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Carbon fiber SMC Chassis Subframe: RUGGED FOR HIGH ROAD LOADS

AUGUST 2018

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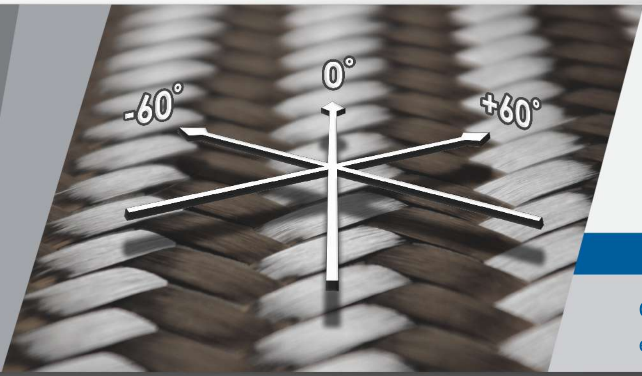

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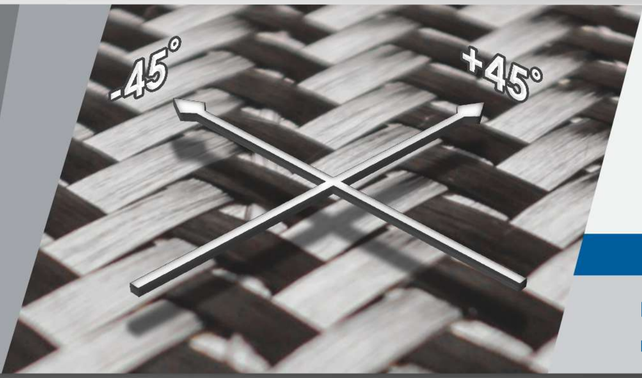

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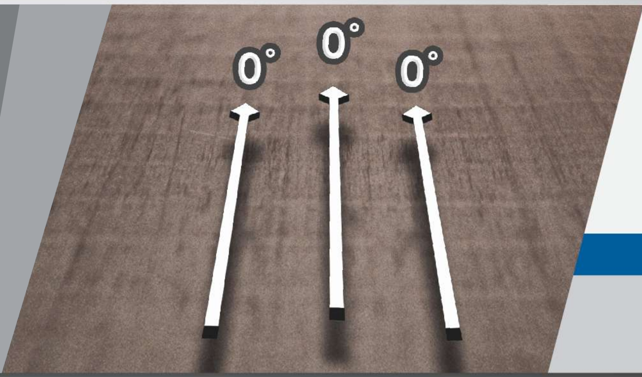

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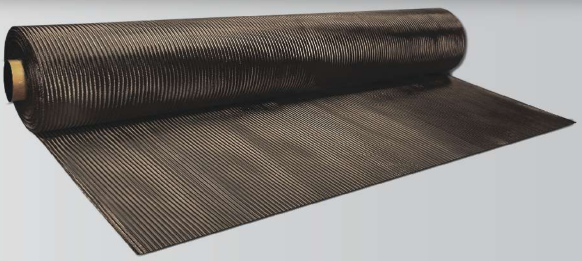

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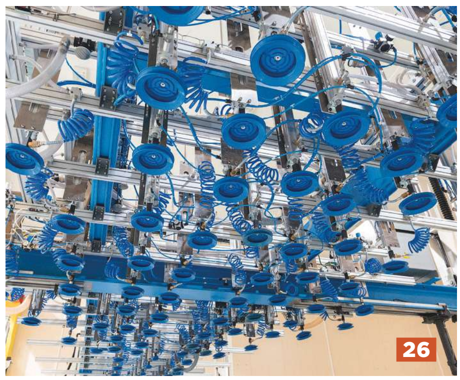

FEATURES

» DEPARTMENTS

» ON THE COVER

Stainless steel sleeves like this are overmolded into this complex SMC molded component to accommodate four body-mount and two steering-mount connections for a carbon fiber composite front chassis subframe designed to replace a steel version in Ford Motor Co.'s (Dearborn, MI, US) *Fusion* compact. Read more about the effort, led by Magna International (Aurora, ON, Canada), on p. 44.

Source / Magna International

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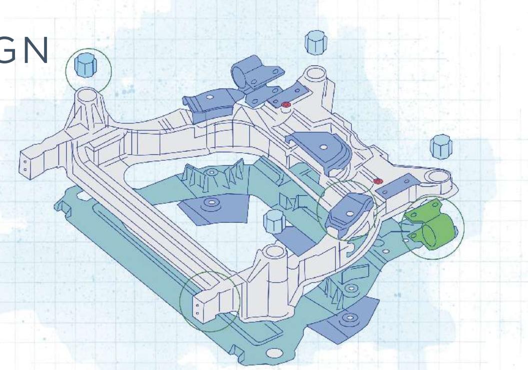

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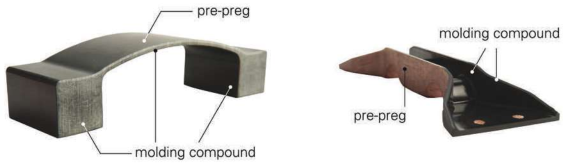

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Honoring a friend in composites, and focusing on the leaders of the future.

» Katie Thorp died on July 7. She was only 51. Katie, a Ph.D, had been in and around the composites industry for more than 25 years, most recently as a materials engineer at the US Air Force Research Laboratory (AFRL) at Wright-Patterson Air Force Base, OH, US. I did not know Katie very well, but I wish I had. People I know who worked with her and knew her well have extolled her virtues as a strong composites proponent with a great sense of humor who was heavily involved in SAMPE and a dynamic industry leader and mentor.

Whenever the composites industry loses someone of Katie's stature, knowledge and experience, I am reminded of the history we possess, and the thousands of people who have brought this industry to where it is today. I am reminded that although we talk about composites manufacturing as a massive agglomeration that fabricates composite parts and structures, it is, in fact, a community of people who work together to solve problems and meet the real needs of customers, who also are people.

With Katie's death, we also lost her personal history — the stories of her contributions to composites, her memories of triumphs and stumbles, tales of her first job, tales of her most memorable accomplishment. Katie left behind, of course, a web of colleagues, friends and associates, who each benefited in their own way from Katie's work with composites, and these people now bear responsibility for carrying Katie's legacy forward.

Katie's passing has called to my mind that there are many, many more people like her, working in composites today, with decades of accumulated knowledge and experience, helping shape ideas and technologies. Each of these people has a story to tell as well. It is those very stories that we have been collecting for the past year via the *CW Talks* podcast. We are attempting, with the podcast, to preserve composites history, to understand the people who have helped composites manufacturing become what it is today, and to learn from them how they think this industry will evolve going forward.

But as much as we want to preserve and cherish memories, it's forward that we must go. Katie's death marks a milestone in composites history, but our professional future will be written by those she leaves behind, including the thousands of young people who are joining the composites community today. Indeed, many of you reading this have likely already developed or soon will discover the technological innovations that will propel composites onward.

What will those innovations be? Who will develop them? How will they be developed? Will they be pursued intentionally or discovered inadvertently? Will the composites industry be ready for the innovation, or will it be premature?

However it happens, it promises to be interesting, occasionally thrilling and sometimes frightening. But in the end, it will come down to people — you. Each of you — each one of us — has a story and a place in the history of composites. And if we're willing, dedicated to working with our web of colleagues, and committed to the composite community, we, like Katie, can leave a lasting legacy.

JEFF SLOAN — Editor-In-Chief


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Reinforced phenolics: Still disruptive after all these years

» Developed by Belgian-American chemist Leo Baekeland in Yonkers, NY, US, in 1907 and patented in 1909, the filled phenolic resin known as Bakelite was the first commercial composite material. Strong, electrically insulating and resistant to heat, it could be molded into almost limitless shapes. The result was disruptive. It was soon used in place of legacy materials in a broad range of products that included fountain pens, ashtrays, telephones and insulation for electrical wiring. It made a host of products affordable for the masses for the first time. Its use radically altered the established supply chain for these products, and it rapidly put makers of legacy materials (shellac, for example), out of business. Today, the automotive industry is on the brink of a period of significant disruption, and high-performance phenolic composites could be a key enabler in this change.

Fiber-reinforced phenolics could be a key enabler of a coming automotive industry disruption.

When I entered this industry in 1988, high-performance composites were considered something of a novelty. The materials had found niche applications and were selected over competitors based on assessments of their performance and price. Fast forward 30 years and the composites industry is a global powerhouse, worth tens of billions of dollars per year and still growing.

The key catalyst for change in the vast majority of markets where composites now find use has been environmental legislation. The low mass of composites compared with competitors, namely metals, is now their unique selling point (USP).

The auto industry is the ultimate case in point. Global regulations on carbon dioxide (CO_2) emissions are becoming increasingly punitive. For example, in the Europe Union (EU), the fleet average emissions figure that must be achieved by OEMs in 2021 is 95g of CO_2/km. Failure to hit this target will trigger massive fines.

In their quest to satisfy these regulatory requirements, carmakers have sought to reduce vehicle weight. A lighter car can travel farther on a given quantity of fuel, reducing the amount of CO_2 released into the atmosphere. As a result, carbon fiber composites — previously the preserve of supercars and fighter jets — have been employed in the structures of mass-production vehicles, such as BMW's *i3*, *i8* and *7 Series*, and Audi's *R8* and *A8*. Innovative applications for glass fiber composites, used for exterior body panel production since the 1950s, continue to be developed. Under the bonnet, meanwhile, heat-resistant and dimensionally stable phenolic composites have been instrumental in the shift towards smaller, more fuel-efficient — but hotter-running — engines.

Initial results have been impressive. Since 2001 we have seen a continuous decrease in CO_2 emissions from vehicles, but in 2015-16 there was a slight increase. This was due in part to the so-called Dieselgate emissions scandal. The public, particularly in Europe, started to buy more gasoline-powered vehicles in response, and there was also an increase in the sales of larger vehicles, such as SUVs. These trends are worrying for carmakers given that fleet average emissions targets in the EU are likely to be reduced further to 75g of CO_2/km in 2025.

This is driving a move away from vehicles with conventional internal combustion engines (ICE) to those with plug-in hybrid (PHEV) and fully electric (EV) powertrains. Indeed, in China, the government has set *mandatory* EV production quotas for OEMs operating there to reduce tailpipe emissions. Many mainstream carmakers have announced ambitious electrification plans, and there could be well over 300 electric and hybrid electric vehicle models launched over the next three years.

This will have a significant impact on the automotive supply chain. A modern ICE powertrain comprises approximately 1,500 parts. Electronic drivetrains have roughly 60 to 70 parts, depending on their complexity. Competition will be fierce amongst suppliers of ICE parts as they attempt to maintain their relevance, and some will find that their current products for such powertrains — exhaust and catalyst systems, for example — are virtually obsolete.

All of this disruption creates opportunities for reinforced phenolics. PHEVs and EVs will need to be as light as they can be. They are heavier than their ICE counterparts; in PHEVs this is due to the dual powertrain, the battery and the converter. In EVs, the battery is very heavy. This added mass requires a stronger chassis and bigger brakes to cope, which adds further weight, not to mention expense. In turn, this reduces the range these vehicles can travel on a single charge.

Phenolic composites are light, but at Vyncolit we are targeting a number of parts in the drivetrains of PHEVs and EVs where the other properties of these materials — such as their corrosion resistance and their knack for enabling functional integration — also can shine.

For instance, a number of automotive suppliers are developing E-axles. PHEVs and EVs currently feature one or two electric motors at the front and one or two at the rear, together with a power converter and a control unit. All of these are separate components. In E-axles, the electric motor, power electronics and transmission are combined in a compact unit (E-motor) that directly powers the vehicle's axle. Depending on the car's size, it may require only one E-motor (e.g., the Renault *Zoe*, on its front axle) or several (e.g., the Tesla *S P100*, with three E-motors, one on the front axle, two on the rear). This aids in making electric drives less complex, cheaper, more compact and more efficient. Phenolics can be used to overmold light and strong housings for these electric drives, in a cost-effective manner.

Backing plates for brake pads also could benefit from being produced from phenolic composites. These materials are regularly used in disk brake pistons —1.2 billion of which have been manufactured since 1978. Current backing plates are made from steel, to which the friction material is bonded. Sumitomo Bakelite Co. Ltd. has shown that by using phenolic composites rather than steel for these parts, their weight can be reduced by as much as 70% — a significant savings, given that there are eight backing plates on each vehicle. Further, the friction material can be overmolded, so production is simplified, and the bond strength between the pad and the plate can be increased. Further, the inherent vibration-damping properties of the material eliminates the need for shims between the plate and the piston in conventional constructions.

Perhaps most importantly, composite backing plates are inherently corrosion resistant. This is a boon for any vehicle, but will be of particular significance for PHEVs and EVs. In these vehicles, the regenerative braking system plays an important role in deceleration, meaning that the friction brakes are used much less frequently. Indeed, they are equipped with only 5 mm of friction material rather than the conventional 10 mm. When they are fitted with metal backing plates, corrosion renders the PHEV and EV brakes unroadworthy before the friction materials wear through. The use of composites eliminates this problem, optimizing their service life.

Although phenolics have been labeled by some as difficult because they can off-gas moisture during processing at elevated temperature, phenolic molding compounds today can be readily, reliably and efficiently transformed by injection molding, compression molding and transfer molding. The surface quality of molded parts is more than adequate for the applications I've described here.

Phenolic and epoxy composites are already being used in induction electric motors for Renault's electric vehicles and in rotor magnet fixation used in Internal Permanent Magnet E-motors for a carmaker in Asia — these parts have been in serial production for two years. Bakelite may be old technology, but the current balance of cost, processability and in-service performance its phenolic successors can deliver will be key in enabling the new economy. CW

ABOUT THE AUTHOR

Hendrik De Keyser is chief innovation and technology officer for Vyncolit NV (Ghent, Belgium). A chemical engineer by training, he has logged more than 30 years in the advanced materials and composites sector, and has worked for Vyncolit NV since 1988, beginning as a marketing development manager, responsible for developing applications for phenolics in a variety of industries, and then was responsible for taking these solutions to the North American market. After the company was bought by Sumitomo Bakelite Co. Ltd. (Tokyo, Japan) in 2005, De Keyser returned to Europe to take his current position in January 2016.

Lakes, rivers and the high seas: Boating's influence on composites

» In February 1987, the Society of the Plastics Industry held its annual Reinforced Plastics and Composites Conference in Cincinnati, OH, US. The forerunner of the American Composite Manufacturers Assn.'s Composites Show and today's CAMX event, it was then the premier US trade showcase for fiberglass-based composites (SAMPE hosted a separate event for advanced composites). Each night that conference week, following dinner, I and several Dow Chemical colleagues, and a few of our customers, would find a late-night bar with ESPN on television, so we could watch the America's Cup yacht racing finals, live from Fremantle, Australia. Although the hulls of the Australian and American finalists were made of aluminum and wood, not composites, we were glued to the TV screen that February. Four years earlier in 1983, *Australia II*, from the Royal Perth Yacht Club, had won the cup and the right to host the next challenge — the first time a non-US entry had prevailed since 1851. With its famous "winged keel," the boat had been able to make tighter turns than conventional boats and had opened a new era of technological innovation in sailing. In 1987, we watched as skipper Dennis Conner employed additional design innovations in the keel shape and hull surfaces to recapture the cup for the US. But that America's Cup series represented another major turning point in yacht racing, because New Zealand's boat with the first Cup hull ever fabricated from composites, albeit fiberglass, made it to the finals of the challenger series (the Louis Vuitton Cup) before falling to Connor's aluminum hulled boat. It didn't win, but the door was opened for composite materials, going forward.

We have the marine industry to thank for many of the advances seen in large-part composites fabrication.

They have played a key role in the America's Cup ever since. Today, the sport resembles *Formula 1* auto racing more than the traditional "old money" version of sailing. Boats use high-modulus carbon fiber, often to the point of razor-thin safety margins (and the ugly consequences of not accounting for rougher than expected seas or high winds). Major collections of composites-based yacht design and fabrication facilities have evolved in select waterfront boatyard havens: Rhode Island in the US, New Zealand, the west coast of France, and even along Lake Geneva in Switzerland.

Composites have a long history in watercraft, causing one to wonder why it took so long for the America's Cup to embrace them. The earliest reported construction of a fiberglass boat dates clear back to *1937*. Commercial production of fiberglass-hulled boats began in earnest in the 1950s, first with small craft, then larger powerboats and sailboats from the 1960s onward to become the world's largest market for fiberglass.

Although it has since been eclipsed, volume-wise, by the automotive and wind energy industries, we have the marine industry to thank for many of the advances seen in large-part composites fabrication, including advanced gel coats, isophthalic polyester resins, multiaxial non-crimp fabrics and advanced core materials. Concerns over open molding techniques and styrene led to development of low-VOC resins and closed-mold vacuum infusion techniques, even for very large yacht hulls. These advancements have found their way into other markets, optimizing production of wind turbine blades, bridge decks, corrosion-resistant tanks and building exteriors. Notably, low-temperature-cure prepregs were introduced specifically to serve the *marine* market. And many fiberglass-hulled sailboats and yachts feature long, stiff and lightweight *carbon fiber* composite masts, more representative of aerospace construction.

According to data released by the National Marine Manufacturers Assn. (Chicago, IL, US) in May this year, the recreational watercraft market had its best year in the previous 10 in 2017, with sales of new powerboats exceeding 262,000 units. Most of these employ composites in hulls, decks and interiors. The Web site superyachts.com claims that more than 500 boats greater than 24m in length are currently in production around the world. A sizable portion of those up to 40m long have both hulls and decks of fiberglass, carbon fiber or glass/carbon hybrid composites.

Emirates Team New Zealand won last year's America's Cup, contested in Bermuda, and will defend its title in Auckland, in March 2021. The New York Yacht Club will field a contender featuring a new 75-ft monohull with advanced airfoils that will provide enough lift, at speed, to enable the boat hull to sail above the water. Fabricated in Rhode Island, the boat will benefit substantially from use of advanced composites. But so will the contenders from elsewhere in the world. Because the races will again be held "down under," it will be televised (and streamed or available via augmented reality, I presume) live in the late-night hours in America. I know I'll be watching. CW

ABOUT THE AUTHOR

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

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Composites Index trending lower but still in growth mode

June 2018 – 56.5

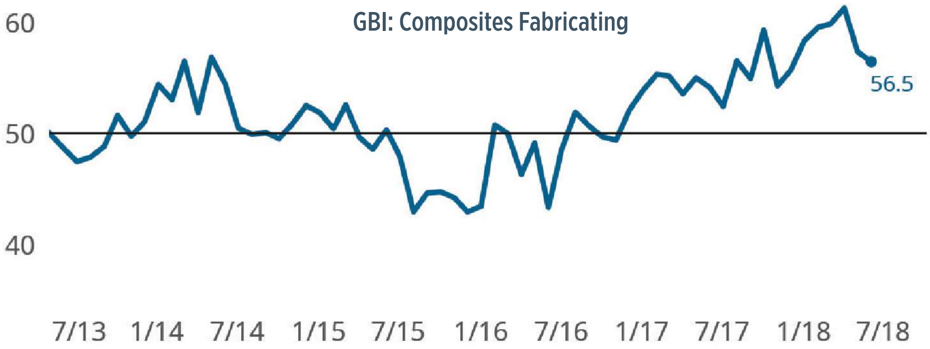
» The GBI: Composites Fabricating Index for June registered 56.5, indicating that the US composites industry was experiencing modestly slower growth compared to the preceding three months. But seen in the context of the extended history of the Index, June's results were still very encouraging. During 2017, for example — the best calendar year in the history of the index — the average monthly reading was 55.1. Furthermore, the Composites Fabricating Index's lifetime average of 51.5 is significantly lower than the June reading. Compared to the same month one year ago, the Index had increased approximately 4.2%.

The Gardner Intelligence team's review of the underlying data for the month of June indicates that the Index was pulled strongly higher by the Supplier Deliveries and Employment subindices. Concurrently, the Index, an averages-based calculation, was pulled lower by Backlog and Exports.

Growth in both Production and New Orders has slowed significantly from the blistering pace set during the first quarter of the year. In their place, Supplier Deliveries and Employment became the two most significant upward drivers of the Index's latest performance. This change in primary drivers from New Orders and Production to Employment and Supplier Deliveries is consistent with the Gardner Intelligence team's view that the business cycle up-swing in evidence since early 2017 is maturing. The industry, which was faced with a surge in New Orders, has made significant changes over the past 18-24 months to handle consistently greater levels of demand. The continuation of strong New Orders volumes will play a decisive role in the longevity of the current phase of the business cycle. CW

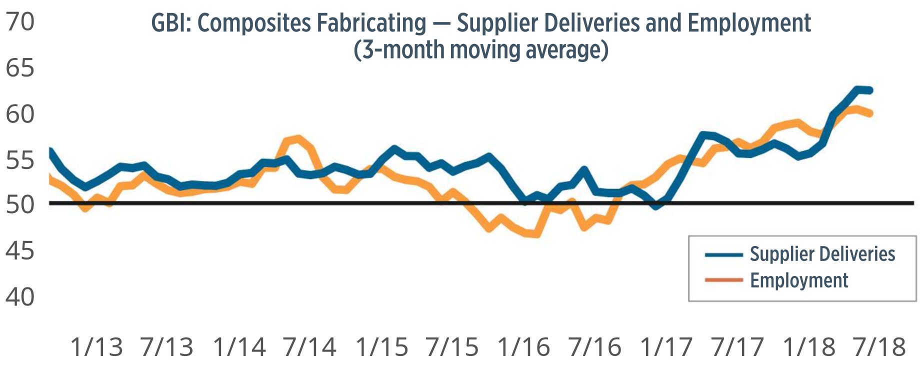
ABOUT THE AUTHOR

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**



Trending lower but still growing

The Composites Fabricating Index fell farther away from its all-time high reached in April. Supplier Deliveries and Employment, in June, supplanted New Orders and Production as the key drivers of the Index.



Supplier Deliveries and Employment now key Index drivers

Expansion of the composites supply chain over the past 12-18 months has enabled higher levels of production. Supplier delivery levels and employment growth are higher now than in any prior year in the history of the Index.

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_CW_ Talks with carbon fiber supply-side veteran Tom Lemire, and a growing 3D production printer reveals its internal efforts to transcend the current two-dimensional limitations of additive manufacturing technology.

Q&A: Tom Lemire, TFLemire Consulting

Editor's note: CW Talks: The Composites Podcast*, recently spoke to Tom Lemire, currently principal of TFLemire Consulting (Irvine, CA, US) and a longtime veteran of the composites industry. Lemire's career dates back to the late 1960s, and he eventually did most of his work in the composites industry for carbon fiber suppliers BASF (Florham Park, NJ, US) and Toho Tenax (now Teijin, Rockwood, TN, US). Lemire talks about getting his first job with Owens Corning Fiberglass (OCF, Toledo, OH, US), then working with the resin transfer molding process, selling carbon fiber for the* B-2 *bomber, convincing officials in Japan to let him establish US operations there, and more. What follows is an excerpt from* CW*'s interview with Lemire. For the full conversation, please visit* www.compositesworld.com/podcast*, or search for* CW Talks: The Composites Podcast *on iTunes or Google Play.*

***CW*: When you graduated college in 1969, you landed a job with Owens Corning Fiberglass. You had a degree in social sciences and so did not have much familiarity with glass fiber. How did the company bring you up to speed?**

TL: In my case, they sent me to a fiberglass reinforcement plant to see how the reinforcements were made, and then luckily they sent me to a compression molder named Premix, located in North Kingsville, Ohio, for about a week, putting sheet molding compound and bulk molding compound into tools to produce parts. .... Then they assigned me as caravan manager for Shape Show '69.

***CW:* What was Shape Show '69?**

TL: Shape Show '69 was a combination of a movie and slide presentation, along with actual FRP parts displayed within a large 40-ft semi-trailer that I rode throughout the US. ?. Our target market was appliance and equipment manufacturers. So, I would contact the local OCF salesperson who had responsibility for accounts, and we would travel to those companies, such as Whirlpool or Maytag, GE or Amana, and show them parts made out of SMC and BMC. .... We even had the classically designed GMC motor home to show how metal parts could be converted to composites. .... So we would show up at appliance manufacturers, and we would bring molders, such as Premix or MMFG, G.B. Lewis, Glastic — they would come to our show and they would be right there ready to talk to the engineers and offer pricing quotations and estimates ?. It was the classic dog-and-pony show, and it was very successful.

***CW:* By 1975, Owens Corning had developed an interest in a new technology at the time called resin transfer molding. What drove that interest?**

TL: There was growing concern about styrene emission from polyester resins [in open molding processes] and we decided to promote a novel concept called resin transfer molding. In fact, I got to meet its founder, a man named Dr. Irving Muskat of Marco Chemical [Plainfield, NJ, US]. And we felt his process had some merit, so we began helping molders embrace this manufacturing technology.

***CW:* How did the RTM of 1975 compare to what we have today?**

TL: I would say it was fairly crude. We just had fiberglass molds and they were alright, but they weren't great. But the big thing, of course, was to make the thing airtight, so we didn't bleed off styrene emissions or have resin dripping all over the floor. It was still a very crude process. We had, maybe, 30 or 40 engineers within the lab facility to look at it and critique it.

***CW*: How successful was OCF with RTM?**

TL: Since I had the recreation market, I went to Winnebago in Iowa and I asked them if there was a small part we could make in RTM for them. They gave us a hood for a smaller-type motor home and maybe it was 36 inches by 12 inches, so it was fairly small. And we made an RTM part for them. .... Then there was interest by Coleman to make a pop-up camper top, and this part was probably 10 ft by 12 ft — it was a very, very large part. And on our first attempt to make that in RTM, we were worried about air dams and non-wet-out fiberglass sections, so we adjusted our resin viscosity and we kept pumping and pumping. What we found was that it sucked up all the resin, but we realized our tooling was too weak. The tool was buckling in the middle. So, what should have been an 85-lb part turned out to weigh about 135 lb. .... That moved us to vacuum-assisted molding to make better parts.

***CW:* You eventually wound up, in the 1980s, at BASF, where you were first exposed to carbon fiber, selling a product called Celion. What kind of work did you do there?**

TL: Celion referred to a name Celanese had given to a [carbon fiber] technology licensed from Toho Rayon in Japan. So, BASF had bought that business from Celanese. .... I was selling that material for a black-classified [Department of Defense] program. .... Later, it became known as the *B-2* stealth bomber. .... I was supplying carbon fibers, I believe it was 6K and 12K fibers, to people who would either weave it into fabrics or make unidirectional tape, and they would ask me various technical questions.

***CW*: In 1992, BASF surprised a lot of people when it decided to sell its carbon fiber business to Toho Rayon. Walk me through that.**

TL: It was quite a shock, but I remember the date, which was March 10, 1992 ... and [our president] called a special meeting for all of us to come before the Anaheim SAMPE conference, and of course we went in very cocky. We were expecting an announcement about another potential acquisition, since BASF was such an industry leader. .... To our surprise, [president] Dave Forrest came in and announced that both our carbon fiber and our prepreg business units would be put up for sale. We were just shocked, but at that point the announcement had come out that the B-2 bomber was limited to just 20 aircraft, instead of 150 aircraft, and I think perhaps in Germany [BASF headquarters], they just felt there was not enough of a market to keep the operation in the US going.

CW: When you look at the industry today, what are your impressions?

TL: It's a very exciting time for composites. I was excited to see the number of younger people attending the recent 2018 SAMPE conference in Long Beach. They bring a vitality, a creativity that our industry really needs. It's refreshing to see them applying new thinking and new technologies. I think you couldn't ask for a better time now to be in composites, given what we are facing today.

BIZ BRIEF

The **Bell Boeing Joint Program Office** (Amarillo, TX, US) announced July 2 it has been awarded US$4.2 billion for modification of a previously awarded V-22 tiltrotor aircraft advance acquisition contract to a fixed-price, incentive-fee, multi-year contract. This contract provides for the manufacture and delivery of 39 CMV-22B aircraft for the US Navy; 14 MV-22B aircraft for the US Marine Corps; one CV-22B for the US Air Force; and four MV-22B aircraft for the government of Japan. The US Navy will use its new CMV-22B for transporting personnel and cargo from shore to aircraft carriers, eventually replacing the C-2 *Greyhound*, which has been in service since the mid-1960s.

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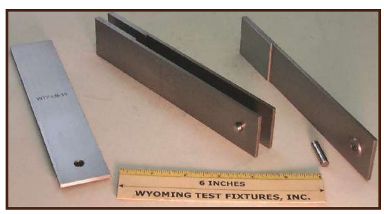

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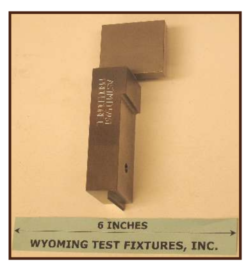

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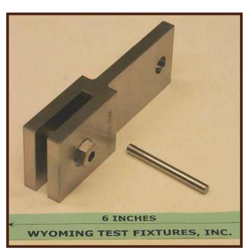

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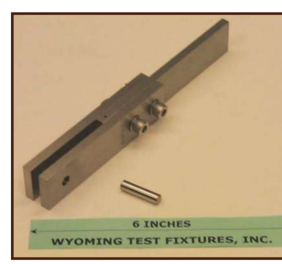

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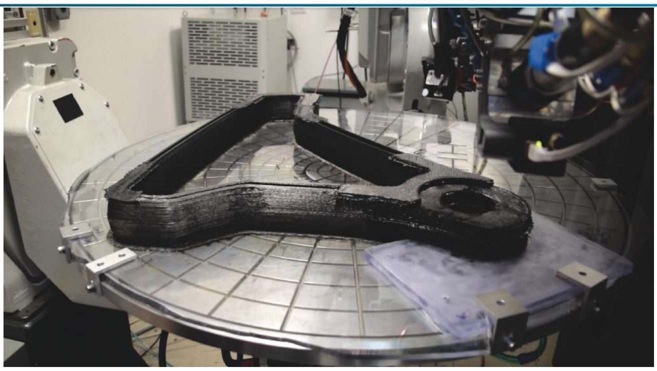
Arevo industrializes production of continuous fiber 3D-printed thermoplastic parts



In the field of additive manufacturing technology, a limiting factor in the printing of *fiber-reinforced* plastic components has been the technical inability of currently available commercial 3D printing equipment to orient reinforcement fibers in more than two of the three component dimensions — x and y, but not z — and that equipment's limitation, both in the software and hardware realm, to building parts by stacking thin, *flat* printed "slices" derived from the part's CAD design. This results, of course, in a part with a significant difference in the mechanical properties that can be achieved in the x and y axes vs. the z axis. Arevo (Santa Clara, CA, US) — notably, a commercial 3D printer, *not* a machine manufacturer — recently has been in the forefront of efforts to develop closed-loop robotic control for 3D printing that not only enables placement of fiber in the z-direction but also along 3D curves. Arevo also is in the vanguard of efforts to 3D print components with *continuous*, as opposed to discontinuous (typically very short), fiber reinforcements.

Arevo's new CEO, Jim Miller, an early Amazon employee and eight-year Google veteran, most recently as its VP of worldwide operations, says, "I was excited by Arevo's approach to 3D printing of composites and see a huge opportunity to change how the world designs and fabricates complicated structures across myriad applications." Miller explains that Arevo's new manufacturing cells use a standard industrial robot, a rotating build platform and a laser for heating. "We call the process direct energy deposition (DED)," he says. Inside its laser-safe cell, the robot has a printhead end-effector with proprietary thermal management equipment, customized electronics and vision systems that enable in-situ inspection. "The process is mostly hands-off," Miller points out, claiming, "These new cells produce more than a hundred-fold increase in production speed."

Arevo's chief technology officer Wiener Mondesir adds, "The laser provides unlimited energy. We can control that and go faster in order to achieve industrial production rates."

Miller argues that machine speed and material laydown rates are only part of the value proposition: "We are building complex structural composites at one-fourth the cost of traditional composites. We are pursuing economically viable fabrication of large-scale thermoplastic composite parts." He notes Arevo's approach is unconventional, but points out

that Arevo's printhead does integrate compaction capability and parts conform to conventional composites quality requirements. "We can achieve thermoplastic composite parts with a void content much less than 1%," he claims.

Arevo's credits its advances in large part to a significant investment in its in-house digital design and process software. "We've collapsed an entire workflow into the software," says Miller. "It can provide a complete 3D analysis of the part and develop the optimized fiber orientation, using additive FEA [AFEA] modules. We run the computer-generated design through our process simulation software and it shows the process parameters, including temperatures, print path, warpage and shrinkage of the printed material, as well as residual stresses. This allows us to understand and optimize the process in order to produce very high-quality parts." Manufactured parts are reportedly within 5% of simulated properties.

Arevo has demonstrated its capabilities in work with design firm StudioWest Concepts LLC (Longmont, CO, US) developing what it calls a "cantilever fiber frame," for what it claims will be marketed as the world's first 3D-printed bicycle (see photo). "We ended up with a very unique design," says Miller, using continuous 12K carbon fiber tow and polyetheretherketone (PEEK) thermoplastic resin.

Arevo, however, has not limited itself to bike frame production. Mondesir also points to high-stress impeller and propeller applications. Both the bike frame and impeller applications take advantage of Arevo's ability to print along a 3D curve.

This year, Arevo says it will install eight DED manufacturing cells to address its production parts backlog. The company also is working with strategic customers on key applications and product development.

"Our third major focus is to continue refining the deposition process to increase speed while maintaining quality and yield," he notes. "We will also demonstrate parts with different fibers and tow sizes." He says the DED process can handle variable tow shape and diameter up to 24K tow, and it's practically unlimited in terms of thermoplastic matrix and fiber combinations. "We can print with PEKK, PAEK, PPS and also with continuous glass and aramid fiber."

"There really is no limit to what size we can print," Miller adds. "We are making a 2.5m-by-1.5m part for an aerospace company and are also looking at using multiple robots together." The company's DED manufacturing cells are of modular design and, therefore, capable of integrating and performing secondary operations, such as finishing for high-quality surfaces. Miller says Arevo's technology also is easily integrated into existing or new processes.

"Arevo is not in the printer business," Miller sums up, "but this adaptability opens some opportunities." Those might include, eventually, marketing its software to its customers, thus enabling them to design products and visualize their construction on a virtual 3D Printer, that will ensure the part is already well-adapted for Arevo's production line. And should Arevo's DED production capabilities attract global attention? Arevo's not adverse to selling the actual printing system (see, for example, this recent Arevo coverage at Engineering.com) | short.additivemanufacturing.media/ArevoEngCo

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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

TPI Composites and Vestas add two production lines in Mexico
The companies will add two more V136 blade manufacturing lines (two were added in April, for a total of six, under an existing multiyear supply agreement.
07/10/18 | http://short.gardnerweb.com/TPIVest2nu

General Atomics maximizes fuel capacity for US Navy's first carrier-based UAV
General Atomics uses advanced composites expertise to develop integrated fuel tanks in MQ-25 unmanned aerial refueling vehicle test article.
07/09/18 | short.compositesworld.com/GANavyUAV

FACC composite technology plays role in new Pearl 15 engine
FACC has supplied composite components for the bypass ducts for Rolls-Royce's newest line of jet aircraft engines.
07/09/18 | short.compositesworld.com/FACCPearl

MHI Vestas 9.5-MW offshore wind turbine receives final certification
The world's most powerful commercially available wind turbine receives an S-class type certificate, clearing the way for installations to begin in late 2019.
07/06/18 | short.compositesworld.com/MHI95Cert

BASF expands 3D printing operations with two manufacturer acquisitions
The company is integrating Advanc3D Materials GmbH and Setup Performance SAS into its subsidiary, BASF 3D Printing Solutions GmbH.
07/06/18 | short.compositesworld.com/BASFexp3D

Airborne Oil & Gas begins TCP riser qualification program in South America
The thermoplastic composite pipe riser qualification program is aimed at operators with international deepwater applications.
07/05/18 | short.compositesworld.com/TCPRiser

Facebook ceases *Aquila* drone development
The company puts an end to its carbon fiber WiFi drone program, opting instead to partner with aviation companies that are also working to develop the technology.
07/03/18 | short.compositesworld.com/FBAquilaNo

Owens Corning partners with CPIC to support growing wind energy demand
The two companies announced a joint investment in a new facility dedicated to the manufacture of high-modulus glass fiber products in China.
07/02/18 | short.compositesworld.com/OC-CPIC

Bell Boeing awarded multiyear V-22 production contract
The new multi-year production contract provides program production stability for the V-22 tiltrotor aircraft through at least 2024.
07/02/18 | short.compositesworld.com/V-22Cntrct

Rhode Island marine association launches fiberglass recycling initiative
The Rhode Island Marine Trades Assn. aims to recycle end-of-life FRP boats.
06/27/18 | short.compositesworld.com/RIRecycle

SAMPE and CompositesWorld Congratulate the 2018 finalists

of the SAMPE Young Professional Emerging Leadership Award. The YPELA recognizes the achievements of select Young Professionals by sending application finalists to the SAMPE North America technical conference and exhibition to network with peers and industry professionals, and to increase their understanding of the materials and process community.

Left to right: **Rodrigo Cesar Berardine**, Strategic Business Development Manager Latin America, Owens Corning **Ian Swentek**, Ph.D., PEng, Applications Development Engineer, Hexion | **John Misasi**, Ph.D., Assistant Professor, Western Washington University | **Ayou Hao**, Ph.D., Research Faculty, Florida State University | **Andrew C. Becnel**, Ph.D., Professional Faculty, Department of Aerospace Engineering, University of Maryland | **Ashley Tracey**, Ph.D., Engineer, The Boeing Company* | **John J. Gangloff Jr.**, Ph.D., Senior Research Engineer, Advanced Materials, United Technologies Research Center

***Ashley Tracey, Ph.D. was honored with the SAMPE Young Professional of the year designation and won travel and registration to attend CAMX – The Composites and Advanced Materials Expo.**

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SPE ACCE 2018 preview

Mobility composites are expected to draw an international crowd to this annual Motor City gathering.

» For the 18th time in as many years, the Society of Plastics Engineers' (SPE, Bethel, CT, US) long-running Automotive Composites Conference & Exhibition (ACCE) returns to the Diamond Banquet & Conference Center at the Suburban Collection Showplace (Novi, MI, US) in the Detroit suburbs, Sept. 5-7, to highlight innovations and applications in transportation composites. The three-day event combines multi-track technical presentations and an exhibit floor, plus panel discussions, student poster competitions, awards and more. The lively event typically draws more than 1,000 attendees from five continents who are passionate about advancing composites in mobility applications.

Not just automotive

Although its name describes the event's original composites focus —automotive — attendees actually hail from a richer, more diverse range of transportation industries, including truck, bus, rail, off-highway, agricultural equipment and even aerospace, and also from the sporting goods market. The full supply chain is represented, from OEMs and tier suppliers to additive, resin and reinforcement suppliers and compounders, equipment providers, research organizations, universities and consultants.

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The conference has managed to maintain a friendly feel even as it has grown to a much larger size, so networking opportunities are excellent and everywhere to be found. Organizers schedule regular breaks between sessions to encourage those attending the technical programs to get out and see exhibitors on the show floor, and networking receptions are held on the first two evenings. There's even a pre-event golf outing for those who arrive early and want to start networking right away. Students from high school through post-doctoral studies are there to report their research and to learn about the industry — with many of them looking for jobs.

Annual meet-up in the Motor City

The SPE Automotive Composites Conference & Exhibition (ACCE) returns to the Detroit suburbs to combine a three-day, multi-track technical conference, complete with keynote addresses, panel discussions, poster and part competitions, awards for scholarships and best papers, and a large exhibit floor. SPE ACCE draws visitors from around the world.

Source | Society of Plastics Engineers / Photo | Pam & Mike Brady

Seeing the big picture

To help the audience track key trends impacting transportation composites, conference organizers have scheduled two keynotes and three panel discussions. John Viera, global director – sustainability and vehicle environment, Ford Motor Co. (Ford, Dearborn, MI, US) will discuss "Sustainable Manufacturing at Ford and How Composites can Help to Address Industry Challenges," and Mark Voss, engineering group manager – body structures advanced composites, and pickup boxes at General Motors Co. (Detroit, MI, US) will describe "The World's First Carbon Fiber Pickup Box."

Day 1 (Sept. 5) will feature a panel discussion on "How Can the Plastics Industry Profit from the Next Generation of Vehicles?" Confirmed panelists thus far include Jud Gibson, VP, commercial Americas, DSM Engineering Plastics (Troy, MI, US) and Paul Platte, manager – automotive and transportation, Covestro LLC (Pittsburgh, PA, US).

The panel discussion for Day 2 (Sept. 6) will focus on "How 3D Printing is Changing the Automotive Composites Business" and will feature Ellen Lee, technical leader – additive manufacturing/3D printing, Ford; Jeff LeGrange, chief commercialization officer, Impossible Objects Inc. (Northbrook, IL, US); and Kara Noack, regional business director, BASF 3D Printing Solutions NA (Heidelberg, Germany).

On the last day (Sept. 7), a final panel will focus on "Sustainable Materials Management & the Circular Economy in Automotive Applications." It will include Debbie Mielewski, senior technical

Panel discussions every day

A perennial event favorite, and renowned for its lively, interactive format, the ACCE panel discussion encourages audience members to pose questions directly to panelists. Given that this is the automotive industry, few punches are pulled, and discussions can become very passionate. Accordingly, event organizers have three panel discussions on the docket for the 2018 event.

Source | Society of Plastics Engineers / Photo | Pam & Mike Brady

leader – sustainable materials and advanced materials, Ford; Jay Olson, global manager – materials engineering and technology, Deere & Co. (Moline, IL, US); Charlene Wall, director – sustainability, BASF; Don Wingard, senior research scientist – Wellman Advanced Materials (Johnsonville, SC, US); and Mike Saltzberg, global business director – biomaterials, DowDuPont (Midland, MI, US, and Wilmington, DE, US).

Organizers currently expect 80-90 regular technical papers distributed among 11 sessions:

- Additive Manufacturing & 3D Printing;
- Advances in Reinforcement Technologies;
- Advances in Thermoplastic Composites;
- Advances in Thermoset Composites;
- Business Trends & Technology Solutions;
- Bonding, Joining & Finishing;
- Enabling Technologies (process/machinery);
- Nanocomposites;
- Opportunities & Challenges with Carbon Composites;
- Sustainable Composites (recycled, bio-based, and natural fiber-reinforced composites); and
- Virtual Prototyping & Testing.

Read more about the coming SPE ACCE event at the SPE Web site | **speautomotive.com/acce-conference** CW

ABOUT THE AUTHOR

Contributing writer Peggy Malnati covers the automotive and infrastructure beats for *CW* and provides communications services for plastics- and composites-industry clients.
peggy@compositesworld.com

Plant Tour: Agility Fuel Solutions, Salisbury, NC, US

This systems integrator enables CFRP pressure vessel growth in commercial vehicles by combining composites and alternative fuel systems expertise.

By Ginger Gardiner / Senior Editor

» Agility Fuel Solutions (Costa Mesa, CA, US) has become a global leader in the manufacture of Type IV composite cylinders and alternative fuel systems in commercial vehicles. These include Class 7 and 8 tractor-trailers, refuse collection trucks, transit buses and medium-duty trucks and buses. When combined with cars and light-duty vehicles, the global fleet totals 25 million vehicles. In the US alone, there are more than 175,000 natural gas vehicles (NGVs, which also include liquid natural gas or LNG), with 50 manufacturers producing 100 models of vehicles and engines.

There's good reason for growth in CNG adoption. Natural gas can cost up to 60% less than gasoline and diesel fuel and reduces greenhouse gas (GHG) emissions by 30-90%, so the market for these alternative fuel vehicles is significant.

Agility's leadership position in this high-growth market reaches back to the 1963 founding of Brunswick Composites in Lincoln, NE, US, and around the world to the company's 50% stakeholder Hexagon Composites (Aalesund, Norway). As Europe moves to ban diesel cars by 2040 and reduce vehicle emissions by 30% in 2030, composite pressure vessels

■ **Nebraska to Norway to North Carolina**

Agility Fuel Solutions' composites expertise dates back to the 1963 founding of Brunswick Composites in Lincoln, NE, US (opposite page). Agility ships composite cylinders from Lincoln to its new facility in Salisbury, NC (at left).

Source (here and p. 20) | Agility Fuel Solutions

used in CNG and other alternative fuel systems are sure to be a key driver for increased carbon fiber (CF) demand. Composites Forecasts and Consulting LLC (Mesa, AZ, US) predicts this demand will grow to 45 MT per annum by 2025 (see Learn More, p. 25) — second only to wind turbine blades for carbon fiber consumption.

CW recently visited Agility Fuel Solutions' systems production facility in Salisbury, NC. Carbon fiber-reinforced plastic (CFRP) cylinders are not made here. Instead, they are transformed. Before a vehicle can use them, a system for safe tank enclosure and fuel delivery must be designed, produced and installed. For CNG, this fuel system comprises typically 2-4 cylinders (but as many as 10 can be used), a structural chassis or rack to hold them, plus high and low pressure plumbing, fuel management and pressure regulation devices, safety equipment and crash protection (see Fig. 1, p. 22). *CW* got the following close look at how this is done as Agility NC hosted a partially virtual, partially actual walk-through, covering the complete process chain, from filament-wound composite cylinders in Nebraska to installed systems on commercial vehicles across the globe.

Path to vertical integration

First, there was history. Agility Fuel Solutions began in 1996, with the founding of FAB Industries in Ontario, Canada, which then expanded into the US. It merged with EnviroMECH Industries (Kelowna, BC, Canada and Long Beach, CA, US) in 2010 to form Agility Fuel Systems. By 2015, Agility had developed more than 125 fuel system designs for buses and trucks, many based on Type IV all-composite cylinders. It also had become Hexagon Composites' largest customer.

Hexagon Composites also was becoming a powerhouse, consolidating expertise and production capacity across all NGV and hydrogen fuel segments. It had begun in 1992 as Devold AMT, a Norwegian technical reinforcements producer, and had merged with Norwegian Applied Technology in 2000. Renamed Hexagon Composites, it had then acquired high-volume LPG cylinder producer Ragasco (Ragasco, Norway) in 2001, CNG cylinder supplier Raufoss Fuel Systems (Raufoss, Norway) in 2003 and CFRP expert/Type IV CNG cylinder manufacturer xperion Energy & Environment (Kassel, Germany) in 2016.

Hexagon had also secured a presence in the US market, acquiring Lincoln Composites (Lincoln, NE, US) in 2005. This icon of filament winding contributed 50+ years of composites »

■ **H_2 pressure vessels: An emerging target market**

Agility and Hexagon Composites share technology leadership in hydrogen storage, for which Agility is developing larger-diameter CFRP cylinders to be used in emerging longer-range trucking applications. Source | Agility Fuel Solutions

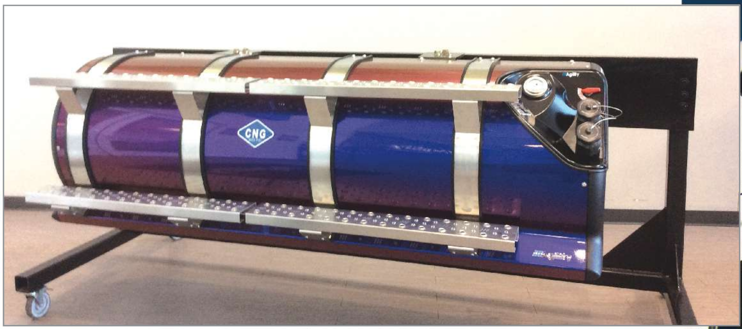


FIG. 1 More than CFRP cylinders

Agility Fuel Solutions integrates CFRP cylinders with plumbing, fuel management, safety and crash protection systems and installs them on vehicles. CNG fuel systems are mounted into trucks behind the cab (as at right) or are side-mounted, also called rail-mounted (as above), and are typically roof-mounted for buses.

Source (top photo) | CW / Photo | Ginger Gardiner

Source (photo at right) | Salisbury Post / Photo | John Lakey

experience. Founded as Brunswick Composites, it produced filament-wound missile bodies and pressure vessels for use in manned space flight and obtained its first certification for composite CNG pressure vessels in 1993. Sold in 1994 and renamed Lincoln Composites, it was then acquired in 2002 by General Dynamics (Falls Church, VA, US), which sold the Commercial Products Group to Hexagon.

Agility Fuel Services formed a joint venture with Hexagon Composites in 2013 and merged the following year with Hexagon's global commercial vehicles businesses, forming Agility Fuel Solutions. "We are vertically integrated from cylinders through to installed systems on vehicles," says Charlie Silio, Agility Fuel Solutions VP of corporate strategy, development and marketing. "We design CNG fuel systems for a variety of vehicles and customers, and then integrate the composite cylinders with the plumbing and other systems and install these into each vehicle so that it operates seamlessly, reliably and cost-effectively."

Production of Type IV cylinders

That vertical integration begins in Lincoln, where the original Brunswick Composites company had its roots. The town is now home to Agility Fuel Solutions, General Dynamics and Hexagon Lincoln which house their production in unique facilities. The Agility facility has grown to a 9,290m² manufacturing footprint and currently includes three filament-wound Type IV composite cylinder production lines.

> Agility Fuel Systems is vertically integrated, from cylinders through installed systems on vehicles.

Compared to Type I steel cylinders, Type IV cylinders — featuring a composite structure wound over a plastic liner — offer a weight savings of up to 70%. This increases payload to more than 85% of the pressure vessel weight and reduces fuel cost more than 60% vs. steel cylinders. Type IV tanks also are lighter than Type II and III cylinders, which are made by winding composites over a metal liner. The Type IV plastic/composite construction resists cyclic fatigue better than metal, offering lower maintenance and operating costs (see Learn More).

Chet Dawes, senior VP of Agility's Cylinders & Europe business unit, describes Type IV production in Lincoln, "We wind carbon fiber and epoxy resin over a plastic liner, which acts as a mandrel for the composite structure." (See Fig. 2, p. 23.) Liners are typically high-density polyethylene (HDPE) for CNG cylinders, but polyamide (PA or nylon) offers improved properties for hydrogen (H_2) cylinders and better resistance to the smaller H_2 molecules vs. CNG. Agility makes its own plastic liners in the Lincoln facility.

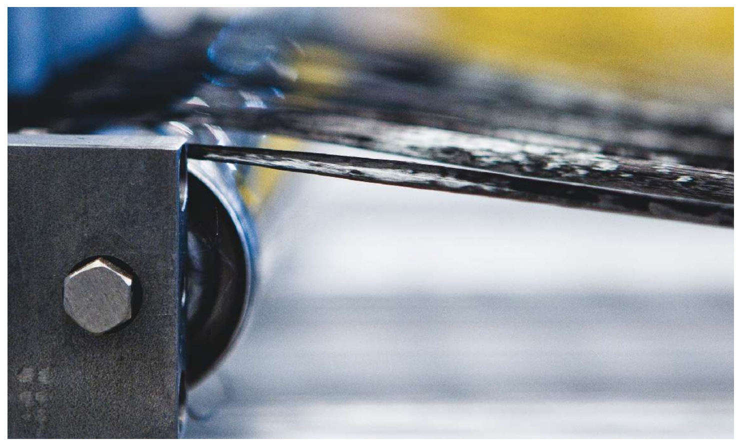
"We also use our own formulations for the epoxy resin," Dawes continues, "and high-strength carbon fiber. We have longstanding relationships with our carbon fiber suppliers, which include Toray, Teijin, Hyosung and Mitsubishi." Although a larger tow size — typically 12K or 24K — carbon fiber is used, Dawes says it is not spread. The three production lines use highly automated winding machines that include proprietary inline resin impregnation systems.

"We can wind cylinders that are 229 mm in diameter up to 762 mm in diameter, and in lengths from 0.6m to 3.8m," notes Dawes.

FIG. 2 High-performance, industrial-scale CFRP cylinders

Agility Fuel Solutions' Type IV cylinders are produced by filament winding carbon fiber impregnated inline with epoxy resin (bottom photo) over a plastic liner using automated production lines (top photo) that enable high precision at industrial scale (photo at left) in a wide range of cylinder lengths and diameters.

Source | Agility Fuel Solutions



"We have the ability to make much larger vessels with much thicker walls, which would traditionally be painfully slow, but we've become experts in production of carbon fiber composite pressure vessels at scale. Our winders are some of the fastest in the world, and our production lines are focused on flexibility for quick changeover to make different products as needed. We can run at a high rate, even with larger cylinders, enabling us to scale while maintaining product performance which keeps production costs low."

This performance is certified through testing. "We do almost all of the testing in-house," says Dawes. This includes proof, burst, leak, permeation and hydrostatic cycle tests. These are required by transportation regulations, notes Silio, because these cylinders are part of commercial transportation systems. The specifications and standards for pressure vessels are different for H_2 and CNG, and also vary by geographical region worldwide. Silio says 250 bar is the standard pressure for CNG cylinders used in North America but 200 bar is the norm for the rest of the world. For H_2 cylinders, 350- or 700-bar are typical pressure standards for vehicles, but this increases to 950 bar for vessels used in stationary refueling stations. "We have the ability to test per all of these standards, as well as third-party witness requirements and destructive tests," says Dawes. However, certain tests for cylinder performance are done off site, specifically when tanks are subjected to fire and penetration tests (the latter involving gunfire). "Once validation is complete, we ship the cylinders all over the world, including to our vehicle systems production facilities in North Carolina, California and Norway, and vehicle OEMs and other customers," says Dawes.

Fuel systems production

CW's tour of the North Carolina fuel systems production facility is led by Shawn Adelsberger, Agility Fuel Solutions director of plant operations (a position now held by Bryan Mewhort). From the lobby, he enters a large, open space with cubicles in the center, offices on the perimeter and a conference room near the entrance. "We broke ground in December 2014 and started production in December 2015," he notes. This site is strategically located in the Southeast near key customers, including Daimler and Volvo. Other considerations for choosing this location included community and workforce availability and development programs. "We partnered with Rowan County Community College and the NC Manufacturing Institute to develop an 8-week class focused on manufacturing," says Adelsberger. Graduates are Certified Production Technicians (CPTs). "We have over 80 graduates now, and 113 employees per shift." The site typically runs two shifts. Within the 18,580m² facility, almost 17,000m² is production space, with room to grow, says Adelsberger, walking through a large employee break area and a door into the open production floor. »

FIG. 3 Fuel system final assembly

At the Salisbury plant, CNG fuel system assemblies are built up on carts as machined and painted parts are added at each station in three independent production lines.

Source | Agility Fuel Solutions

FIG. 4 System shipping or direct installation

Completed systems are then shipped to customers. Alternatively, customers can elect to have systems integrated directly into their vehicles on the Agility facility's installation line, pictured here.

Source | *CW* / Photo / Ginger Gardiner

He points out that Agility was "entrepreneur-founded and we still have that entrepreneurial spirit. We have a strong engineering prowess and wanted to couple that with manufacturing prowess here." Although at one time the company purchased all of the system components, "today, we make more of the pieces ourselves and have achieved improvements in lead time, cost and quality," says Adelsberger, pointing out, "This is the only vertically integrated facility for CNG fuel systems in North America." Originally, composite tanks were also going to be built in the NC factory. "But after the merger in 2016, we decided to leave all tank manufacturing in Lincoln," he says. "Once we opened this site, we relocated most of our North American fuel system production here, except for our operation in California that assembles some systems for buses."

Adelsberger walks through an area titled, "Visual Management," ringed by various boards and displays that track production metrics. "We use these to drive continuous improvement," he says. "We have continued evolving our products in collaboration with our customers."

From this entry point on the north side of the production floor, the tour proceeds toward the rear and long side of the rectangular area, with the paint operations center on the left and eastern short side. Adelsberger notes the paint center takes up about 25% of the floor, and is another key part of the company's vertical integration strategy. "We have a wet paint line and a powder coat line and can match to any color specification per OEM — and also match OEM paint quality and durability," he claims.

Beyond the paint area, in the southeastern corner of the production floor, raw aluminum sheet and extrusions are brought in. Stretching from here across the rear half of the factory are the machining cells used to form the parts for the fuel system structures and covers. "We have invested in the latest equipment," Adelsberger says. "For example, automated drilling centers cut the time to produce some structural parts from 24 minutes per cycle down to 4 minutes." He also points out robotic tube bending stations. After machining, parts are painted and then supplied as needed to the assembly lines.

Halfway across the floor, Adelsberger turns back to face the north long side of the space and the entry to the assembly area. "We have three independent assembly lines," he explains. These run left to right (east to west) just in front of the machining cells and occupy the center and front half of the production floor. As is done in Lincoln, production lines here are set up for flexibility and ease of switching between different products. Adelsberger details the day's product mix: "The number one line on the far left is set up for refuse trucks; the number two line is for behind-the-cab systems (similar to what is displayed in the lobby); and the number three line is side-mounted, or what we call rail-mounted." (Fig. 1, p. 22.)

The process begins with carts that are used to transport the assembly as it is built up through the stations (Fig. 3, p. 24). Different metal parts are joined to form the system structure, and then a crane is used to place the large CNG cylinders. "We use many different cylinder sizes, depending on the type of vehicle and size of system being installed," says Adelsberger. The remaining system components are installed, and each completed unit is then tested. "We use nitrogen up to 4,000 psi [275 bar] to proof and leak test the system," he explains. "The operating pressure is 3,600 psi [250 bar]."

Just forward of the assembly lines, along the front or northern long side of the building, is where the fuel management modules (FMMs) are assembled. These comprise various tubes, valves and electronics. FMMs pass through their own quality checks and pressure testing station and are fed into the fuel system assembly lines once completed.

To the right of the assembly lines is the installation area at the western end of the building, where completed CNG fuel systems are integrated into vehicles. Installation runs perpendicular to the assembly lines, with vehicles driving in from the side and exiting the front. Adelsberger explains that quite a bit of installation is done at customer facilities. "Once we finish building the system, we have several options: Ship out to the vehicle OEM factory for installation; ship to one of several third-party installers (such as Fontaine), located across from Volvo in Greensboro, NC; or do the installation here, in which case we fuel up the system and check it out." Although only one line operates now, there is room to add a second as the market grows.

Ready for growth

The outlook for growth is good. Currently, only 1.5-2% of *heavy trucks* produced globally are CNG vehicles. The Natural Gas Vehicle Association (NGVA) Europe forecasts a market share of 20-25% for heavy trucks and 30% for buses, while CNG market share in the US is aimed at 10%.

However, Agility Fuel Solutions is adding to its portfolio. Although it has manufactured H_2 fuel systems for buses and trucks since 2002, it is now expanding this product line to include fuel systems based on larger-diameter Type IV cylinders for longer-range regional Class 8 trucking applications. One example is Toyota Motor North America's (TMNA, Plano, TX, US) Project Portal initiative, begun in 2017, which is designed to extend zero-emission H_2-powered fuel cell technology into heavy-duty trucks by demonstrating their use at the Port of Los Angeles.

In 2017, Agility launched its Powertrain Systems business unit, which now produces natural gas and propane engines, including the 488LPI, based on its patented liquid propane injection (LPI) technology. Thomas Built Buses has already signed on to use the technology in its school buses. Agility also announced this year a partnership with Romeo Power Technology (Vernon, CA, US) to make high-performance, modular battery packs for commercial vehicles.

"Whether it's CNG, H_2 or electric vehicle technology, commercial vehicles must carry a significant amount of stored energy onboard without excessive weight," says Silio. "Our composites and systems expertise help us to provide a lower total cost of ownership than a diesel vehicle. As a result, we're seeing increased interest in our advanced clean vehicle technologies in North America, Europe and, starting last year, in India." Dawes reiterates the importance of CFRP composites in this advance. "We share technology leadership and a collaborative R&D relationship with Hexagon, including a jointly funded composites center of excellence in Lincoln. As an example of their continued advancements in accurate, high-performance parts at high-volumes, he cites the Hexagon liquid propane gas (LPG) Type IV tank line that has produced more than 12 million pressure vessels on a fully automated, no-touch line (see Learn More).

"There are still a lot of steel cylinders out there and an opportunity for CFRP to replace steel in more established CNG markets, as well as capitalize on new markets like hydrogen," says Silio.

He acknowledges that at the individual cylinder level, CFRP is more expensive when compared to steel, "but you can create more efficiency at the systems level with composites by using fewer, larger, sometimes higher-pressure vessels. This enables a solution that's cost-effective at the level of a complete system, with much less weight. This is a good composites story but to make it work in the marketplace you have to not only be able to make the cylinders at scale, you have to make it easy for vehicle OEMs to use those pressure vessels by *delivering them as part of a complete turnkey engineered solution*." He emphasizes. "We are able to do that and create a pull for CFRP cylinders." CW

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Infused wing sheds light on aerocomposites future

In the Irkut *MS-21* infused and co-cured wings, the aerocomposites industry gets a glimpse of how out-of-autoclave technologies might be applied to primary aircraft structures.

By Jeff Sloan / Editor-in-Chief

» As much as the aerocomposites industry says that it wants to get out of the autoclave and into fabrication technologies capable of faster throughput, the truth is that the autoclave is proving a difficult habit to break. It has to its credit decades of industry experience, mountains of applicable processing data to guide its reliable use, and plain old familiarity. And, quite simply, when it comes to the one job that matters more than all others when making composite primary structures — consolidating the laminates of very large composite structures to very low levels of void content — no other equipment or process does it better.

Proof of this is not difficult to find. Aerocomposites for the Boeing 787, the Airbus A350 XWB and the forthcoming Boeing 777X all feature major aerostructures fabricated with carbon fiber prepregs in massive autoclaves. But, with these three programs in early or full production, the aerocomposites industry is looking to the future, and one of the big questions is whether out-of-autoclave manufacturing processes have a role to play on next-generation aircraft programs. Can they do what the autoclave does (or do it well enough to meet spec) at a rate that will satisfy OEM desires to pick up the pace of production on future aircraft models?

Getting out of the autoclave means moving away from prepreg materials, which have been the mainstay of aerocomposites manufacturing for decades. The alternative to prepreg is to begin with a dry fiber form, which must be impregnated with resin, either via vacuum bag infusion or resin transfer molding (RTM), each of which has its own challenges. The two biggest challenges, particularly in relation to aerospace manufacture, are

■ **A first for commerical aircraft and for the resin infusion process**

Moscow-based OEM Irkut is developing the *MS-21* single-aisle passenger aircraft, set for 2020 market introduction, featuring wings and wingbox fabricated via resin infusion and oven cure by sister company AeroComposit. The wingskins and stringers are co-infused and the composite spars are fabricated separately, all out of the autoclave. Source | Irkut

consistent fiber wet-out and porosity, the latter of which must be less than 2% to meet OEM strength and stiffness requirements. The thermoset-based, non-prepreg process most discussed as a viable option for getting out of the autoclave and meeting those challenges is vacuum-bag resin infusion.

Infusion is not new to composites fabrication in general, but has seen limited use in primary aerostructures, and almost no use in commercial aerostructures. There are, however, two major exceptions: The wings for the Bombardier *CSeries* single-aisle commercial aircraft feature dry fiber infused via a process Bombardier calls resin transfer injection, or resin transfer infusion, but the process *does* employ an autoclave. The second, however, is the carbon fiber composite wing structure for the single-aisle *MS-21* passenger aircraft under development by Irkut Corp. (Moscow, Russia). The process also involves infusion, but is done entirely out-of-autoclave (OOA), which makes it truly unique in the aerocomposites industry. This aircraft is quietly proving to the aerocomposites industry the viability of large, infused, OOA primary structures for commercial aircraft. In short, the *MS-21* is shaping up to be that first next-generation aircraft.

The specifications

The *MS-21* (also sometimes referred to as *MC-21*) was designed and is being assembled by Russian OEM Irkut, but composite structures for the *MS-21* are being fabricated by sister company AeroComposit (Moscow). Both companies are owned by United Aircraft Corp. (Moscow).

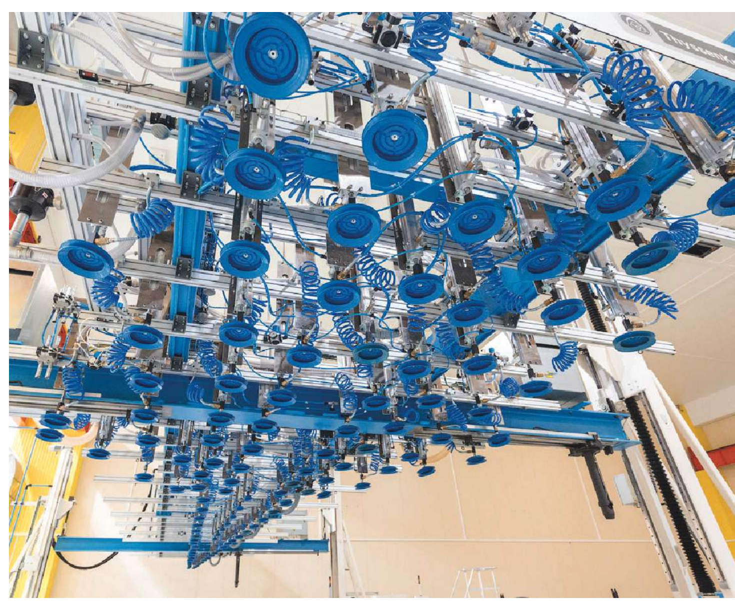
Two *MS-21* test aircraft have been built to date. First flight was achieved in May 2017 and the plane is expected to enter the market in 2020. It features two Pratt & Whitney PW1000G or Aviadvigatel PD-14 turbofan engines and has a range of 6,000-6,400 km. The plane will be offered in two configurations, the *MS-21-200* (132-165 passengers) and the *MS-21-300* (163-211 passengers). There are 175 firm orders for the plane, almost exclusively from Russian carriers/leasers, including Aeroflot, Red Wings Airlines, UTair, Ilyushin Finance Co. and VEB Leasing.

In addition to the outer wings, the *MS-21* also will feature infused carbon fiber composites in the wingbox. But autoclaved carbon fiber prepreg will form the wing trailing and leading edges, flaps, spoilers, ailerons, engine fan cases, and interior floor panels and floor beams. Glass fiber composites will be featured in the nose cone, cargo bay floor panels, the leading edge of the vertical tailplane and wing-to-body fairings. Aluminum and other metals will be used to fabricate the fuselage skin, stringers and frames, as well as all doors and wing slats.

Placing, infusing dry fibers

The *MS-21* outer wings feature a standard design that includes an upper wingskin, a lower wingskin, stringers on the inside of each skin, ribs running perpendicular to the stringers, and forward and rear spars. All parts are composite except for the ribs, and the skins and stringers are integrally molded and co-infused. Each outer wing is about 18m long and 3.5m wide at the root. The wingbox is manufactured separately and integrated with the *MS-21* fuselage at Irkut's final assembly line.

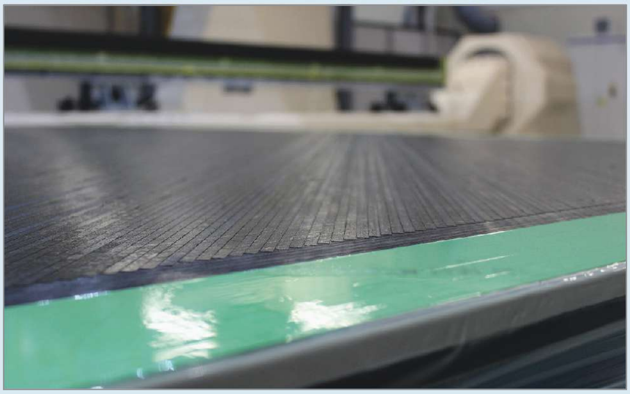
AeroComposit's goal with the *MS-21* wing and wingbox was not only to employ OOA infusion, but also to do so with as much automation as possible. Further, the company wanted, wherever possible, to co-infuse composite structures so as to minimize postmold assembly and mechanical fastening. Meeting this challenge would require the use of automated tape laying and fiber placement (ATL/AFP) systems to lay down dry fibers. That presented an additional challenge: Placement of prepregs, whether by hand or machine, offers the advantage of tack that helps stabilize the stackup and minimizes ply-to-ply slippage. Dry fibers, conversely, are inherently untacky and, therefore, »



■ **Automating large-part transport**

One of the key motivations behind efforts to employ out-of-autoclave methods in the manufacture of next-generation commercial aircraft is the potential to reap a signifcant reduction in overall production cycle time. Toward that end, AeroComposit has gone to great lengths to minimize touch labor in *MS-21* wing fabrication. This suction-based automation system, for example, is used to move wingskins from one station to another throughout the manufacturing process.

Source | Alexander Popov



1 The wingskins are laid up via automated fiber placement (AFP) using a Coriolis machine. The material is Solvay's PRISM TX1100, which is comprised of Teijin's IMS65 24K tow UD fiber surrounded on each side by a film layer of Solvay's Cycom 7720 binder, a thermoplastic that offers the tack needed to provide ply-to-ply friction. Source (all step photos) | Alexander Popov

2 An AeroComposit technician inspects the fiber-placed wingskin, looking for laps, gaps, wrinkles and foreign object debris in the layup. In the background is the tool used to lay up the spar.

3 The *MS-21* wing stringers are laid up flat and then press-formed into an L shape. Two L-shaped preforms are placed in the tools pictured here, back-to-back, to create the T-shaped stringers that will be co-infused on the upper and lower wingskins.

4 Skins and stringers are vacuum bagged, infused with Solvay's PRISM PE2400 one-part epoxy resin, and cured in a standard oven in a process that takes 8-10 hours to complete. The resulting wingskin with co-infused stringers (shown here) undergoes CNC machining operations — trimming, routing, drilling, cutting — in an MTorres gantry-based system.

must be modified if they are to be successfully used in automated placement.

Sam Hill, applications and research engineer, Solvay Composite Materials (Alpharetta, GA, US), who consulted with AeroComposit on materials and processes development for *MS-21* wing fabrication, says Solvay was tasked with solving that problem and developing the wing's infusion material system. Solvay's PRISM TX 1100 is a slit tape comprising Teijin's (Tokyo, Japan) IMS65 24K tow UD fiber and Solvay's CYCOM 7720 binder, which, when heated, offers the tack needed to provide ply-to-ply friction. Further, topping each tape is a lightweight veil (proprietary Solvay technology) designed to provide weft stability, permeability for the infusion process itself and enhanced mechanical performance. For infusion, Solvay developed PRISM EP2400, a single-part 180°C-cure, toughened epoxy with a low-viscosity/temperature profile that enables injection at temperatures as low as at 70°C. The resin offers a wet T_g of 150°C and — designed expressly for use in fabricating primary aerostructures — it has an infusion open time of about 8-10 hours, says Hill.

How it's done

AeroComposit operates two plants that fabricate composite parts and structures for the *MS-21*. The first, in Kazan, Russia, does the autoclave-based fabrication, such as ailerons, rudders, flaps, spoilers and air brakes, as well as the nose of the plane and the tailplanes. The other site is in Ulyanovsk, Russia, where the infusion work is done on the wings and wingbox in a 11,000m² cleanroom.

Irkut's decision to infuse the *MS-21* wing and wingbox dates back to the plane's launch in 2009. Irkut could have employed conventional prepreg/autoclave technology, but opted instead to

5 After finishing, a wingskin and stringers undergo nondestructive inspection operations.

6 The front and rear spars of the *MS-21* wing are laid up in one piece on a male mold using an MTorres system. Solvay says the PRISM TX 1100 material has proven uncommonly steerable, which means it can accommodate varying angular placement with no wrinkling. Thus, AeroComposit has avoided the more conventional practice of building spars that require angular displacements in separate sections that must be secondarily bonded/fastened.

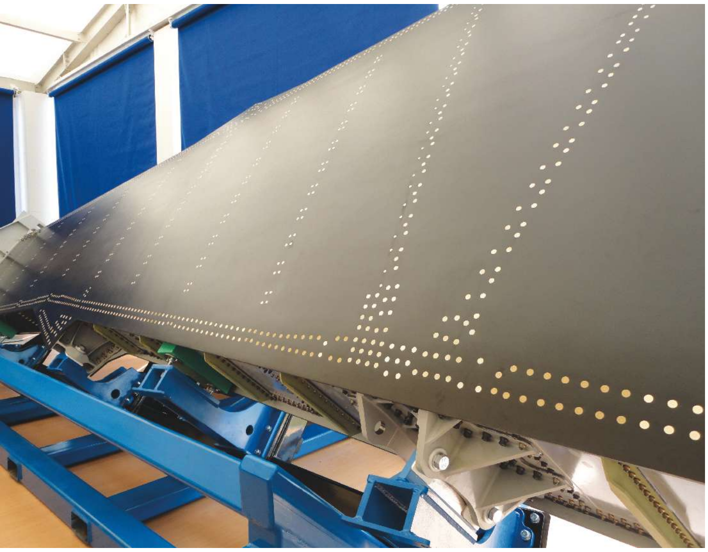
7 A cured spar undergoes ultrasonic nondestructive inspection. After inspection, the front and rear spar, the metallic ribs and the skins/stringers are assembled with mechanical fasteners.

leap-frog legacy materials and pursue first-of-its-kind infusion. It did not do so alone. AeroComposit had help not only from Solvay, but also, initially, from partners Diamond Aircraft (general aviation), aerocomposites manufacturer FACC (Ried Im Innkreis, Austria), automation specialist MTorres (Torres de Elorz, Spain) and infusion equipment specialist Stevik (Cergy, France).

AeroComposit did much of its own research and development to understand how use of infusion would affect wing design and manufacture. Anatoly Gaydansky, general director at AeroComposit, says trial and error was a consistent theme. "We encountered a lot of difficulties," he said. "First of all, the uniform permeability of such a large-sized part as a wing panel was a challenge. We were confronted with the task to fully exclude the possibility of dry spots and potential cracking that may occur in the process of thermosetting."

Maintaining tolerances for all manufacturing operations presented several difficulties, he says. These issues were partially addressed by adjusting and optimizing the manufacturing processes. In some cases, AeroComposit modified the infusion process, which in turn was followed by modifications in the tooling. The company also had to overcome springback when the part, after being freed from the tool, tended to change its geometry. "We were forced to introduce specialized devices and additional fixtures to improve the manufacturing accuracy at different stages," Gaydansky says. "It is a huge package of manufacturing solutions. Sometimes, when these measures proved to be insufficient, we had to introduce changes into the wing design."

Arguably, the most complex structures AeroComposit fabricates are the co-infused wingskins and stringers. Dry fiber-placed »



On the brink of big change

This photo of a fully assembled *MS-21* wing was taken at the 2012 Farnborough Air Show in Farnborough, UK. The wing was, at the time, in prototype stage. Since then, AeroComposit has manufactured 10 shipsets of the wings and wingbox (also infused) and has recently progressed to early production. The wing also has undergone static testing, with fatigue testing scheduled later this year. Source | *CW* / Photo | Jeff Sloan

separately, skins and stringers are then brought together for co-infusion. Wingskin layup is relatively straightforward and involves automated fiber placement (AFP) of the 0.25-inch Solvay PRISM TX 1100 dry fibers on an Invar tool, performed with a Coriolis Composites (Queven, France) AFP system using a KUKA Robotics 6-axis robot (Steps 1 & 2, p. 28).

Meanwhile, says Gaydansky, the stringers are also laid up via AFP as flat preforms, about 100 mm wide and in varying lengths, using the same PRISM TX 1100 material. Each flat preform is then hot-formed to create an L-shaped preform. "After that, the two L-shaped halves of a stringer are connected together, resulting in a T-shaped stringer," says Gaydansky. "Further on, using special equipment supplied to us by Dutch-Shape [Borne, The Netherlands], the part is cut to specified geometry and installed on the wing panel." Each stringer is supported on the skin by Invar tooling, which clamps together to maintain the desired T shape (Step 3, p. 28).

Gaydansky says AeroComposit uses vacuum bag infusion: "The technology developed by our company involves the installation of two membranes," he notes. "Besides, we are practicing our own patented scheme of vacuum bagging. One might as well say that we have created still another version of infusion technology, specially adapted for building large-size primary structural elements."

"After the stringers set is installed on the wingskin preform, it is wrapped in a number of auxiliary materials," Gaydansky says. "For bagging, we apply vacuum membranes, breathing and draining materials. Tubes are installed for resin supply and for vacuum level control. Finally, all is covered up with a vacuum-bag film which is secured and sealed along the perimeter of the preform, after which vacuum is applied." Infusion, he says, is done at 100°C, followed by cure at 180°C. AeroComposit uses a standard curing oven, supplied by a European manufacturer, that measures 6 by 22m. The entire infusion and cure process takes just less than 24 hours, followed by trimming, routing, drilling and cutting via a CNC machine (Step 4, p. 29) provided by MTorres. Finished wingskins are nondestructively inspected (Step 5, p. 29).

Meanwhile, in parallel, AeroComposit fabricates the C-shaped forward and rear spars. These also are made with the PRISM TX 1100 material, laid up on a male mandrel, using an MTorres AFP system (Step 6, p. 29). Infusion of the spars typically takes 12 hours, using the same cure profile as the skins/stringers. The thickness of the spars ranges from 6-14 mm, and they benefit, says Solvay's Hill, from the steerability and low bulk of the material.

"The microstructure of TX 1100 provides the ability for the tape to bond to the adjacent layer," he says. "In addition, the tape is able to manipulate without changing the form. As you steer the tape, you can recognize the limits of how much you can steer the tape by how much it starts to develop defects." This capability is important because, conventionally, composite spars are fabricated in sections, which are subsequently bonded or fastened together. This is necessary to accommodate direction and angle changes designed into the forward and rear sections of the wing. The steerability and low bulk of TX 1100, says Hill, allows AeroComposit to change directions and fabricate each *MS-21* spar as one structure.

> Comparable alternatives to styrenated products are available to those who wish to purchase them.

Nondestructive testing (NDT) is performed with one of two systems (Step 7, p. 29). The first is an ultrasonic system supplied by Tecnatom (San Sebastian de Los Reyes, Spain). It applies phased arrays via a 7-axis robot, using converters that were specially designed and manufactured for the AeroComposit-Ulyanovsk facility. The Tecnatom system is equipped with an automatic head changer to minimize touch labor. The second NDT system is a mobile Omniscan machine produced by Olympus (Waltham, MA, US). This water-based system uses C-scans and reportedly can scan at high speed to check quality and integrity.

Upper and lower wingskin/stringer structures and front and rear spars, when cured, are then joined with the metallic ribs. "This is performed in a customized, automated assembly jig procured from MTorres," says Gaydansky. "This is high-precision assembly equipment that allows us to position and fix large-size panels to the pre-assembled structural frame, composed of spars and ribs. Here, mechanical fasteners are used for attachment. Fixation of wing panels to the structural frame is implemented with titanium fasteners."

One of the biggest uncertainties facing the use of OOA infusion to fabricate large primary composite aerostructures revolves around questions of porosity. As is well known, the aerospace industry expects less than 2% porosity in its composite structures, which is typically easily achieved with autoclave cure. Can infusion, limited as it is by atmospheric pressure, meet that porosity threshold? Gaydansky says the infusion process developed by AeroComposit typically provides less than 1% porosity.

LEARN MORE

Read this article online | short.compositesworld.com/MS-21Wing

Going forward

AeroComposit has completed prototype manufacturing and is in early stages of production of the *MS-21* wings. Gaydansky says, "We have already accomplished the manufacturing of 10 shipsets of the outer wing. The full manufacturing cycle of composite parts, starting from the layup of the preforms and until they are delivered for assembly, takes, as of now, approximately two months."

As serial production ramps up, he says, the composite part cycle will take about one month. The assembly process, at the moment, requires four months; in serial production, it will be less than three months. Thus, the total time to build a wing, in production, is expected to be about four months. Gaydansky says the infused outer wings have completed static testing, which "demonstrated that the strength characteristics of the composite wing are not lower than the design values." Fatigue testing will be done later in 2018.

As an early adopter, AeroComposit, and by extension, Irkut, have done a significant amount of the troubleshooting required to apply new materials and processes to aircraft manufacturing, and they clearly have developed a viable system for wing and wingbox fabrication. The remaining challenge appears to be one of rate. How might the aerocomposites industry apply AeroComposit's lessons to other aircraft? Frank Nickisch, director of strategic projects, composite materials aerospace at Solvay, believes that just having applied infusion successfully is a major milestone. However, he contends, "The big challenge is cost and rate at the end of the day. I think a few things will need to come together to make infusion a winning solution: Mechanical performance, design integration, automation of manufacturing process. This will need to be really efficient. We need to get labor out to be really cost-competitive." CW

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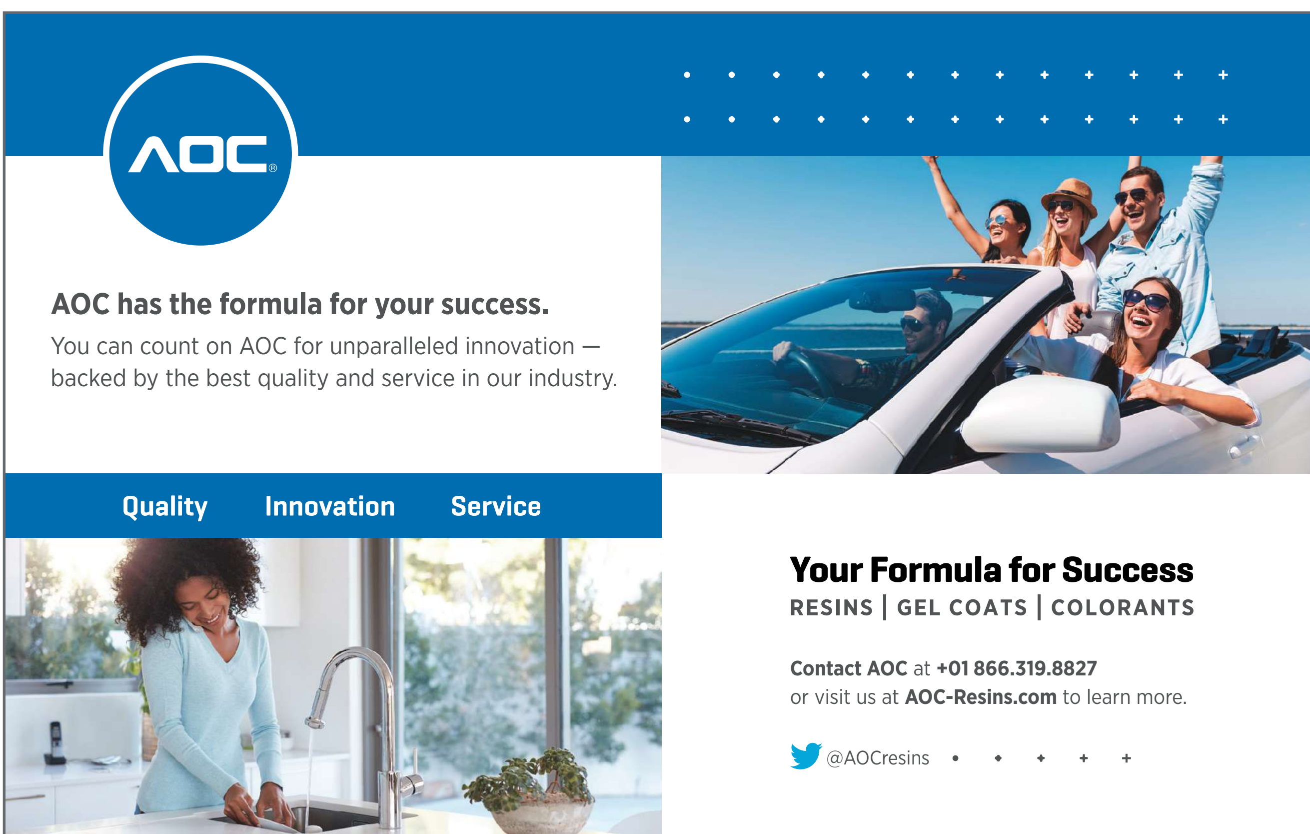
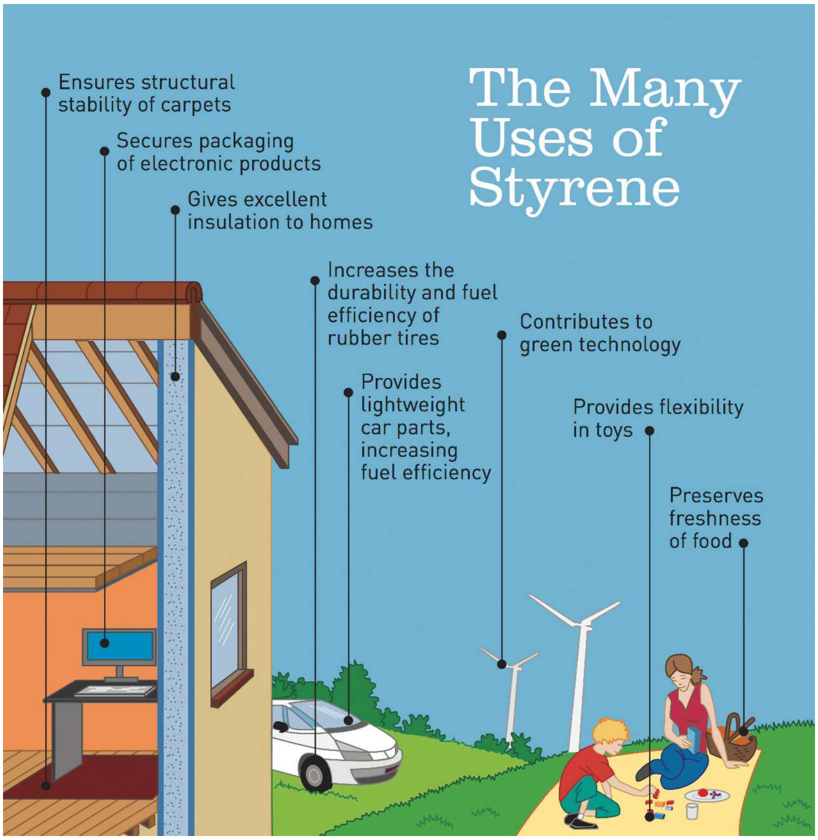


US styrene-reduction mandates: Go or no-go?

Legislative changes are slow in coming, but technology forges ahead.

By Peggy Malnati / Contributing Writer



Styrene: Can it be used safely?

The issue of whether styrene's listing/status should be changed is both subject to scientific interpretation and capable of having a potentially great economic impact — especially on some of the highest-volume segments of the plastics and composites industries. Source | Styrene Information & Research Center

» It's been seven years since the US National Toxicology Program (NTP) listed styrene in its "12th Report on Carcinogens (RoC)" (*Federal Register*, June 2011) as "reasonably anticipated to be a human carcinogen." What's happened in the North American composites industry since that time? *CW* set out to answer that question. Since styrene was added to the NTP's RoC, activity has progressed on two fronts. On the first, resin manufacturers have worked to replace styrene with alternatives that are less likely to pose regulatory challenges. On the second, composites industry lobbyists and scientists have advocated removal of styrene from the RoC — that is, they are pursuing elimination of the classification— arguing that styrene's threat to human health has been overstated. To make an already complicated topic more complex, there are a variety of groups involved in this issue. These include regulators, such as the US Environmental Protection Agency (EPA) and various state authorities, as well as other governmental agencies that don't regulate (such as NTP). There also are trade associations and nongovernmental organizations (NGOs), many of which are engaged in activities *CW* will cover here.

It's important to emphasize that NTP is *not* a regulatory body, so it doesn't set regulations. Rather, its charter is to provide information about *potentially* toxic chemicals to regulatory agencies and other health-related research groups. (This information could subsequently prompt regulatory agencies to consider limiting exposures or uses of a substance.) It's also important to point out that NTP assessments are hazard assessments, not formal, quantitative assessments of risk. A hazard assessment differs from a risk assessment. Specifically, *hazard* refers to a substance's *potential* to cause an adverse effect but *does not consider the exposure level at which an effect might actually occur*. "Risk" refers to the *likelihood* that harm will actually occur by *looking at both potential hazard and actual exposure*. This critical distinction often is the crux of the issue. Although globally, regulatory decisions are based on risk, in the US, various governmental regulatory and nonregulatory agencies and NGOs at both the federal and state levels use NTP's hazard assessments *as though they were* risk assessments, which they are not.

Impacts on legislation

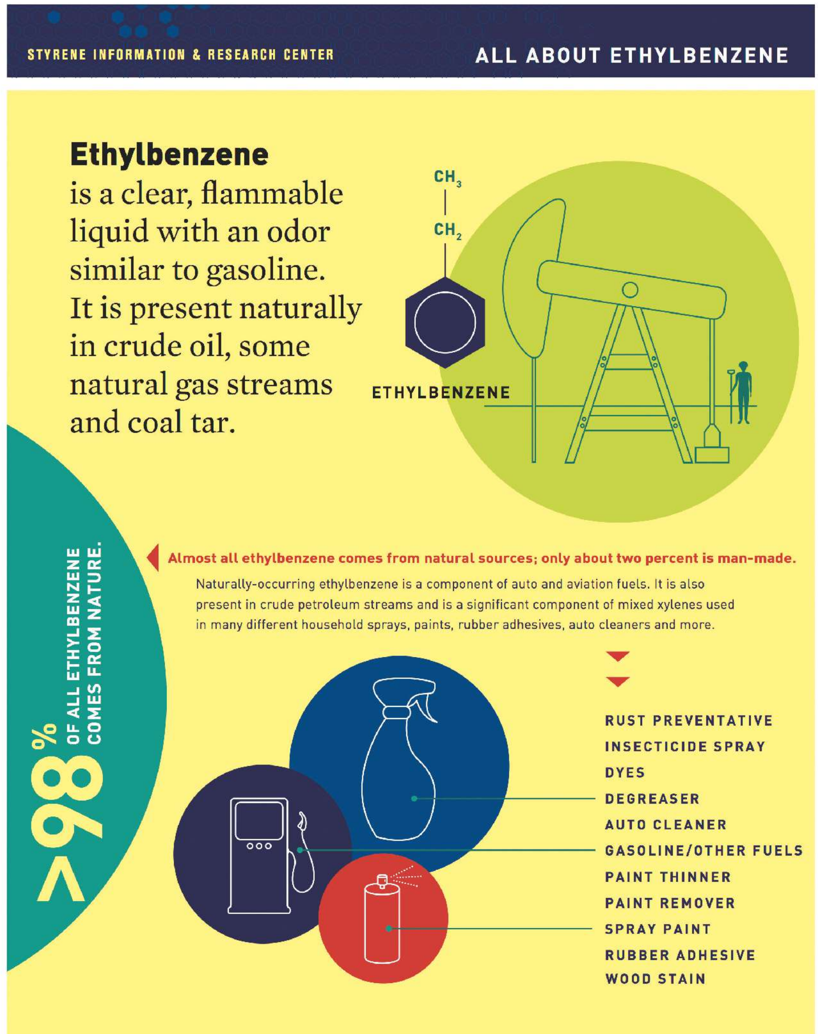
Are they right? Should styrene's classification/status be changed? The answer is subject to scientific interpretation, and how those interpretations play out in the regulatory realm can have potentially significant economic impact — especially in some of the highest-volume segments of the plastics and composites industries.

Styrene is the subject of divided opinion. Its odor is unpleasant, and many health organizations recognize that chronic, unprotected exposure to relatively high levels of styrene can lead to health issues, ranging from headaches, fatigue/weakness, depression and respiratory and gastrointestinal irritation to hearing loss, kidney damage and even death at extremely high exposure levels (see Learn More, p. 38). Critics, however, contend there is *no* solid evidence that *properly protected* workers in the manufacturing environment, let alone consumers in proximity to products made with styrene, will suffer harm from styrene exposure. Interestingly, styrene naturally occurs in a variety of common foodstuffs and in a major tree genus (see the Side Story on p. 34).

A significant example of regulation with potential economic impact is a European Union (EU) legislative package passed in December 2006 that is beginning to phase in now. Designed to reduce exposure to many chemicals, including styrene, the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulations are described by the European Chemicals agency as "improving human health and the environment from the risks posed by chemicals while enhancing the competitiveness of the European chemical industry." Many composites supply-chain members with business in both the EU and North America are watching REACH carefully, unsure how it will affect their own businesses or that of their European customers.

"In the EU, styrene is classified as a developmental toxicant, and an occupational exposure limit of 20 ppm for an 8-hour average is recommended," notes John Schweitzer, senior manager with the American Composites Manufacturers Assn. (ACMA, Arlington, VA, US). "The same data available to the EU was reviewed in 2006 by US regulators, who concluded that styrene presents 'negligible concern for adverse developmental or reproductive effects.' Accordingly, any impact of EU regulations on US manufacturers is not driven by regulatory or health concerns."

In the US, the Styrene Information & Research Center (SIRC, Washington, DC, US) reports that legislation and regulation related to styrene and governing its manufacture, sale, transportation, use and disposal can and do vary between federal and state levels and from state-to-state. (A nonprofit organization with membership that comprises 95% of the North American styrene industry, SIRC describes itself as the leader in ongoing research, setting guidelines and advocating for science-based regulatory treatment of the chemical as necessary. SIRC says it has conducted more than US$20 million of research over the past 30 years to better understand styrene's potential impact on both health and the environment.) Groups like ACMA and SIRC have established what they call common-sense guidelines for »



Styrene monomer: Important industrial role

Styrene monomer is a very important reactive diluent for thermoset resin suppliers and compounders that work with vinyl ester and unsaturated polyester. And (poly)styrene polymer is used in many thermoplastic resins. Properly called ethenylbenzene, styrene monomer also is used in many commonly available commercial products (listed in the graphic). Interestingly, styrene is naturally found in a wide range of foodstuffs as well as a major genus of trees. Source | Styrene Information & Research Center manufacturers about the types of protection workers should use, and have published information employers should consider when setting exposure limits and workplace practices for employees.

SIRC notes that styrene emissions are covered under the US Clean Air Amendments of 1990, which regulate air emissions of styrene and other substances classified as hazardous air pollutants (HAPs). Enforcement of these federal standards is done at the state level via issuance of operating permits to facilities that emit HAPs. Additionally, SIRC says nine states have established their own regulations for the chemical, using health-based emissions standards/guidelines, with a minimum of four of those states using "at least partially outdated information provided by the US EPA in the 1980s."

SIDE STORY

Styrene ≠ polystyrene: An important distinction for composites

Definitions are important when discussing technology. Although often used interchangeably, the terms styrene and *poly*styrene refer to *different* materials. Preferentially called ethenylbenzene by the International Union of Pure and Applied Chemistry (IUPAC, Zürich, Switzerland) and also known by nine other common names, styrene ($C_6H_5CHCH_2$ or C_8H_8) is a thick, colorless and sweet- but strong-smelling monomer derived from benzene. Polystyrene ($(C_8H_8)_n$), on the other hand, is a *solid* thermoplastic polymer made up of a great many repeating units of the styrene monomer.

Notably, styrene occurs naturally in such common plants as sweetgum-genus tree sap and foodstuff, such as cinnamon, coffee beans, peanuts, beer, beef, wheat, oats, strawberries and peaches. Further, it is found in coal tar, a byproduct of coke and gas production from coal, which, itself, is formed from fossil plants. Presently, 98% of all ethenylbenzene is extracted from *natural* products; only 2% is currently synthesized.

Polystyrene is an important polymer used to produce other thermoplastic copolymers, including acrylonitrile butadiene styrene (ABS), styrene acrylonitrile (SAN), acrylonitrile styrene acrylate (ASA) and, of course, foam polystyrene — the latter informally and often incorrectly called by The Dow Chemical Co. (Midland, MI, US, now DowDuPont Inc.) tradename, Styrofoam. Styrenic thermoplastics are known for their excellent surface aesthetics, good stiffness and their good adhesion to both paint and plating, making them an important class of polymers for aesthetic applications in industries that range from packaging to small appliances to automotive trim.

On the thermoset side of the business, styrene monomer is commonly used as a reactive diluent (solvent) in vinyl ester or unsaturated polyester resins and gel coats. "The curing reaction that transforms a liquid mixture of resin, glass, fillers and other materials into a solid, durable composite product involves the crosslinking of vinyl ester and unsaturated polyester molecules by styrene," adds John Schweitzer, senior manager with the American Composites Manufacturers Assn. (ACMA, Arlington, VA, US). "Styrene is a uniquely capable and cost-effective reactive crosslinking agent for these resins."

Air-quality emissions limits can restrict manufacturers' ability to expand production of products that, for example, use styrene in the manufacturing process. Since higher production levels can mean higher emissions of styrene, manufacturers must sometimes choose between trying to increase the emission limits in their air-quality permits, which can be time-consuming and costly, or switching to more-expensive, lower-emitting materials or processes. "Research compiled by SIRC continues to show that styrene is unlikely to cause cancer or any other serious health impact in humans if normal safeguards are followed," adds ACMA's Schweitzer. He notes that, in any case, growing businesses could find that they risk exceeding styrene or other VOC emission limits in their state operating permits, and then opt for increased use of lower-volatility resins. "However," he contends, "this would be in response to regulatory and economic considerations and not health concerns."

Some states also have enacted legislation that seeks to limit "chemicals of concern" based on lists developed by the US EPA, NTP, the EU or other authorities. SIRC notes that "styrene often is included in such lists but has not been identified, to date, as a candidate substance for further action by any US state that has developed a list of this type." For example, in 2008, the *Texas Commission on Environmental Quality (TCEQ) Review* concluded that its existing "fence-line" exposure limit to styrene of 110 µg/m³ (based on odor detection) would be left as is. TCEQ reportedly conducted "a comprehensive review of scientific information related to styrene and styrene's potential to impact human health" and concluded that "data are inadequate for an assessment of human carcinogenic potential."

On the other hand, California passed a ballot initiative called the Safe Drinking Water and Toxic Enforcement Act of 1986, also known as Proposition (Prop.) 65, in November 1986. That law aims to protect the state's drinking water from sources of chemical contamination "known to cause cancer, birth defects, or other reproductive harm" by maintaining and updating a list of chemicals "known in the state of California to cause cancer or reproductive toxicity" and also to provide warnings to consumers who may come into contact with products that contain the listed chemicals. The law requires manufacturers who use these chemicals to inform Californians about potential exposure risks. California EPA's Office of Environmental Health Hazard Assessment (OEHHA) announced in February 2015 that it intended to add styrene to the Prop. 65 list of chemicals of concern, based on NTP's classification of styrene in 2011.

Prop. 65 has different guidelines and requirements relating to different types of contact with chemicals such as styrene: for example, occupational (job-related) exposure, environmental releases to the state's waters, and consumer exposures from use of finished products. If a consumer's estimated average daily styrene exposure (over a lifetime of 70 years) from any consumer product containing styrene is below the 27-µg/day threshold, a warning label is not required; if exposures are higher, a warning label is required. Again, according to SIRC, OEHHA established a State Public Health Goal for styrene of 0.5 ppb in drinking water, yet at the end of the state's own tests of

15,000 samples of drinking water, styrene was undetectable in all but a single sample.

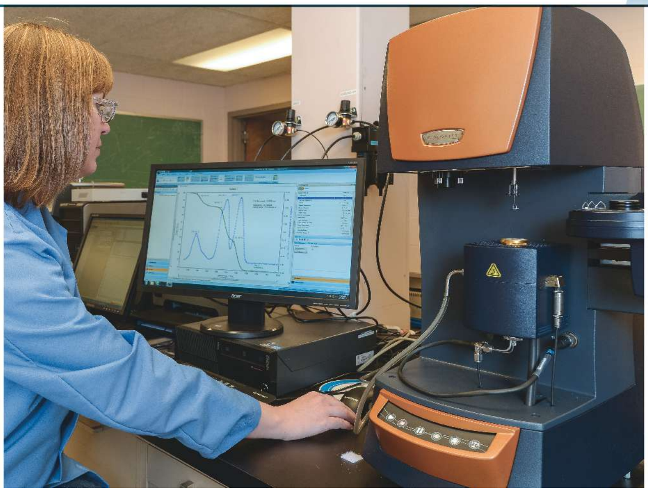
"We maintain that the scientific basis that OEHHA used to set the very-low PHG for styrene … is neither appropriate nor scientifically supportable … because research available to OEHHA at the time it established the PHG indicates that finding of lung tumors in mice — but not in rats or humans — exposed to styrene is not relevant to human risk assessment," explains Ray Ehrlich, SIRC executive director. "This view is similar to the conclusion reached by the EU and several other regulatory agencies." (See Learn More.)

Two other organizations that potentially could impact perceptions about styrene's potential health impacts include the American Conference of Governmental Industrial Hygienists (ACGIH, Cincinnati, OH, US) and the International Agency for Research on Cancer (IARC, Lyon, France), part of the World Health Organization (WHO). Earlier this year, an ACGIH committee announced it might recommend reducing its 8-hour exposure limits for styrene to 2 ppm; ACGIH has stated it will determine how to respond to its committee's recommendation by year's end.

ACGIH sets suggested workplace exposure limits, or threshold limit values (TLVs), for certain chemicals. The TLVs, along with other information, are intended to be used by industrial hygienists to guide worker-protection efforts. "If a state uses the proposed TLV guidelines when setting its own standards, then this could affect the industry," says Fletcher Lindberg, marketing VP at resin manufacturer AOC LLC (Collierville, TN, US), as well as current chair of SIRC. "However, right now we don't know what kind of impact the change might have, if any, or if the proposed reduction will be adopted by ACGIH."

The ACGIH's recommended limit on styrene isn't binding, he notes, but it could eventually be used by insurance carriers when writing policies for manufacturers. "In the short term, it may have limited impact, although it does suggest that the trend will be toward more rules and regulation for styrene in the future," Lindberg adds.

At its March 2018 Monograph meeting, IARC upgraded its classification of styrene from Group 2B ("possibly carcinogenic to humans") to Group 2A ("probably carcinogenic to humans"). However, a full report on the IARC Monograph, which will include the panel's rationale and decision to reclassify, will not be available until 2019. "[Like NTP], IARC classifications are based on *hazard* assessments, not *risk* assessments," explains Ehrlich. "So, IARC classifications are not indicators of real-world potential risk. The mere presence of, or exposure to, a chemical is not an indication of risk or potential harm." SIRC contends IARC's upgraded classification is not supported by a complete review of the available science. "The safety profile for styrene has not changed," Ehrlich adds. "IARC Monographs have limited utility for national regulators. However, some states do reference IARC classifications when making their own regulatory determinations." Ehrlich says SIRC opposes any classification of styrene based on a hazard assessment only, rather than a quantitative risk assessment because hazard assessments are typically based on findings arising from extreme conditions that do not represent typical use or »



Finding and offering alternatives

Significant work over the past decade by SMC resin suppliers and compounders has been devoted to reducing resin styrene content, finding alternative diluents to replace styrene in whole or in part, to switching from solvent-based to hot-melt compounding systems, and/or to using resin matrices other than vinyl ester and unsaturated polyester. The result is a range of SMC product options for customers in a variety of industries should regulations on styrene be tightened further. In this photo, Laura Littlejohn, scientist at Ashland LLC (Columbus, OH, US), uses thermogravimetric analysis (TGA) to measure weight changes at temperature and over time in SMC samples to evaluate composition analysis and thermal stability.

Source | Ashland LLC

Styrene-free alternatives

Another way SMC resin suppliers and compounders are responding to concerns about tighter styrene limits is by switching to alternative resin systems. One example is the LYTEX SF family of SMC grades from A. Schulman Inc.'s Quantum Composites portfolio (Bay City, MI, US), which uses epoxy instead of vinyl ester or unsaturated polyester. Available reinforced with either chopped carbon fiber or glass fiber, the resins are styrene-free, low-VOC and low-odor. The company reports the materials are simple to process (reducing system costs) yet offer excellent surface appearance and outstanding thermo-mechanical properties, making them ideal for lightweighting solutions. Source | A. Schulman Inc.

Preparing for the worst case

Anticipating more stringent styrene regulations, thermoset and thermoplastic resin suppliers and compounders have been developing low- and no-styrene/VOC polymer formulations. For example, resin supplier Polyscope Polymers BV (Geleen, The Netherlands) offers a portfolio of styrene maleic anhydride (SMA) copolymers and styrene maleic anhydride N-phenylmaleimide (SMANPMI) terpolymers designed to address the need for styrenic engineering plastic compounds with higher temperature resistance and lower VOCs. These neat resins are available under the brand names XIRAN SZ and XIRAN IZ and are used to boost thermal performance in styrenic thermoplastic compounds such as ABS and ASA. Source | Polyscope Polymers BV

exposure and often are not based on the weight of the entire body of scientific evidence. Additionally, the use of hazard assessments only sets precedents that other groups may follow."

Thermoset technology changes

Thermoset resin suppliers and compounders who work with vinyl ester (VE) and unsaturated polyester (UP) have not waited for additional styrene regulations, but have instead prepared for them by introducing alternative diluents, changing compounding methods, or entirely reformulating resin systems as not only styrene-free but also low-VOC/low-odor.

"We're doing a significant amount of work to address a variety of customer needs in different markets," notes Laura Gigas, senior product manager – transportation at Ashland LLC (Dublin, OH, US). "For example, we've developed styrene-free versions of our products for every market, using alternative monomers or even [styrene-] monomer-free versions of products. [Styrene-] monomer-free products for prepreggers or SMC compounders would entail switching from solvent-based compounding to hot-melt systems."

She acknowledges that not everyone has the equipment necessary to use those types of products, so another approach Ashland has taken is to use a combination of proprietary technologies to drive the conversion of styrene during resin crosslinking to higher levels (as measured by differential scanning calorimetry), leaving less unreacted styrene and hence reducing VOCs. "In SMC, we now have grades where we can drive cure from a typical 95% to a higher level of 99.7%," Gigas adds. "Interestingly, we see slightly better mechanicals with these alternative-monomer products vs. those using styrene, but they're still close to our conventional grades. And because styrene is cost-effective, and a very effective reactive diluent, a third approach we've taken is to develop lower-VOC, lower-odor versions that replace a portion of the styrene with alternative diluents of lower volatility. We've found we can retain 20-30% styrene but reduce volatiles from 3,000-5,000µg/bag to 10-50. That minimizes impact on the customer, and those products perform just as well as styrenated versions — regardless of whether you're using open-mold, pultrusion or compression molding."

"Polynt-Reichhold has been a leader in reducing VOC and styrene content for over 20 years," explains Steve Voeks, North American R&D director, Polynt-Reichhold Group (Carpentersville, IL, US). He cites the low-styrene/low-VOC gel coats and UP resins the group commercialized in the 1990s prior to the activation of Maximum Achievable Control Technology (MACT) standards codified in Title III of the 1990 Clean Air Act Amendments. He also points to the group's work developing and promoting low-cost, closed-mold technologies with inherently lower emissions, plus development of numerous technologies to remove all styrene and, in some cases, most VOCs in advance of regulatory requirements. "We have a strong, market-facing strategy to address customer needs for the foreseeable future — even in the face of more stringent styrene regulation," Voeks adds. "Using a combination of strategies and working closely with trade associations and regulatory officials, we've arrived at achievable goals for gel coats as well as resins and we continue to develop new chemistry and other technologies that will provide further reductions." Depending on the market and its requirements, the group has either reformulated existing resins by replacing some or all of the styrene with alternative reactive diluents, or has developed new diluent-free resins with low odor under the Polylite HS tradename.

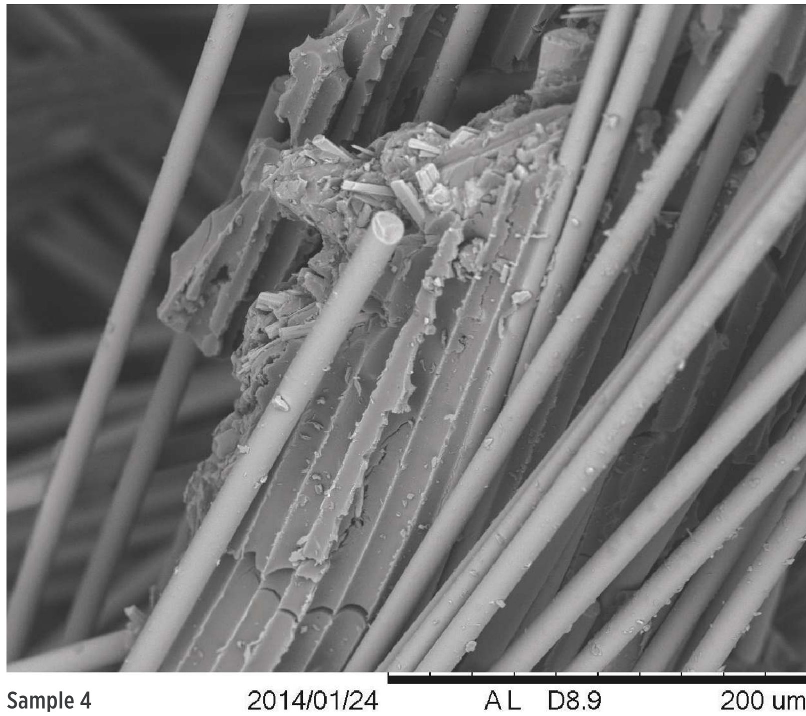
"Our early products with reduced styrene or alternative monomers were less user-friendly and offered lower performance vs. high-styrene formulations," he notes. "However, over the last

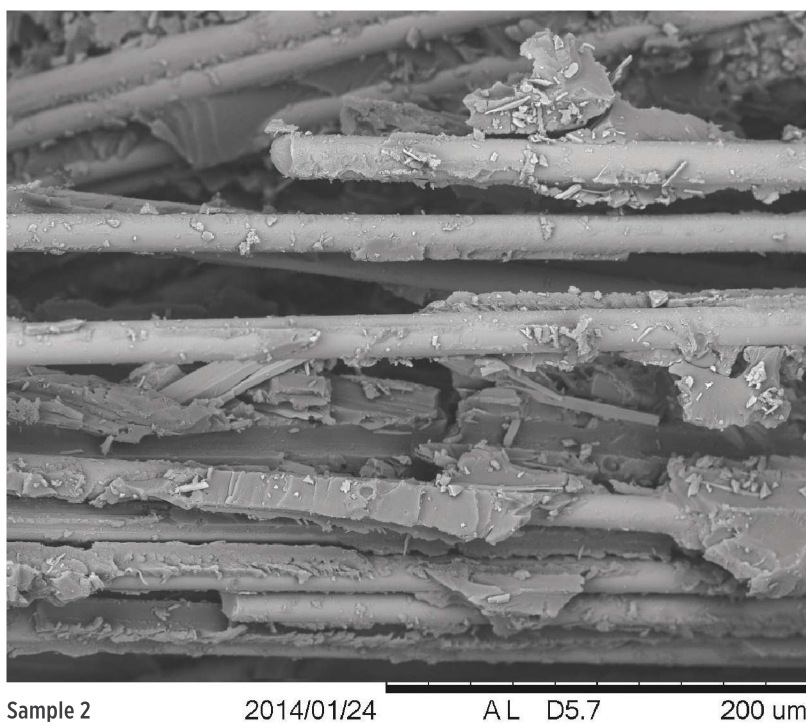
10 years, we've designed new polymers and formulations that overcame these issues. As it stands today, we have a broad range of MACT-compliant products meeting the requirements of composites applications. Our products are being used in industries ranging from automotive interiors to cured-in-place pipe for residential neighborhoods." Voeks says the group's R&D team will continue working closely with customers to understand their needs, to reduce or eliminate styrene and to develop technical solutions based on cost vs. performance metrics. He adds that managing the supply chain for alternative monomers is critical for security of supply and cost.

Doug Gries, market development director – Engineered Composites & USCAN at A. Schulman Inc. (Fairlawn, OH, US), says the company has received specific requests from automotive and aerospace customers — especially those in the EU — to develop high-performance products with low outgassing, reduced VOCs and low odor. "In response to changing customer and market demands, A. Schulman has recently launched its Quantum LYTEX SF line of styrene-free, epoxy-based SMC," adds Gries. "Anticipating further changes in the market, we're planning to launch a global initiative to develop and commercialize an entirely styrene-free portfolio comprising standard products and custom formulations to meet evolving application needs for lower styrene and other VOCs. Plus, we also plan to offer a range of low-styrene formulations with lower VOCs. We pride ourselves on our innovation and willingness to listen to what customers and markets are telling us. We're committed to working with our supply base on raw materials that help move the industry in a desirable direction."

"Styrene is a major commodity chemical and, as a raw material, it is very important to the composites industry, although its use in composites is, overall, a very-small part of the overall styrene market," explains AOC's Lindberg. "Industry has used styrenated composites for decades and styrene has been heavily studied in terms of its overall health effects. It's noteworthy that many of these studies are relatively positive toward styrene."

He notes that so far, the EU and Prop. 65 regs haven't caused significant changes in how AOC goes to market, but if future regulations require different formulations, then the company will be ready. "Almost 20 years ago, when the potential »





Replacing styrene in resins and sizings

Work by resin suppliers and compounders to reduce or remove styrene and other VOCs from their polymers has had an impact on fiberglass suppliers, too. Owens Corning Co. (Toledo, OH, US) reports that during the past 10 years, it has significantly reduced VOCs and styrene in its facilities. Further, its fiber sizings, which these scanning-electron micrographs show, make the difference between poor (top) and good (bottom) bonding of fiberglass and the resin matrix. These sizings were reformulated and have been styrene-free for seven years. Source | Owens Corning for increased styrene regulation became a real possibility, AOC developed styrene-free analogues for our entire product line using different reactive diluents and alternative raw materials ingredients," Lindberg explains. "We did this for contingency purposes and because many customers wanted to test these alternative products for efficacy. In most cases, they found performance was comparable with current styrenated products, although they were more expensive." He adds that these alternative formulations are currently available for customers who wish to purchase them and could be produced in significant quantities should styrene regulations tighten in the future.

Lindberg also notes that two considerations currently cause the most requests for lower-styrene products. "Many of our clients have permits for emissions, so if business is good and it looks like they'll exceed their production limits, which would put them out of compliance, then they'll often purchase products with less styrene," he adds. "Also, in the case of cured-in-place pipe for sewer rehabilitation, we've seen increases in the number of installations that use styrene-free resins, which is typically the result of specification preferences by some engineers at various municipalities and engineering firms."

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Thermoplastic technology changes

Restricting or eliminating styrene monomer would not just affect thermosets, but also many thermoplastic resins and compounds, so what is that side of the industry doing about the situation?

"I don't expect that styrenic resins will be phased out completely in the near future," states Patrick Muezers, managing director, Polyscope Polymers BV (Geleen, The Netherlands). "Concerns about styrene will most likely lead to requirements for lower VOC levels in resins and compounds, which already is the case in the automotive industry. Products with lower VOCs are seen as higher-value products. At Polyscope, we've already introduced XIRAN IZ, a heat-boosting additive for ABS [acrylonitrile butadiene styrene] and ASA [acrylonitrile styrene acrylate] resins with lower VOC levels than alternatives and with similar or better performance. We will continuously support the industry by developing innovative solutions, such as products with lower VOCs."

LEARN MORE

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

The hazards of styrene are enumerated online by the US Occupational Safety and Health Admin. (OSHA) | osha.gov/SLTC/styrene/hazards.html

Read more online about Public Health Goals (PHG) determinations by regulatory agencies | styrene.org/science/human-health/

"We're putting more low-VOC materials into our product line, and new business is already coming from these grades — especially in the EU automotive market," notes Brian Grosser, VP – North American Automotive for LOTTE Advanced Materials Inc. (Seoul, South Korea). He notes they've had to change some ingredients to comply with EU REACH requirements. He also says that most automakers already include lower VOCs in their specs for interior trim parts. "Of course, they want these improved materials at the same or lower cost than their predecessors," he quips.

He too believes that styrenic resins won't be phased out as long as industry needs aesthetic surfaces achieved via secondary operations like painting and plating. "Also, in many cases the physical properties of styrenic polymers are superior to those of other [thermoplastic] resin families." He acknowledges that materials selection will change on an application-by-application basis and will follow technology improvements in the industry. "We will keep providing innovative materials solutions for the automotive industry," he adds.

Reinforcement technology changes

Interestingly, work by thermoset and thermoplastic resin suppliers to reduce or remove styrene from their polymers has impacted fiberglass suppliers, too. "Over the last decade, we've significantly reduced VOCs and styrene in our facilities and all our sizings have been styrene-free for the past seven years," reports Anne Berthereau, VP, innovations, Composite Solutions Business at Owens Corning Co. (Toledo, OH, US). She says the company has made significant investments to commercialize products that are formaldehyde-free as well as styrene-free. "As news of new domestic regulations continue to pulse, we've intensified our innovation efforts to deliver optimal efficiency and performance in low-VOC and styrene-free resins," she adds. "Creating solutions that grow our customers' business is always top-of-mind for Owens Corning and doing so in a way that positively impacts the communities in which we live and the world around us is paramount."

What's next?

For now, it's a wait-and-see game. Will styrene regulations tighten or stay as they are? "At the end of the day," AOC's Lindberg sums up, "styrene is a pretty important component for making composites work well. It's a relatively low-cost ingredient that is also a very effective reactive diluent. As a raw material ingredient, styrene does its job well and replacing it altogether will be very disruptive for the marketplace. Nonetheless, if regulations or customer preferences change, we'll comply with all requirements and make sure our products meet or exceed customer expectations." CW

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Composites Events

Aug. 19-22, 2018 — Lausanne, Switzerland
12th International Conference on Sandwich Structures (ICSS-12)
icss12.epfl.ch

Aug. 21-22, 2018 — Kaysville, UT, US
Fly Away with Composites – Advanced Materials and Processes Workshop
eventbrite.com/e/fly-away-with-composites-tickets-43170265426

Aug. 21-23, 2018 — Detroit, MI, US
7th Annual Global Automotive Lightweight Materials Summit
global-automotive-lightweight-materials-detroit.com

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

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

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

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

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

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

Sept. 13-15, 2018 — Xiamen, China
BIT's 7th Annual World Conference on Advanced Materials (WCAM-18)
bitcongress.com/wcam2018/default.asp

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

Sept. 25-28, 2018 — Hamburg, Germany
Global Wind Summit 2018/WindEnergy Hamburg
wind_europe.org/summit2018

Oct. 1-3, 2018 — Atlanta, GA, US
2018 Polyurethanes Technical Conference
polyurethane.americanchemistry.com/2018-Polyurethanes-Technical-Conference.html

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

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

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

Oct. 25-27, 2018 — Istanbul, Turkey
Eurasian Composites Show
eurasiancomposites.com/2018/event-brochure

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

Oct. 31-Nov. 1, 2018 — Birmingham, UK
Advanced Engineering UK 2018
thenec.co.uk

Nov. 5-6, 2018 — Stuttgart, Germany
4th Int'l Composites Congress (ICC)
composites-germany.org/index.php/en/dates/4th-icc

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

Nov. 14-15, 2018 — Vienna, Austria
German Wood-Plastic Composites Conference
10times.com/wood-plastic-composites

Nov. 14-16, 2018 — Seoul, Republic of Korea
JEC Asia
jeccomposites.com/events/jec-asia-2018

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

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Workplace safety is important in the composites and high-performance materials manufacturing industries. And, there are simple steps you can take to insure your employees are protected from materials and chemicals. Composites One is renowned for its commitment to safety and has partnered with some of the industry's leading personal protection experts to highlight the latest in Personal Protection Equipment (PPE). Technology will be featured from 3M, DuPont, and Ansell. You will also get a brief summary of the regulatory issues facing the composites and high-performance materials industries today presented by the Composites One Health, Safety, and Environment (HSE) department.

PARTICIPANTS WILL LEARN:

- Safety Clothing and Its Uses
- Why Respirators? & Fit Testing
- Hand and Eye Protection
- Regulatory Compliance
- Overview

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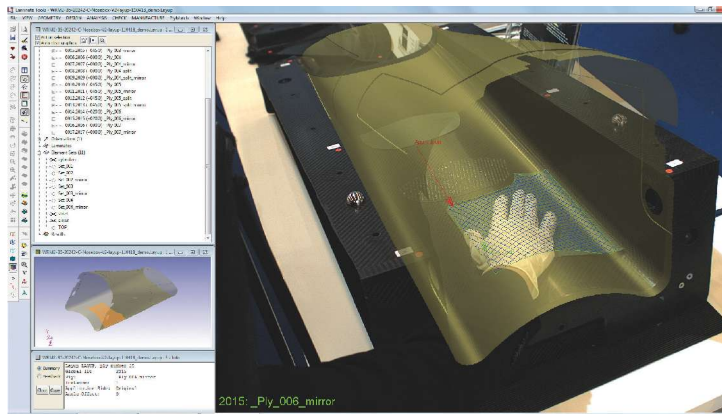
New Products

» COMPOSITE LAMINATE DESIGN & ANALYSIS SOFTWARE

Laminate tools software update



Anaglyph Ltd. (London, UK) has announced the release of Laminate Tools Version 4.8, in which it introduces a number of new features in the software's Design, Analysis, Check and Manufacture modules.

The new version features a new option for ply forming and a new mesher for CAD import. Functions to manipulate the mesh, plies and layup have been improved. Other additions include H3D FEA results import, as well as support for Rhino v6 and Abaqus 2018. Across the board, modules have been enriched with features based almost exclusively on user input. (Detailed information on this is available online | **www.anaglyph.co.uk/lt_versions.htm**

Laminate Tools is a standalone Windows application that is intended to address the entire Geometry Import-Design-Analysis-Check-Manufacture process of composites structural design. It is designed to link the various disciplines, communicate original data between all involved in the process and save valuable team time. Laminate Tools reportedly interfaces with most CAD and FEA applications, allowing for a flexible workflow. It is used by composite structures designers and stress analysts in automotive, aerospace, marine, energy and leisure markets. **www.anaglyph.co.uk**

» THERMOSET RESINS & ADHESIVE SYSTEMS

Covalent bonding aerospace adhesive

Solvay (Alpharetta, GA, US) has launched FusePly, a new bonding technology designed specifically for use in prepreg-based aerospace composites fabrication applications.

Solvay developed FusePly to enable the build of reliable, bonded composite parts using conventional manufacturing processes, through the creation of covalently bonded structures, thus offering the potential for eliminating the need, in terms of part certification, to ensure sufficient bond strength through the use of rivets or other fasteners. The adhesive reportedly addresses the manufacturing challenges faced by aircraft builders looking for improved performance, build rates and lightweighting.

Solvay contends that FusePly offers users a clear step-change in bonding performance and resulting benefits:

• *Improved reliability:* Through the creation of chemical bonds, it reportedly enables part manufacturers to have increased confidence in bonded structures.

• *Higher part performance:* Compared to mechanical fasteners, FusePly offers higher performance because drilling holes into fiber-reinforced structures introduces structural damage and creates stress concentrations that ultimately reduce the load capacity of the part.

• *Lightweighting:* The reduction and replacement of fasteners with FusePly bonding will substantially reduce the overall weight of the aircraft.

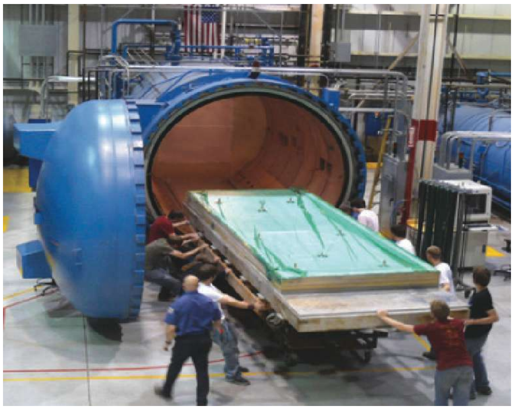
• *Greater design freedom:* Adhesives offer much greater design flexibility in terms of manufacture and assembly at lower cost. FusePly, Solvay maintains, can easily be integrated into existing manufacturing processes as an upgrade for conventional surface preparation methods.

solvay.com

» PUBLICATIONS, VIDEOS & RESOURCE MATERIALS

Urethane board material selection guide

Coastal Enterprises (Orange, CA, US) has rolled out its *Material Selection Guide*, which customers can use as a guideline for choosing the best density of its variety of Precision Board high-density urethane board products for a particular job. Examples of how the guide can help are in scenarios such as those where one must determine if a Precision Board low-temperature (PBLT — continuous to 200°F) or Precision Board high-temperature (PBHT — continuous to 300°F) product is needed.



The information in the *Guide's* chart represents PBLT and PBHT densities ranging from 4-75 lb/ft^3, used in a variety of applications, including signage, sculpture, theme parks, tooling, prototypes and autoclave tools.

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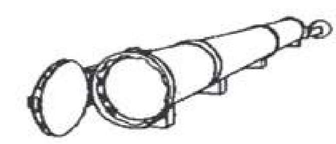

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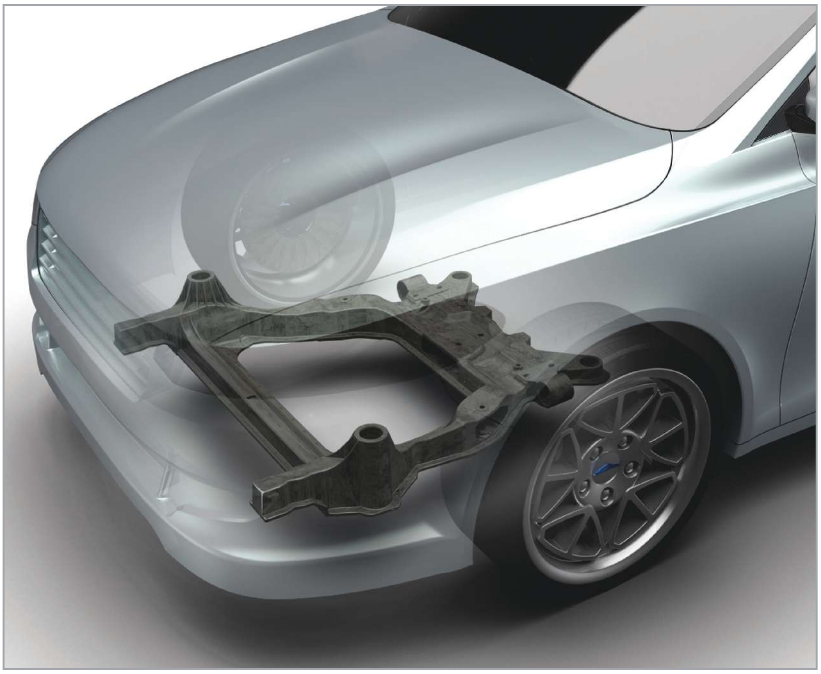
ADVERTISING INDEX

Teaming to define what automotive CFRP could be

Ford and Magna explore a high-volume chassis front subframe built from co-molded chopped fiber and noncrimp fabric SMC

By Ginger Gardiner / Senior Editor



High-volume CFRP front subframe

OEM Ford teamed with Magna International to explore how much weight could be removed in a high-volume (200,000/yr) vehicle front subframe by using as much carbon fiber as possible — revealing limits, challenges and new technology solutions. Source (all photos) | Magna International

» Carbon fiber-reinforced plastic (CFRP) body frame/chassis components have been used in high-end sports and racing cars for decades. Their performance and lightweight enabled more recent expansion into higher volume production models, including BMW's *i3*, *i8* and *7 Series* models, as well as Audi's new *R8* and *A8* luxury sedans. However, most of these parts, including roof rails and cross members, lower side sills, B-pillars and rear walls, use continuous fiber.

Ford Motor Co. (Dearborn, MI, US), in a joint research project with Magna International (Aurora, ON, Canada), has developed a carbon fiber composite subframe made using a sheet molding compound (SMC) that combines continuous *and* chopped fiber SMC. The application is novel, because the subframe, located in the front of the car, supports the engine and chassis components, including the steering gear and the lower control arms that hold the wheels and, therefore, takes significant loads.

"There were dozens of engineers involved in this project," says Brian Krull, global director of innovation for Magna Exteriors. "We had structural engineers, manufacturing engineers, testing engineers, product engineers and computer aided engineering (CAE) specialists, as well as support from different departments at our customer, Ford, including vehicle modeling and simulation." The Magna Composites Center of Excellence in Toronto also supported this project, "as did our body and chassis team at Cosma," adds Cosma International global director of R&D Gabriel Cordoba.

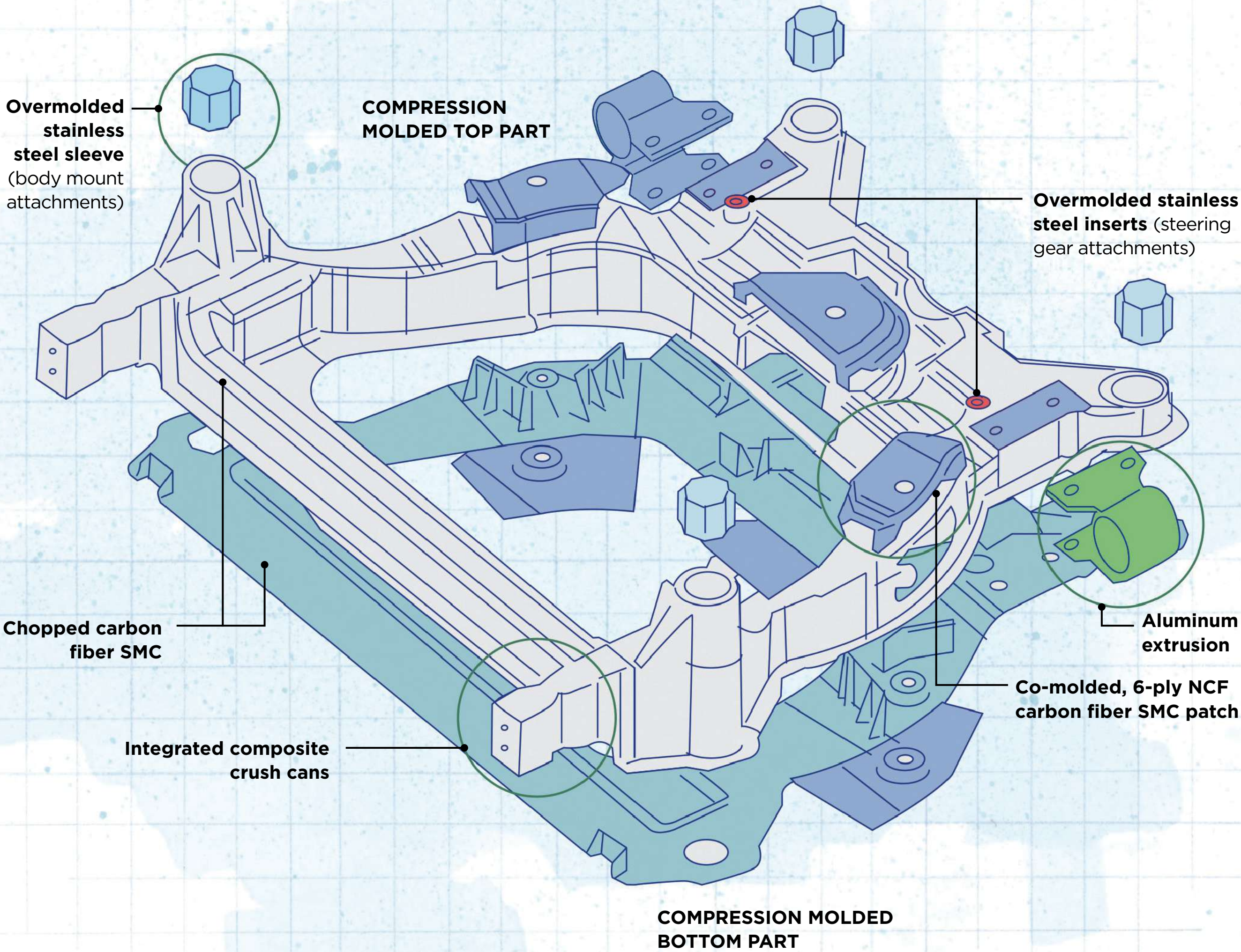
"We wanted to explore what the challenges would be to use CFRP parts on a high-volume production vehicle," recalls David Wagner, technical leader at Ford Motor Company. "The goal was to make as much of the structure CFRP as possible while using manufacturing that could accommodate high-volume production [200,000 vehicles/year] see how much weight that would take out and where the limits and challenges would be."

From initial discussions to completed design, the project spanned a little over one year. Prototype subframes were delivered to Ford at the end of 2017 and are now undergoing tests.

Redefining the design envelope

The Ford *Fusion*'s stamped steel subframe served as the baseline. "Ford provided the design space for the project — the vehicle-level design inputs — and held weekly design meetings," says Wagner. Cosma then took that packaging environment, Cordoba explains, "and began exploring what weight savings we could achieve. How could we retrofit the design into that space but still meet stiffness, strength and durability requirements?"

Stiffness vs. package space was an early challenge. "You typically drop modulus when you move from steel to composite," notes



DESIGN RESULTS | **Ford/Magna High-volume, Lightweight CFRP Front Subframe**

- Weight reduction of 34% compared to stamped steel equivalent.
- Parts reduction of 82%, replacing 54 stamped steel parts with two compression molded composite components and six overmolded stainless steel inserts.
- Optimized SMC material duo: chopped carbon fiber SMC achieves complex molded geometry while 0°/90° noncrimp fabric (NCF) patches resist high attachment loads at select locations.

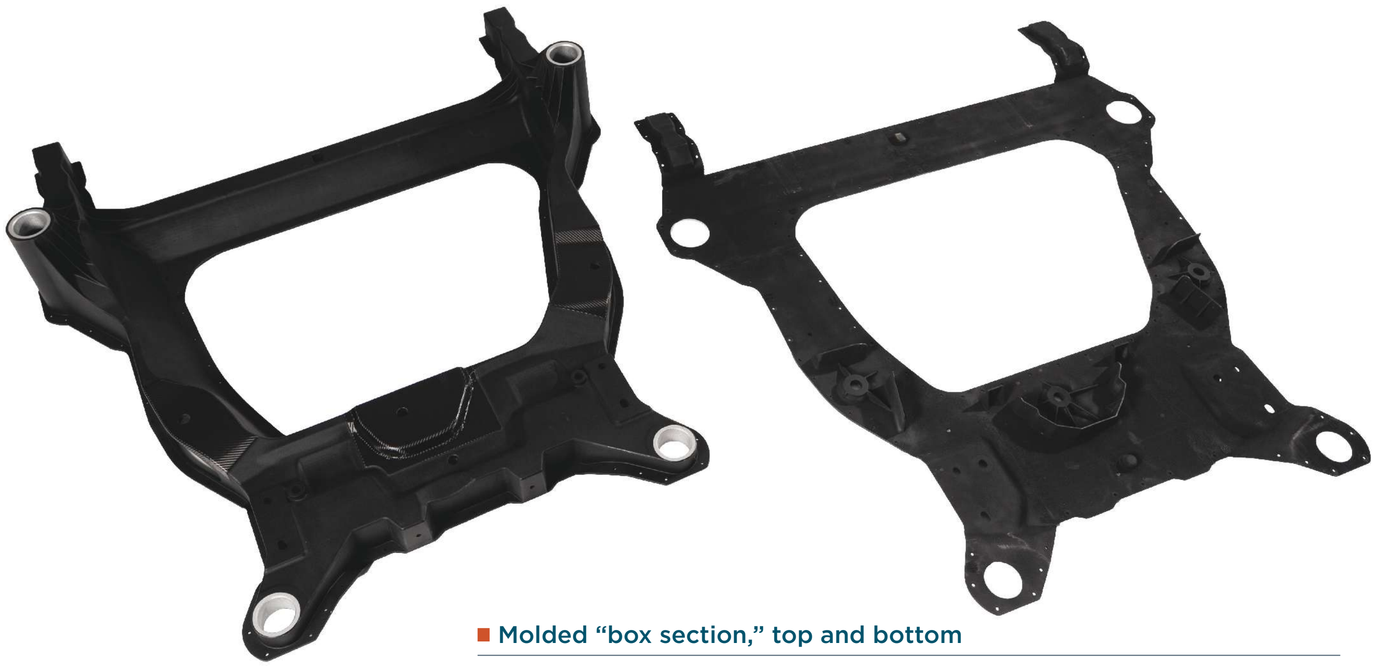
Illustration / **Karl Reque**

Wagner, "so you need more section in the members. We defined how much the new design could change from the baseline dimensions and shared some initial topology optimization with Magna."

Topology optimization (TO) is a CAE analysis that optimizes material placement within a given design space — including loads, boundary conditions and constraints — with the goal of maximizing performance and minimizing weight. "We started with our own TO for understanding the critical load paths," says Cordoba. These involved loads at subframe attachment points, including control arms and engine loads, as well as road loads, engine torque twists and crash requirements.

"We had to look at our different stiffness vs. steel and the properties we wanted to have," recalls Krull. Because composites offer many resin, fiber and fiber orientation choices, their properties can be specifically tailored, but "it is more complex than just plugging in the properties of steel," he points out.

"Plugging in properties" refers to entering material data into software tools. "We used all of the standard software, including »



■ Molded "box section," top and bottom

The hollow box design, prescribed by topology optimization to ensure subframe stiffness using minimal material, was realized by molding separate top and bottom halves, which were joined by adhesive and rivets.

Nastran [MSC Software, Newport Beach, CA, US] for static analysis, Abaqus [Dassault Systèmes, Waltham, MA, US] for nonlinear static analysis, Fibersim [Siemens PLC, Waltham, MA, US] for laminate draping simulation and HyperWorks [Altair Engineering, Troy, MI, US] for TO, generating finite-element models toward analyzing different load cases," says Cordoba.

Multiple analyses iteratively refined the modeling of the subframe for different loads, boundary conditions and materials. Krull notes that many composite materials were evaluated. "We began to look at compression molding as a manufacturing process that could provide high-volume production," he adds. "SMC was a good fit for making this part, and we did have in-house development of carbon fiber SMC, so that is how we moved."

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The next step was the part envelope. "The TO resulted in a box section as the best solution," recalls Cordoba. "As we looked at the SMC compression molding process, the design that emerged was to use two parts to achieve this." Thus, the frame comprises separately molded top and bottom halves, which are joined with polyurethane structural adhesive (Ashland, Columbus, OH, US) and rivets.

Co-molded dual SMC

Magna developed the carbon fiber SMC using its glass fiber SMC experience and a pilot line that it had acquired. "We developed proprietary technology for how we process the carbon fiber for this SMC and found we could also run NCF on that line," Krull explains. The material is similar to prepreg in that it is impregnated before molding, but unique in that this is done on the SMC line with the same resin and, thus, termed NCF SMC. "As we refined the subframe design analyses, we used properties testing results from these materials."

The EpicBlend SMC is compounded by Magna using chopped 50K carbon fiber tow from Zoltek (Bridgeton, MO, US) and Ashland vinyl ester resin modified in-house. The vinyl ester gives good adhesion to, and wet-out of, the carbon fiber. This would be locally reinforced and co-molded with six plies of 0°/90° NCF SMC, made by Magna with the same vinyl ester resin and NCF fabric from Zoltek, and cut into patches.

Combining the short- and long-fiber SMC was key to the design, but also a real challenge. The short-fiber SMC enables the molding of complex geometry and overmolding of the steel inserts for engine and steering mounts while the NCF patches resist high loads where the engine and lower control arms are attached. The combination of the two SMC materials cuts 9.3 kg vs. the stamped steel subframe. "It took quite a bit of work to develop the co-molding of the 0°/90° SMC patches," Krull recalls, noting issues with how to achieve flow of the chopped fiber SMC during molding to get the NCF patches integrated without dry spots or other quality issues.

Bolted connections

Bolted connections were also an issue. "The point loads into the composite are high — 80-100 kN — where the control arm and steering get bolted to the subframe," says Wagner. There are four

Overmolding and co-molding

Stainless steel sleeves are overmolded into the SMC subframe (top) for four body-mount and two steering-mount connections. Co-molded patches of noncrimp fabric SMC (bottom) were also key, resisting high loads at high-load areas, such as where the top and bottom parts are riveted and adhesively bonded together.

body-mount connections and two steering-mount connections where stainless steel sleeves are overmolded into the composite part. "For attachment, each body-mount bushing gets press-fit into the sleeve for an interference fit," Krull explains. "Stress is driven into the molded part through the circumference of the sleeve. We looked at forces when the bushing is inserted and input those into the computer design models. We also looked for cracks in the composite material during the physical testing but saw none."

Wagner points out that the bolts used are big. "These are M12 and larger, and must have tight positional, diameter and angular tolerances." This necessitated post-machining once the subframe was molded and assembled.

Testing and teamwork

Wagner says the prototype subframes will be tested through 2018. "We hope to finish in early 2019 and publish papers on what we've learned," he adds. Ford will perform a suite of corrosion tests at component and vehicle level to explore various corrosion mitigation strategies. Component and vehicle level durability tests will also be conducted, including stone impingement, testing of bolt-load retention and high-temperature cycles. Component tests will include high-cycle fatigue, joint overload, vibration and safety tests.

"We are doing our own testing of prototype subframes," says Krull. "This is a very large, complex part to be made from SMC, enabled by the co-molding development. We are looking at how to change the design, the SMC flow during molding and fiber alignment to understand where else we might be able to use these materials."

"We wanted to understand the largest cost drivers with this kind of CFRP-intensive part," says Wagner. "Secondary machining is one of the most significant costs. We need to think more creatively to eliminate machining after part molding." He also notes that one of the biggest challenges was developing the absolute material properties of the as-molded part for the design. "We spent a lot of time on material characterization to feed the design analyses," he explains. "This was time-consuming and expensive. It was a real challenge to get from flat plaques to properties that were representative of real parts because of the material flow during the molding process."

Cordoba says the biggest achievement is the teamwork, "not only with Ford as our customer, but as a global team. Wagner agrees: "This is a great example of how we can push our suppliers and ourselves to use advanced, lightweight materials." CW

ABOUT THE AUTHOR

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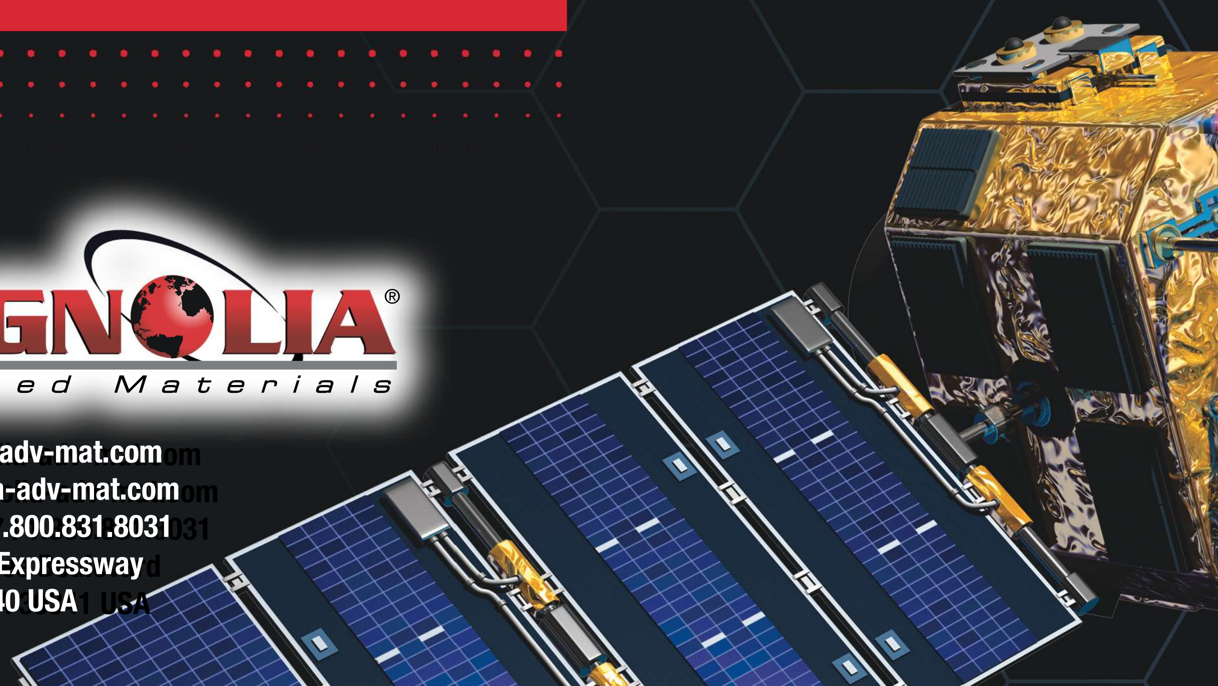

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