, and, unlike thermoset prepregs, they could be stored indefinitely at room temperature.

However, as defense spending waned in the 1990s, particularly in the United States, so did interest in and application of thermoplastic tapes. Suppliers such as DuPont, Phillips Petroleum, Exxon, BASF and Imperial Chemical Industries (ICI), which had invested heavily in thermoplastics tape development, got out of the business. This is not to say that thermoplastics tape development ceased, but it slowed significantly in a time when development of thermoset composites, in general, including thermoset tapes, was accelerating. This led eventually to the application of the latter in large aerospace structures in the Boeing 787, Airbus A350 XWB and other commercial aircraft.

> Thermoplastic tapes offer cycle time and many other advantages that cannot be matched by thermosets.

Fast forward to 2018. The commercial aerospace world is looking to the future, and the next major aircraft program expected to consume large quantities of composite materials, in all likelihood, will be Boeing's new Middle of the Market (MOM) aircraft, designed to replace its 757. Also on the horizon are redesigns of the Boeing 737 and Airbus A320, the narrowbody workhorses that are the backbone of the global commercial aerospace industry.

The material and process economics that justified use of composites on the 787 and the A350 XWB are not the same as those for the MOM, 737 and A320. The biggest difference is rate. The 737 and the A320, in particular, are as close as the commercial aerospace sector gets right now to a commodity, which means the faster they can be made, the more profitable they are for OEMs. And with a targeted rate of 60 per month or more for the 737 and A320 (and whatever replaces them), that's two planes a day, every day. Thermoset composites, cured in an autoclave, are currently not a good fit for such a high-volume environment. And that's where thermoplastic tapes come back into the picture; they offer cycle time, materials storage, toughness, and recyclability advantages that cannot be matched by thermosets.

They already are used today to make smaller parts and substructures, including clips and brackets to connect fuselage skins to stringers and frames (see Learn More, p. 48). And they are employed on a number of structures for smaller aircraft, including tail planes, wings and other parts for business jets (also see Learn More). Further, the oil and gas industry has embraced thermoplastics because of their toughness and corrosion resistance, and the automotive industry is drawn to their adaptability to high-volume manufacturing and recyclability. The biggest question facing those who would use thermoplastics in commercial airframes is, *Are they viable in highly loaded aircraft structures?*

Scott Unger, chief technology officer at thermoplastics specialist TenCate Advanced Composites USA Inc. (Morgan Hill, CA, US), who has worked with thermoplastics for more than 30 years, says, "The growth of thermoplastics is at an inflexion point. The ability to get out of the autoclave, reduce costs and ease parts assembly are big drivers."

The current state of the material and process art

Thermoplastic tapes, for the purposes of this article, consist of unidirectionally aligned carbon fiber tows in widths of up to 12 inches/305 mm, prepregged with a thermoplastic resin (see opening photo, p. 42). The resins most commonly used in aerospace and other high-performance applications are the following »

FIG. 2 Viable processes: Stampforming/compression molding

Most parts made with thermoplastic tapes are manufactured using stampforming or compression molding, which offers relatively quick cycle times. Further, thermoplastics can be welded, which eases and speeds assembly. The most commonly used thermoplastics for aerospace applications are PEEK and PEKK.

Source | Tri-Mack Plastics

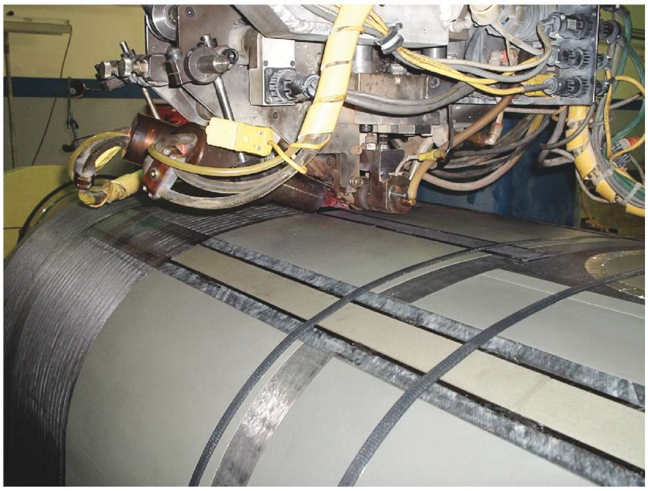


FIG. 3 Viable processes: In-situ consolidation

One promising process for the use of thermoplastic tapes is in-situ consolidation via automated tape laying (ATL) or automated fiber placement (AFP). In this process, prepregged thermoplastic tapes or tows are heated at the tape head to their melting point (>300°C), placed on the tool, and then immediately consolidated by the end-effector. Although an additional high-pressure consolidation step is required at this time to achieve porosity targets, ultimately, this process is expected to provide 100% consolidation in a single step. Source | Automated Dynamics

high-performance thermoplastics: polyetheretherketone (PEEK), polyetherketoneketone (PEKK), polyaryletherketone (PAEK), polyetherimide (PEI) and polyphenylene sulfide (PPS). Some manufacturers offer tapes prepregged with commodity thermoplastic resins, such as polyamide (PA), polypropylene (PP) and others, but these are generally considered unsuitable for large aerostructures.

For the aerospace industry, the materials that hold the most promise are PEEK and PEKK. "In general, both polymers provide excellent high-temperature performance, good toughness and chemical solvent resistance, along with low moisture absorption," says Mike Buck, product manager, thermoplastics, at prepreg supplier Barrday Corp. (Millbury, MA, US). "PEKK also offers a higher T_g for improved temperature resistance and a lower melt temperature for processing."

Arnt Offringa, director, R&D, at aerospace manufacturer GKN Aerospace Fokker (Hoogeveen, The Netherlands), says PEKK's ability to deliver performance on a par with PEEK, but process at a lower melt temperature, makes it the prime candidate for future growth in commercial airframe applications.

Thermoplastic resins typically are applied to the fiber via solvent-based or water-based powder application. The prepreg method used affects the interface properties with the fiber, and the water-based process creates a smoother surface than the solvent-based process. The fiber volume fraction of most thermoplastic tapes ranges from 40-60%, with aerospace-grade materials in the 50-60% range.

"Sixty percent fiber volume is important if mechanical properties are the primary focus and you have a production process with a longer cycle time and plenty of flexibility for pressure and temperature," says Buck. "Higher speed or lower pressure processes, such as AFP/ATL, out-of-autoclave/oven processing, etc., would benefit from higher resin contents."

Tapes can be slit to create narrower tapes, or tows. Tapes also can be cut, like thermoset prepregs, to prescribed shapes to create blanks. Thermoplastics tapes do not have backing paper like thermoset tapes do.

The use of thermoplastics changes considerably the manufacturing steps to make finished parts. The most important difference is that a thermoplastic, by nature, is solid at room temperature and must be heated to melt temperature for forming. As noted, PEKK has a higher T_g than PEEK (160°C vs. 140°C); PEEK has a higher melt temperature than PEKK (390°C vs. 340°C).

Jim Pratte, technical fellow, composite materials research and innovation group at Solvay Composite Materials (Alpharetta, GA, US), says material use depends on the application, noting that PEKK is a co-polymer that can be tailored for different temperatures and crystallinity rates, while PEEK has an extensive database and crystallizes faster.

Such temperature requirements immediately vault these materials beyond the temperatures required to cure epoxy or any other thermoset material. The most commonly used process to manufacture parts from thermoplastic tapes today is stampforming, where tapes, cut to a prescribed shape and then stacked, are inserted into a preheating oven to be softened and preconsolidated. This stackup is then transferred to a forming press, which usually consists of a matched metal tool that fully consolidates and cools the tapes under high pressure (250-500 psi).

"Generally, I have found that processing of thermoplastics often requires a 'backwards' type of thought process vs. processing thermosets," says Buck. "For example, with thermoplastics, you typically don't want to consolidate the part in the mold, but instead form a pre-heated, pre-consolidated laminate, and then use the tool to cool the pre-heated part."

Less common, and still under development, is *in-situ* consolidation (Fig. 3, p. 44), where slit tapes (tows) are placed on a tool via automated fiber placement (AFP) or automated tape laying (ATL). In this system, a high-intensity laser, hot gas or flame at the tape head heats the resin to melt temperature to soften it, while the end-effector applies pressure to consolidate the plies. Ultimately, such a system would perform full consolidation in-situ, but is still being developed for demonstration. For now, further consolidation (autoclave or similar) is required to achieve porosity targets.

Pierre-Yves Quéfélec, global and defense business unit head at Porcher Industries (Eclose-Badinières, France), which specializes in AFP of thermoplastic tapes, says the company works with machinery manufacturer Coriolis Composites (Queven, France) and is targeting <0.5% porosity. "An autoclave is still needed for this," he says, "but we are starting to reach this level with oven cure, depending on the quality of the AFP. The high viscosity of thermoplastics is a challenge, as is the homogeneity and consistency of the impregnation."

Although it is not widely used today, the most promising process in work toward the <0.5% porosity target is possibly *continuous compression molding* (CCM, see Fig. 4, p. 46 and see Learn More). Here, continuous tapes are passed through forming tools that heat and shape the material and create, effectively, a range of shapes, including T, C, H, hat and Omega profiles and others. This process has particular promise for the manufacture of stringers and frames for commercial aircraft.

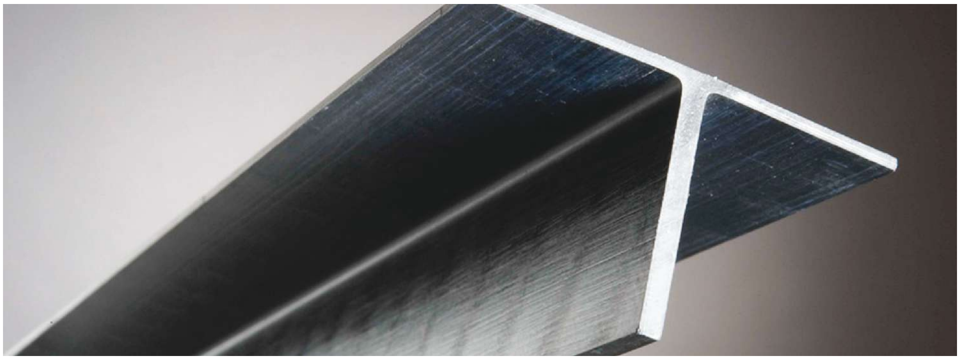
As noted, autoclave cure is an option, and for some, a necessity, to ensure minimal porosity. Offringa notes that Fokker prefers the autoclave because it facilitates resin flow through the fiber and helps maintain process control and consistent part quality. The time required to consolidate a thermoplastic component in an autoclave is usually 3-4 hours — significantly less time than required to cure and consolidate thermoset materials.

Solvay's Pratte says achieving porosity targets is not difficult with most of the thermoplastics processes used today. "Time and temperature takes most of the voids out," he says. The only process that struggles, he says, is in-situ ATL/AFP, because the timescale — the amount of time spent applying pressure at temperature and consolidating the tape — is limited. "The key point here is not so much porosity as wetout of the filaments with polymer in the tape. You might have some porosity in the tape, but you cannot have dry fibers as the in-situ process timescale and conditions will not compensate for that."

Advantages

Thermoplastics in general, and PEEK and PEKK in particular, are difficult to dislike. As already noted, they offer mechanical »

FIG. 4 Viable processes: Continuous compression molding



Not widely used, but considered a highly viable process for aerostructures manufacture, is continuous compression molding (CCM), in which thermoplastic tapes are passed continuously through a series of forming tools to create composite profiles, like this one. CCM is viewed as a good candidate for the manufacture of stringers and frames for an aircraft fuselage. Source | xperion

performance characteristics similar to epoxy, but they are generally tougher than epoxy. Further, they also do not exotherm, and they resist corrosion, wear and fire very well.

Thermoplastics also avoid the storage and out-time limits of thermoset prepreg — not a trivial matter considering the expense of investment in freezers, and the task of managing prepreg expiration dates to determine which rolls of prepreg to use when. Indeed, the cost of disposing of/recycling expired material can add considerably to the cost of manufacturing parts with thermoset prepreg.

Further, because they do not cure and crosslink, "Thermoplastic composites can be remelted/reprocessed," notes Buck. That makes them relatively easy to recycle. "Recycling is a big driver in automotive because volumes are so much larger and the economics are so much more challenging," notes Solvay's Pratte. "If you can't recycle materials, it's going to be that much more of a barrier to adoption." Although it's particularly important to automakers, recycling is becoming an increasingly vital consideration in aerocomposites manufacturing as well, as aircraft OEMs, too, contemplate lifecycle management (LCM) and product end-of-life issues.

> Thermoplastics' remeltability and reprocessability makes them much easier to recycle than thermosets.

Thermoplastics also enable part bonding in a way that is not possible with thermosets. They offer the potential for welding/fusing parts together, which could negate the need for adhesives in some applications."

GKN Aerospace Fokker is famous for its use of thermoplastics welding, and Offringa says there is a need to develop a variety of welding techniques, including resistance welding, induction welding and conduction welding (see Learn More). Porcher's Quéfélec points out that AFP/ATL is a form of continuous welding and reports that many of his customers are looking to use welding to join smaller thermoplastic parts into larger structures.

As composites use increases in aerospace and automotive, the demand for automation will increase. This represents a real opportunity for thermoplastic tapes. "In my opinion, this is an area where thermoplastics will shine," says Buck.

Disadvantages (aka, opportunities)

For all their advantages, thermoplastic tapes lack the maturity of thermoset tapes and, therefore, present some challenges. Web Industries (Marlborough, MA, US), which slits and formats thermoset and thermoplastic tapes, sees these challenges. Grand Hou, director of research and technology at Web, says a thermoplastic resin, because of its toughness, is more difficult to slit and meet tolerance requirements. The material, he says, is also springy, so it requires a different winding pattern with different winding control than those used with thermosets.

Jim Powers, business development manager at Web, notes that thermoset tapes are available in widths of up to 60 inches/1,524 mm and can go thousands of feet without a defect, while thermoplastic tapes typically top out at 12 inches and show as many as 30 defects in just 700 ft. "Thermosets went through the same development curve," says Hou. "We are probably closer than we realize [to major quality improvement]. And as soon as there is a large program using thermoplastic composites, then you will see tremendous improvement in quality."

The other challenge posed by the resin is its application. Thermoset tapes are typically prepregged using resin in film form, which allows prepreggers to apply resin precisely and uniformly, with minimal thickness variation. Thermoplastics, by contrast, rely on a powder-based application process that is more difficult to control and can create resin-rich and dry areas. Such non-uniformity can lead to problematic interply porosity.

Web's Powers says solvent-based resins tend to have a rougher surface and generate more gaps, while water-based systems tend to be flatter, with minimal gauge variation and a smoother surface. "Rougher solvent-based materials offer more surface area," he notes, "but from a spooling standpoint, water-based systems run quicker and provide better rolls."

Another variable is the fact that at room temperature, thermoplastic tapes are characterized by an unusual boardiness, which produces a stiff, occasionally uneven tape that is prone to producing gaps and splits. The boardiness also can cause material waviness, which may lead to some tape width inconsistency. This causes subsequent problems during tape slitting, which relies on consistent tape widths to stay within specifications.

Further, unlike a thermoset prepreg, which has tack at room temperature that facilitates ply-to-ply adhesion during layup, a thermoplastic is dry and tackless. Additional means are required

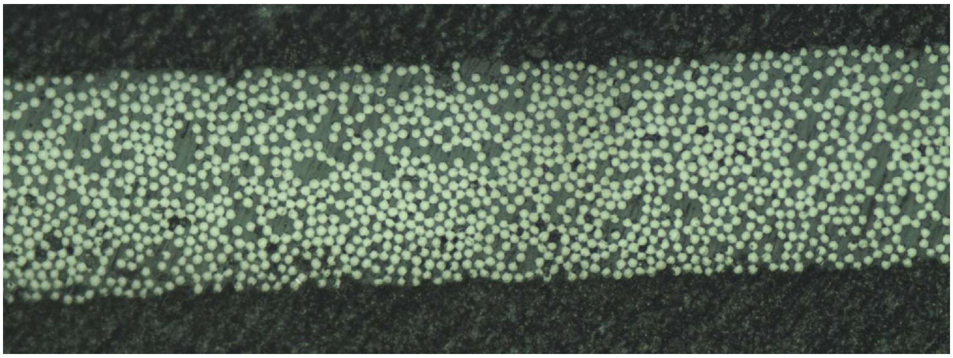


FIG. 5 Processing truism: Quality begets quality

This micrograph of a TenCate thermoplastic tape demonstrates the uniformity and homogeneity possible in tape products. The higher quality the tape, the easier it is for manufacturers to produce high-quality parts. Use of lower quality tape, however, depends on a more robust and possibly time-consuming process to achieve good consolidation.

Source | TenCate Advanced Composites

to eliminate ply-to-ply slippage, such as spot welding.

Automation may be one area where thermoplastic tapes' boardiness is not necessarily a problem, however. "People used to complain that it was stiff and boardy for hand layup," says Solvay's Pratte, "but in automated equipment, stiff and boardy is an asset."

David Leach, director of business development at aerospace thermoplastics composites fabricator ATC Manufacturing (Post Falls, ID, US), admits that thermoplastic tapes are "typically not as consistent as thermoset materials, and that is certainly an area where we would like to see improvement." Leach also notes that uneven resin application can produce regions of resin richness, which can be both helpful and detrimental. He also echoes Web's point that the lengths between defects in thermoplastic tapes is relatively short and that slit tape width is less consistent. That consistency, says Leach, will be mandatory as automation increases.

TenCate's Unger says high tape integrity is paramount to facilitate increased thermoplastics use and to make up for limitations in manufacturing processes. In particular, Unger points to AFP/ATL, which, because of its layer-by-layer processing, introduces potential for interply porosity. As proof of tape integrity, Unger references a micrograph of TenCate thermoplastic tape (Fig. 5, above), which shows uniform ply thickness and resin homogeneity. He says the key point is that high-quality tapes, with low void content, are an enabler of fast, automated processing of high-quality composites. Tapes with high levels of voids will require longer consolidation cycles to produce high-quality parts. »

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Read this article online | short.gardnerweb.com/Tape2Words

Read more about thermoplastic aero clips and brackets in "Inside a thermoplastic composites hotbed" | short.compositesworld.com/CWHotbed

Read more about thermoplastic welding in *CW*'s Plant Tour, titled, "Fokker Aerostructures: Hoogeveen, The Netherlands" | short.compositesworld.com/FokkerTour

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Read more online about "Aerospace-grade compression molding" | short.compositesworld.com/AeroCM

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Get another perspective on this subject in "Thermoplastic composites technology: A view from Europe" | short.compositesworld.com/EuroTPC

Finally, there is the question of cost. PEEK and PEKK currently are more expensive than the epoxies with which they compete, but that is expected to change. "Cost is predicted to go down as volume increases," says Offringa, "if it grows strongly, as expected, with the increased application in highly loaded primary structures." (See Learn More.) ATC's Leach agrees, noting that, although thermoplastic tapes have enjoyed decades of use, volume remained small. "OEMs have a lot of experience with composites and tend to favor tapes," he says. "The big driver for conversion from thermoset to thermoplastic is cost. How can we make thermoplastic parts affordable?"

Porcher's Quéfélec agrees. "The whole value chain … has to re-challenge the business case. High cost hurts competitiveness, compared to thermosets. TRL [technological readiness level] lags, but it is catching up."

Barrday's Buck puts it simply: "The thermoplastics industry could use a polymer with PEKK/PEEK capabilities, but at the price of PPS."

Going forward

These real and potential flaws — lack of tack, gaps, waviness, non-uniformity — engender downstream challenges that, although manageable, make thermoplastic tapes more difficult to process than competitive alternatives. This, in turn, has slowed their adoption in high-performance applications. The advantages they offer, however, are real, and that has spurred much investment in research and development of technologies and processes to help push this material into larger structural parts. "The basic innovations have been done over the last two decades," says TenCate's Unger. "The major innovation going forward will be process and automation maturity and the expansion of part fabrication infrastructure."

On the manufacturing side, the Thermoplastic Affordable Primary Aircraft Structure (TAPAS) consortium, led by GKN Aerospace Fokker, is developing for Airbus a thermoplastic aircraft fuselage structure and a thermoplastic torsion box (for tail and wing structures). Under assessment is a TenCate UD tape comprising Hexcel (Stamford, CT, US) AS4 carbon fiber and a PEKK matrix from Arkema (Colombes, France). TAPAS work was divided into two programs, TAPAS I and TAPAS II, with the latter nearing conclusion (see Learn More). Offringa says the TAPAS work has proven the potential of thermoplastic tapes, particularly in fuselage skins, engine pylons, small wings (see Learn More) and tail structures. "Materials are being qualified, processes are being qualified. These are not huge parts *per se*, but parts that increase the size and volume," he says. Looking further ahead, he says, "A breakthrough is possible at one of the OEMs to decide to really move into a significantly larger thermoplastic part."

Solvay's Pratte agrees: "Small parts have taken off and built the confidence and maturity. Customers are starting to look at it for larger parts." To help drive that effort, Solvay and GKN Aerospace Fokker announced in early 2017 that they will cooperate on thermoplastic composites development, and Solvay will become a preferred supplier to the aerospace fabricator.

The Fundacion para la Investigacion, Desarrollo y Aplicaciones de Materiales Compuestos (FIDAMC, Madrid, Spain), also is assessing application of thermoplastic tapes via out-of-autoclave in-situ fiber placement to manufacture wing and fuselage structures (see Learn More). Fernando Rodríguez Lence, FIDAMC's senior composites expert, says tape quality is a major limitation, forcing slower laydown rates to compensate for tape flaws and achieve consolidation targets: "I trust that our material suppliers are going to improve tape quality, boosting properties to be similar to autoclaved parts, and solving the need for post-processing."

If, as is widely assumed, either Boeing or Airbus makes the decision to fabricate primary structures using thermoplastic tapes, it is likely that resources will quickly be deployed to iron out tape quality issues. Indeed, much of the tape development done during the past 10-15 years has been initiated and funded by material suppliers and fabricators. Such work has been promising, but limited. The effort and money that comes with an OEM commitment would change the thermoplastic tapes landscape considerably.

So, for that 2018 college graduate contemplating his or her future, there is new advice: "I want to say two words to you. Just two words ... *thermoplastic tapes*." CW

ABOUT THE AUTHOR

Jeff Sloan is editor-in-chief of *CompositesWorld*, and has been engaged in plastics- and composites-industry journalism for 23 years.
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Composites Events

Feb. 1-2, 2018 — Melbourne, VIC, Australia
20th Int'l Conference on Advanced Composites and Materials Engineering
waset.org/conference/2018/02/melbourne/ICACME

Feb. 14-15, 2018 — Dubai, UAE
CompIC Middle East 2018 Conference
mecompositesin.construction

Feb. 20-21, 2018 — Indianapolis, IN, US
SPE 2018 Thermoset Topical Conference – TOPCON
4spe.org/Events/event.aspx?EventID=82791

Feb. 21-22, 2018 — Detroit, MI, US
5th Lightweight Vehicle Manufacturing Summit
global-lightweight-vehicle-manufacturing.com

March 1-2, 2018 — Vienna, Austria
14th World Pultrusion Conference
pultruders.org/pdf_news/1_WPC_Save%20the%20date.pdf

March 6-8, 2018 — Paris-Nord Villepinte, France
JEC World 2018
jeccomposites.com

March 6-8, 2018 — Osaka, Japan
4th Annual World Congress of Smart Materials
bitcongress.com

March 15-16, 2018 — Rome, Italy
11th European Thermoforming Conference
www.e-t-d.org

March 26-29, 2018 — Long Beach, CA, US
AeroDef 2018
aerodefevent.com

April 10-12, 2018 — Detroit, MI, US
SAE 2018 World Congress Experience
wcx18.org

April 10-12, 2018 — Knoxville, TN, US
Composites Recycling Conference
s1.goeshow.com/acma/RecyclingConf/ereg346937.cfm?clear

April 30-May 3, 2018 — Denver, CO, US
AUVSI XPonential 2018
xponential.org/xponential2018/public/enter.aspx

May 7-10, 2018 — Chicago, IL, US
WINDPOWER 2018 Conference and Exhibition
windpowerexpo.org

May 14-17, 2018 — Stockholm, Sweden
Int'l Conference on Epoxy and Resins Technology (ICERT 2018)
vbripress.com/bcs18s/pages/epoxy-and-resins-conference

May 16-18, 2018 — Shanghai, China
SAMPE China 2018
sampechina.org

May 21-24, 2018 — Long Beach, CA, US
SAMPE 2018 Long Beach
nasampe.org/events/EventDetails.aspx?id=699309&group=

June 13-14, 2018 — Novi, MI, US
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amerimoldexpo.com

June 13-14, 2018 — Novi, MI, US
Composites Overmolding
compositesovermolding.com

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

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

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

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

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

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

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

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

Sept. 18, 2018 — Augsburg, Germany
Experience Composites
experience-composites.com

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

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

Oct. 30-31, 2018 — Bremen, Germany
ITHEC 2018 – 4th Int'l Conference and Exhibition on Thermoplastic Composites
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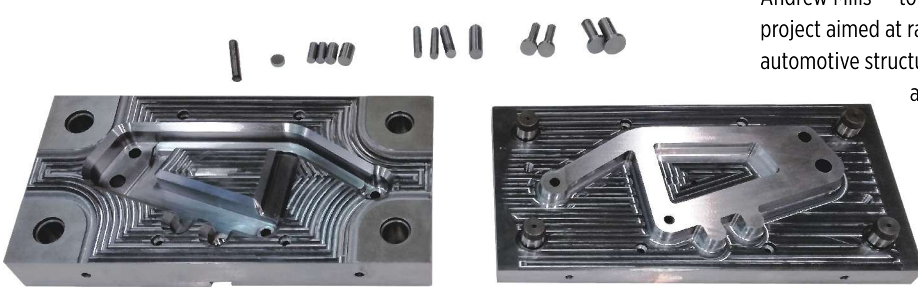
Motorcycle part demonstrates hybrid molding process

Strategy forms FRP parts once too complex for cost-effective, high-rate production.

Since 1959, Métisse Motorcycles (Faringdon, Oxfordshire, UK) has built a loyal following among riders and racers around the world. The late Hollywood action-film star and top amateur racer Steve McQueen described his Métisse *Mk3* as the "best-handling bike I've ever owned." Despite their classic retro styling, Métisse bikes incorporate many modern mechanical technologies that reduce overall weight and increase performance. Among them are hand-laminated GRP parts for the five-piece bodywork moldings on the *Mk 5 Cafe Racer* bike.

For that reason, Métisse was invited in 2016 by two students at Cranfield University (Cranfield, Bedfordshire, UK) — Aurele Bras and Andrew Mills — to participate as a development partner in a UK-funded project aimed at rapid production of lightweight carbon fiber composite automotive structural parts. The project, dubbed MultiComp (Design and Processing of Multi-Layer Structures for Liquid Composite Moulding), was funded by the Centre for Innovative Manufacturing in Composites (CIMComp), as part of the UK's composites research and development strategy, itself funded by the UK government's Engineering and Physical Sciences Research Council (EPSRC).



Métisse Motorcycles (Faringdon, Oxfordshire, UK) participated in a Cranfield University development partnership in which the part highlighted in the close-up photo was designed and prototyped in compression-molded carbon fiber composite. Source | Métisse Motorcycles/Hexcel

The Cranfield students already had developed and optimized a new high-speed compression molding process that combines strategically placed uni prepregs with molding compounds, but needed a part for demonstration and validation. Métisse agreed to join the project, to test out a composite footrest bracket that would replace an aluminum version. Trademarked HexMC-i molding compound and HexPly unidirectional carbon/epoxy prepregs were supplied to the Cranfield team by **Hexcel** (Stamford, CT, US). Both materials were formulated with Hexcel's snap-cure HexPly M77 epoxy resin.

The students worked with Métisse engineers to optimize the composite part for production, with a detailed stress analysis, steel tool design and a fabrication plan. Key to the molding process was combining uni prepregs with the molding compound without compromising overall cure time, and using prepreg only where needed for the design. The students showed that the hybrid approach delivered a significant performance-for-weight improvement vs. a standard composite sheet molding compound (SMC), and the finished bracket weighed 50% less than the all-metal original. All mounting hardware was molded-in, resulting in a ready-to-use, cured part that required no secondary machining. Overall production time for the composite bracket was just under 3 minutes in a lab environment, but should translate to a complete cycle time of less than 2 minutes in an automated production cell.

Although Métisse Motorcycles expects to keep production *volumes* low, with its team of craftsmen that hand-built bikes to order, the Cranfield/Hexcel collaboration, say those involved, has validated the use of a HexMC-i and HexPly UD hybrid approach to replace complex cast, machined or forged metallic parts that could not previously be formed with composites in a high-rate, cost-effective process. Métisse's owner, Gerry Lisi, comments, "This new, cutting-edge Hexcel carbon fiber part is most definitely in the spirit of the Métisse brand." CW

New Products

» VACUUM-BAGGING MATERIALS & ACCESSORIES

Multi-ply, multi-function bagging materials

Airtech International Inc. (Huntington Beach, CA, US) has introduced Combo-Tech, an expanded product line that bonds various vacuum bagging materials together to form what is said to be a better overall product that reduces touch labor. Combo-Tech is available in two- and three-ply combinations up to 2.2m/7.2 ft wide for prepreg, infusion and bonding applications. **airtechonline.com**

» MOLDMAKING MATERIALS & EQUIPMENT

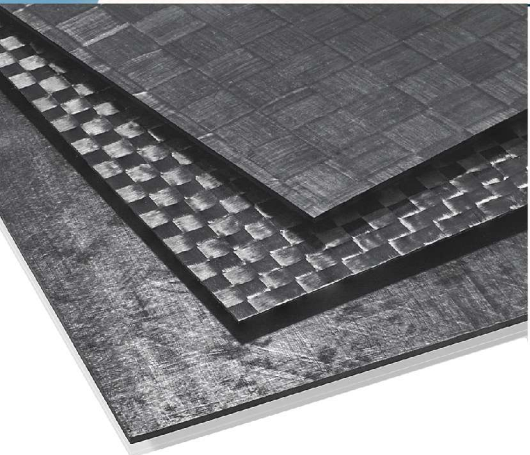
Composite tooling resin

Aliancys AG (Schaffhausen, Switzerland) has introduced its new Neomould 2017-S-1 resin for manufacturing composite tooling. Aliancys says the thixotropic nature of the resin enables application on vertical surfaces without sagging. Neomould 2017-S-1 also is said to offer near-zero shrinkage, which enables greater dimensional accuracy. The company also says that the combination of the resin's enhanced thixotropic profile and optimized curing characteristics make it suitable for producing thick parts — up to 12 layers of glass fiber reinforcements. **aliancys.com**

» COMPOSITE REPAIR EQUIPMENT & SUPPLIES

Hot bonder thermocouple expansion

HEATCON Composite Systems (Seattle, WA, US) has developed the HCS9300E Series thermocouple expansion unit, which expands thermocouple channels from the 20 built into the HCS9200B Hot Bonder to either 40 or 60 channels. HCS9320E offers 20 channels. HCS9340E offers 40. Potential applications include thermal survey, complex composite repair, single-zone repair, expanded control and monitoring of thermocouple channels and data logging. The units accept Type J or Type K thermocouples, with all data recorded/stored on the affiliated hot bonder. The hot bonder must be equipped with Rev. 18 (or later) software. **heatcon.com** »



» SEMI-FINISHED COMPOSITE SHEET MATERIALS

Thermoplastic organosheets launched

SGL Group (Wiesbaden, Germany) has developed a new range of thermoplastic organosheets, designed for flexibility in design and material processing. The sheets use SGL's 50K carbon fiber in a polyamide 6 (PA 6) matrix. Since that introduction, sheet stock with a PA 66 matrix has been made available, and those with a polypropylene matrix will be available in early 2018. Sheets can be customized by selecting unidirectional (UD) tapes, rovings, fabrics or nonwovens. Sheets can be cut, heated and then thermoformed to a variety of shapes, or inserted into a mold for injection overmolding. SGL also offers long carbon fiber-reinforced (LFT) thermoplastics, also based on PAs, for injection overmolding of organosheets. These are targeted toward volume autocomposites manufacturing. **www.sglgroup.com**

» PIPE REHABILITATION SYSTEMS

CIPP products expanded, reorganized

Technical fabrics specialist **Scott & Fyfe Ltd.** (Tayport, Scotland) has reorganized its line of Alphashield CIPP (cured-in-place products), expanding and refining it into four new product groups. Alphaduct is Scott & Fyfe's seamless glass textile liner designed and developed for the fast assistance of pipe rehabilitation systems. The 100% glass tubular knitted structure comes

with either a TPU or PVC outer foil. This material can perform diameter changes as well as lining through multiple 90° bends without folds or wrinkles. Alphaduct also has the ability to cure in both high and ambient temperatures. Alphaduct Retractable Liner has been designed, manufactured, tested and approved across a range of applications, including potable water, and heat-resistant installations. Alphamat is a glass spacer fabric with PVC coating. This product is flat as opposed to tubular, so it can be used in a wider range of applications. One example is wrapping pipe, as opposed to lining it. Another is using it to line diverse and peculiar shapes and sizes. Alphalink consists of Top Hats and T-Liners, a 100% glass main-to-lateral repair solution. Alpharesin encompasses the three main resin types the company will offer: epoxy, silica and UV-curable. **scott-fyfe.com**

» TESTING, MEASUREMENT & INSPECTION SYSTEMS

Benchtop vision measurement system

L.S. Starrett Co. (Athol, MA, US) has introduced the HVR100-FLIP, a new large field-of-vision (FOV) benchtop vision measurement system that is capable of being used in either a vertical or horizontal orientation. It features a high-resolution digital video camera and minimal optical distortion for accurate FOV measurements of up to 90 mm/3.65 inches. The FLIP horizontal or vertical orientation feature lends itself to an array of applications. The system can be easily changed over from vertical to horizontal and back within minutes, and can be placed on most sturdy workbenches. The HVR100-FLIP has a 24-inch LCD touch-screen monitor, a 348-by-165-mm (13.7-by-6.5-inch) stationary top plate and 165-mm/6.5-inches of optics travel with a motorized power drive for accommodating various part sizes and enhanced performance. An LED ring light provides surface illumination and LED backlight offers transmitted illumination. The main operator interface of the FLIP displays a live video image with software measurement tools and graphical digital reading of measurements. A part image can be resized using pan, zoom and measurements by simply tapping a feature on the monitor screen. A wireless keyboard and pointing device also are provided for entering file names and targeting key functions. MetLogix M3 software includes 2D geometric functions, such as points, lines, circles, arcs, rectangles, distances, slots, angles and skew, and use of the part design DXF/CAD file digital overlay is designed to help simplify part inspection. **starrett.com**

MANUFACTURING SUPPLIERS

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Hybrid composite struts reduce vehicle weight, improve handling

Pultruded carbon/glass fiber composite underbody stiffeners move into medium-volume Mercedes-AMG production vehicles.

By Peggy Malnati / Contributing Writer

» A joint development team from Daimler AG's (Stuttgart, Germany) R&D organization and the Mercedes-AMG performance car division began investigating ways to trim mass cost-efficiently from body-in-white (BIW) structural components. An early target (circa 2011) was pairs of all-steel strut bars on various performance-vehicle models — one pair on some vehicles; two pairs on others. Functionally, the struts increase vehicle rigidity and improve handling.

Strut bars — usually inexpensive compressed steel tubes — are well established on production vehicles. Already well optimized in terms of cost and weight, these benchmarks provide limited opportunities to improve either in the incumbent steel format. But composites — particularly in the form of carbon fiber-reinforced plastic (CFRP) — offered new opportunities to lightweight the struts, yet meet demanding mechanical and thermal performance, while also keeping the economics reasonable.

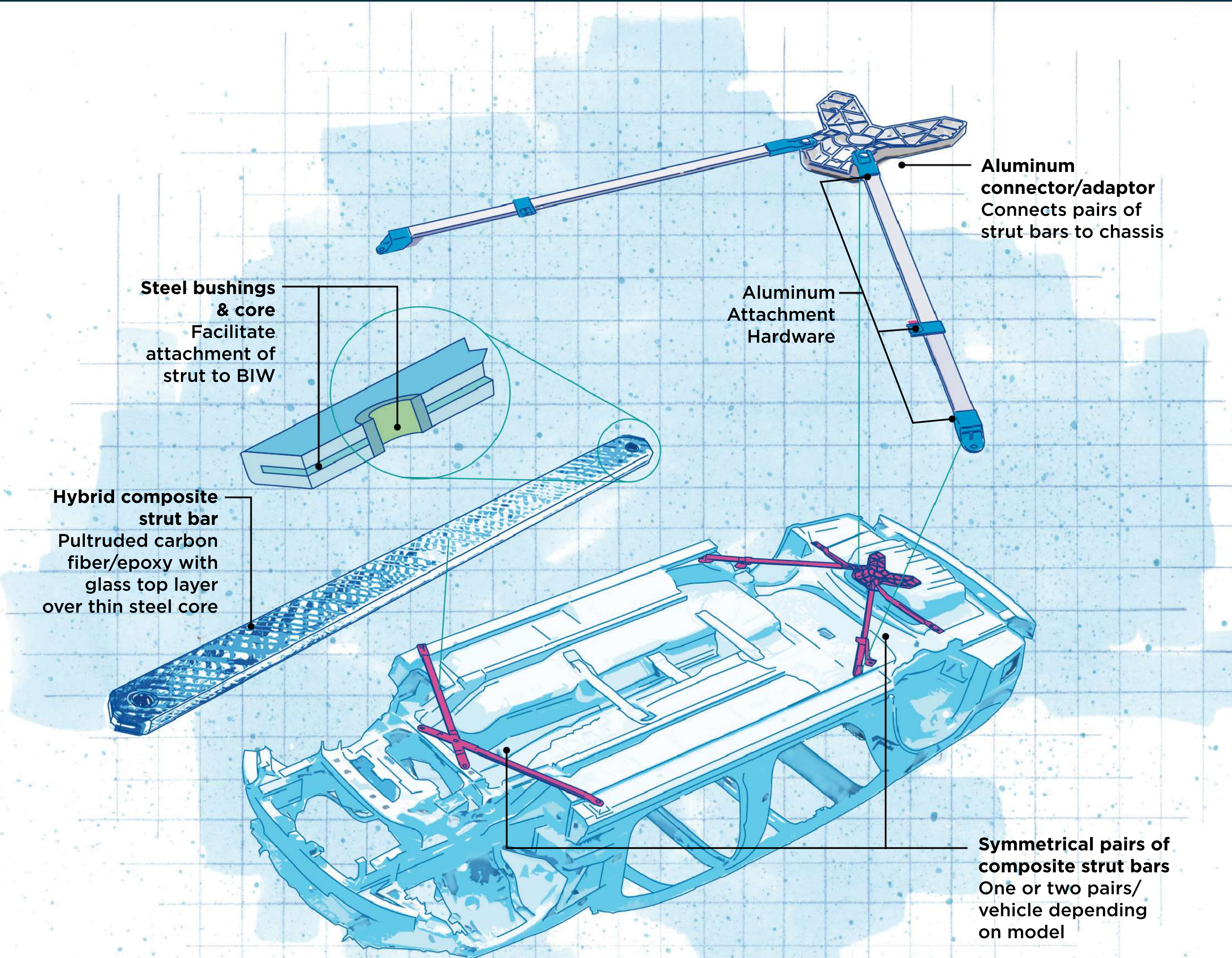
Issues with conventional strut bars

Chassis strut bars are structural components designed to resist compression and tension in the longitudinal direction by providing outward-facing support along each bar's longest axis, thereby holding two components apart and preventing them from flexing or collapsing. Correctly designed and installed, strut bars help stiffen substructures. The practical result is a reduction in chassis flex as vehicles cross uneven surfaces or take tight corners, experienced as improved vehicle "handling" for drivers.

■ Multi-material, multi-vehicle chassis struts

Engineers from Daimler AG's R&D organization and Mercedes-AMG's performance car division jointly developed hybrid composite strut bars that have replaced conventional steel underbody chassis struts, resulting in a number of benefits. The application was first used on the Mercedes-Benz SLS AMG *Coupé Black Series* vehicles (2013) and has since been expanded to four other platforms within the Mercedes-AMG product line. Source | Daimler AG

Although several higher performance metals (e.g., titanium) were considered to replace traditional steel struts, they were eliminated because they would add cost but could *not* meet all of the mechanical requirements for the desired lightweight design. The team then turned to CFRP. "Struts are used frequently in the substructure or front section of



DESIGN RESULTS Mercedes-AMG Hybrid Composite Strut for Chassis Stiffening

- Hybrid (steel-cored, carbon and glass fiber-reinforced epoxy) composite strut bars meet demanding mechanical and thermal requirements at lower weight and acceptable economics, which get better as production volumes climb.
- Pultrusion process was selected to produce strut body owing to low energy, low waste, low tooling costs and ability to scale to higher production volumes cost-effectively.
- Attachment hardware bonded to each end of strut bar to efficiently transfer forces between strut and body-in-white structure.

Illustration / **Karl Reque**

vehicles to rigidify the body shell and optimize the driving characteristics in terms of comfort and sporty handling," notes Jörg Miska, head of body development, Mercedes-AMG. "CFRP's direction-related elasticity and its anisotropic behavior precisely meets these requirements."

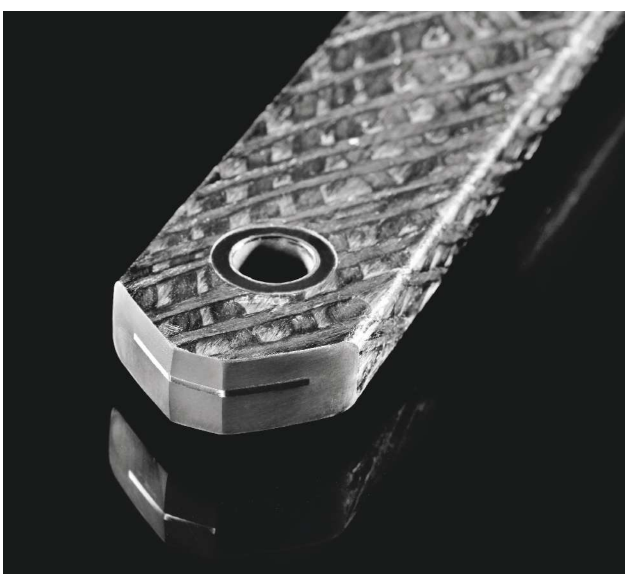
Design and production decisions

The first challenge the team faced was how best to produce the strut bars to help ensure a very stiff and strong part that also would be cost-effective. To meet mechanical requirements, a high fiber-volume fraction of aligned, continuous carbon fibers would be crucial. Given the temperature specs in this area of the undercarriage (near the exhaust system), a high-performance polymer with excellent ability to bond to carbon fiber was necessary. Epoxies were deemed the best choice for Daimler's material-release process as well as for meeting processing, temperature and cost targets.

Because there was a good chance that — assuming the technology was successful — it would be expanded to other Mercedes-AMG or Mercedes-Benz vehicles, the team needed a process with »

■ Struts stiffen the chassis, improve vehicle handling

Chassis struts are designed to resist compression longitudinally, thereby holding two components apart to prevent them from flexing or collapsing. Correctly designed and installed, strut bars stiffen substructures, reducing chassis flex as vehicles cross uneven surfaces or round tight corners. This improves the driver's experience of vehicle handling. Source | Daimler AG



■ A "simple" part with more than its share of complexity

To balance mechanical and production requirements for the strut bars, researchers selected a high fiber-volume fraction of aligned, continuous carbon fibers, for compressive strength, a high-temperature epoxy to handle close proximity to the vehicle exhaust system, adopted a solid rectangular billet geometry that lent itself to variations in mounting hardware, and also made it possible to use the pultrusion process with its low tooling cost and scalable production speed. Finally, researchers added a thin core of high-strength steel (visible on the end in photo) to improve crash performance and ductility, and face layers of fiberglass to reduce risk of galvanic corrosion. Source | Daimler AG

low tooling costs that was scalable to keep expenses manageable as production volumes increased. From a design standpoint, still another issue was that the basic geometry of the strut itself was a solid rectangular billet, but mounting hardware (force-transmission points) on each end of the bars needed to be added to facilitate connections and transfer loads.

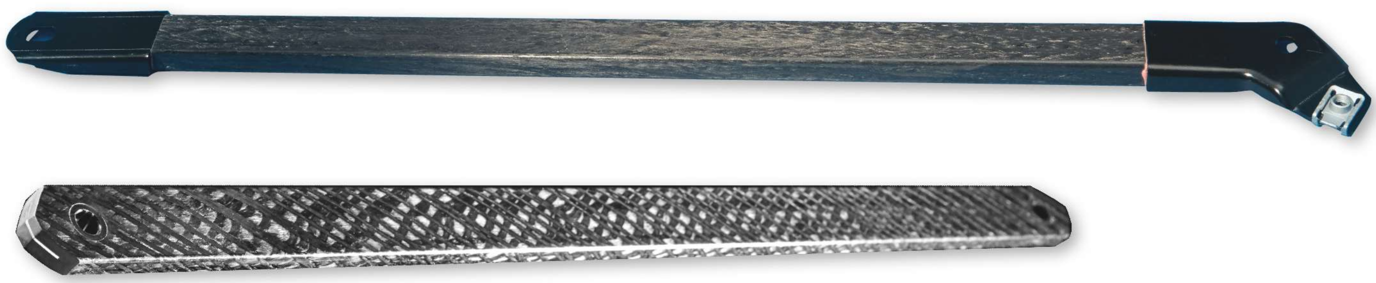
After an internal review, researchers determined that one process would best meet project goals. "We considered all relevant processes right from the beginning," recalls Dr. Karl-Heinz Füller, Daimler's manager – hybrid material and concepts. "However, with our demanding performance requirements and tight cost situation, only pultrusion could provide feasible economics." Team research, which included a complete lifecycle analysis (LCA) that is done for all new production processes introduced at the company, showed that not only did pultrusion operate with virtually no waste — important with high-value CFRP materials — but that it also was the most cost-competitive composites process because it requires relatively little energy (owing to low process forces) and has negligible tooling costs. These features would be important at the start of the project and later, should the CFRP strut program expand to other, higher-volume vehicles.

"Our strategy at Daimler for using CFRP is to start our applications with more exclusive, lower-volume vehicles, like Mercedes-AMG cars," adds Füller. "That gives the CFRP supply chain — fiber and resin producers as well as processors — the time they need to further develop the cost position to meet the demands of high-volume productions. We felt the pultrusion process had the best opportunities of all composite technologies to get developed into this direction."

The team began the hard work of optimizing the pultruded strut's design with epoxy and carbon fiber, running numerous static and dynamic simulations on complete vehicle models in NX Nastran (from Siemens PLM Software Inc., Munich, Germany), including noise/vibration/harshness (NVH), crash, fatigue and delta-alpha simulations (coefficient of linear thermal expansion (CLTE) differentials) using different ambient temperatures. Significant effort was expended to define the best layup of rovings for different carbon fiber types — from 12-50K — to achieve the part's high mechanical performance. Although initial commercial designs featured pure CFRP composite, several years of simulation and physical testing of numerous material and design variants taught the team several things and shifted the focus to a hybrid-composite design with the following features:

First, more economical 48-50K carbon fiber tow would work and the CFRP part was likely to be 45-60% lighter than steel benchmarks. Multiplied by two or four struts, depending on the vehicle, the savings would increase.

Second, to address concerns about galvanic corrosion between the carbon fiber and metal connection hardware, as well as surrounding metallic structures, and to prevent damage from stone chips kicked up by tires, the team decided to add a



Final preparation for underbody installation

After pultrusion, the profile for the hybrid composite strut body is cut to size, holes are drilled on either end and bushings are installed. Next, the surface is prepared and mounting hardware (force-transmission points) is bonded (via structural epoxy adhesive) to both ends of the strut. All metallic hardware that directly touches the struts is protected by either coatings or adhesives or both.

Source | SPE Automotive Div. (top) and Daimler AG (bottom)

protective top layer of slightly heavier but less costly fiberglass. The glass also improved damping values.

Third, simulations showed that it would be beneficial to add a thin steel core to the pultruded profile to increase its ductile crash behavior and offer new cost-efficient mounting designs. In the end, use of the metallic core — which is formed using high-strength steel (0.8-1.2mm/0.03-0.5 inches in diameter, depending on application) and fed directly into the pultrusion die along with glass and carbon fibers — also made it easier to insert attachment bushings into the struts. All metallic hardware directly touching the struts is protected by either coatings or adhesives or both.

Initially an all-CFRP and, later, a hybrid (steel-cored, carbon and glass fiber-reinforced epoxy) composite, the struts were produced by Secar Technologies GmbH (Mürzzuschlag-Hönigsberg, Austria). The strut body is cut from a pultruded profile. Typical length is 0.8-1.3m (2.6-4.3 ft), typical width is 35 mm/1.4 inches, and typical thickness is 8.0 mm/0.31 inch). Holes are drilled and bushings installed. Using standard surface prep, attachment hardware is bonded to each end of the bar via structural epoxy adhesives. Bonding currently is the rate-limiting step in the production process; pultrusion is quite capable of maintaining a high-volume production rate.

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"Thanks to the dedicated mix of various glass and carbon fibers, a high-performance resin and a high-strength metal band at the core, the function and cost of our material mix was optimized," notes Ralf Bernhardt, Mercedes-AMG's manager – body-in-white development. "That made it possible for us to optimize other component functions, such as damping and corrosion characteristics, temperature resistance and crash performance. In combination with the impressive economic efficiency of the manufacturing process, this provides the ideal conditions for larger production volumes."

Award-winning design expands to more vehicles

Initially, pure CFRP strut bars were introduced on Mercedes-Benz SLS AMG *Coupé Black Series* vehicles in 2013. Since then, further design and process developments were applied cost-effectively to vehicles with much greater volumes, such as the Mercedes-AMG *C-Class C63/C63S* coupés/cabriolets (2016), AMG *GT R* (2017), and AMG Mercedes *S-Class* (2017). The application also won the 2016 Innovation Award from the Verstärkte Kunststoffe e.V. (AVK) industry association at the Composites Europe conference.

Although the CFRP and hybrid struts are more costly than earlier steel struts, they meet Daimler's ambitious lightweighting requirements and achieve other benefits as well. "Local stiffness improvements in the right areas lead to a more precise, harmonic, trustful driving experience," notes Bernhardt. "That means that less-experienced drivers can drive more safely and faster, and experienced drivers can drive much faster because it takes less time to understand the character and behavior of the car." He adds that final handling evaluations are subjective and measurable benefits are vehicle-specific.

"For an automotive development engineer, the effort to develop a CFRP part compared to a metal one is significantly higher," Füller reminds us. "Finding a partner that is capable to handle a large automotive series with all boundary conditions, including a satisfactory profit margin, has been a quite challenging journey." Nonetheless, he adds that while the opportunity to convert metal struts to CFRP on passenger cars is limited, still the lessons learned in terms of design and bonding can be applied to other composite structures. A quick look at CFRP innovation on other Mercedes-AMG vehicles shows the team has done just that. CW

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