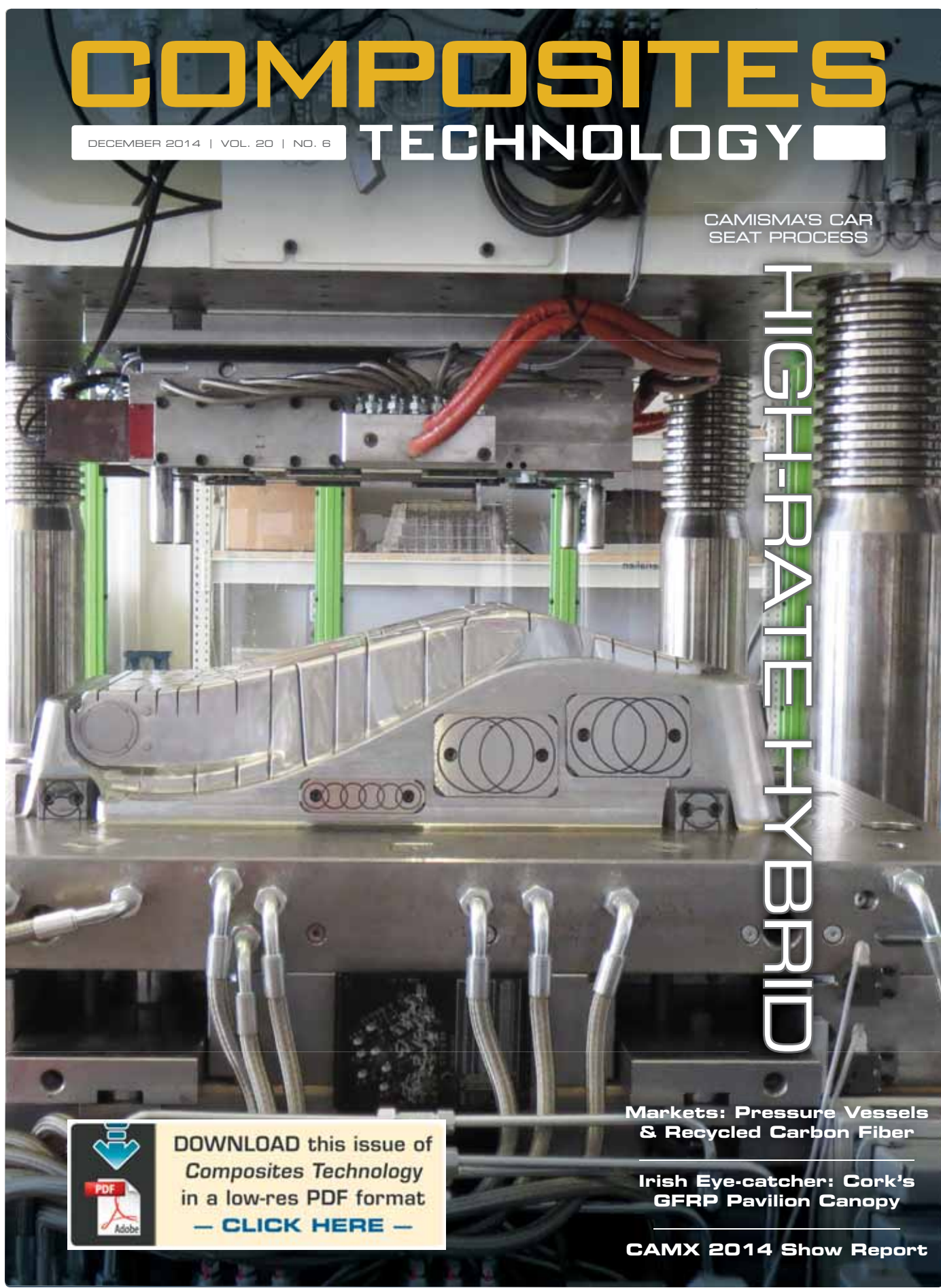


COMPOSITES TECHNOLOGY

DECEMBER 2014 | VOL. 20 | NO. 6

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HIGH-RATE HYBRID



Markets: Pressure Vessels & Recycled Carbon Fiber

Irish Eye-catcher: Cork's GFRP Pavilion Canopy

CAMX 2014 Show Report



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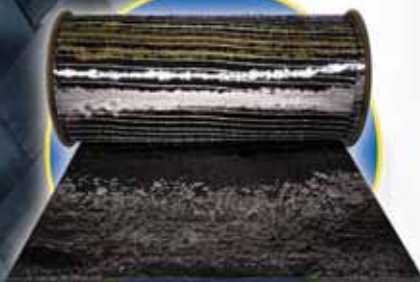
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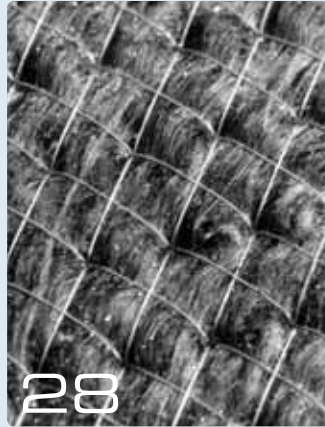
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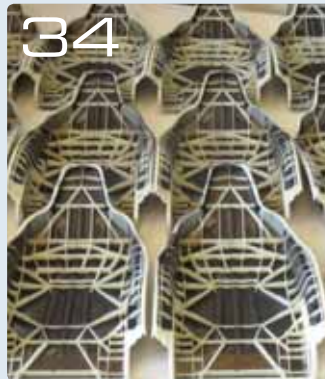
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The complex tool used to combine the three materials that form the CAMISMA project's automotive seat back demonstrator is positioned in a hybrid injection molding/thermoforming press developed during the SpriForm project and supplied by HBW-Gubesch Thermoforming GmbH (Wilhelmsdorf, Germany). Get the whole story, beginning on p. 34. Source | HBW-Gubesch



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MEMBERSHIPS:



Goodbye CT, Hello CW



You have in your possession the last issue of *Composites Technology* magazine that will ever be published. But that is not bad news. It's good news. Let me explain.

CT, as you may know, is one of two magazines we have published over the last two decades for designers, fabricators and other professionals in the composites industry. *CT* has focused on the use of polymers reinforced primarily with glass and plant-derived fibers in continuous and discontinuous forms in automotive, marine, industrial, consumer and similar applications. *CT*'s sister publication, *High-Performance Composites (HPC)*, has focused primarily on the use of continuous carbon fiber and other advanced fiber-reinforced polymers in the aerospace industry and other high-performance applications. Each magazine has been published bi-monthly in alternating months.

I noted here a few months ago that for most of their history, publishing two magazines, one for "advanced" composites professionals and the other for those involved in "industrial" composites, made sense and was very manageable. Over the past few years, however, as the composites industry has evolved to expand fiber and resin integration across multiple and diverse end-markets and applications, the line that separated *HPC* and *CT* has gotten increasingly fuzzy. Finally, that fuzziness has forced us into a new business and editorial paradigm.

And that's the good news: Starting January 2015, *CT* and *HPC* will be consolidated to create one new monthly publication, called *CompositesWorld (CW)*. As this consolidation implies, *CW*'s editorial content will focus on use of all fibers and resins in all end-markets and applications throughout the world. In short, we are growing and changing with the industry we serve.

What does this mean to you, the reader? On that subject, the news is even better.

The same great content you've come to know and trust remains, but now it will come to you every month. In addition, familiar features — Inside Manufacturing, Focus on Design, Work in Progress, Plant Tours and more — remain as well. And *CW* will continue to focus on the automotive, marine, wind, industrial and related applications that have always been the hallmark of *CT*. But in addition, you will now enjoy our coverage of composite materials and processes employed in end-markets for which there seldom was room in *CT*, including aerospace and high-performance automotive.

The new magazine has acquired a new name because we want to emphasize its role as your window into the whole world of composites innovation. And that gave us just the excuse we needed to design a new logo (above) and a new look — for that, you will have to wait until the inaugural issue of *CW* arrives in your mailbox in January 2015.

It is not without a tinge of regret that we say goodbye to a longtime friend with the discontinuation of *CT*, but we are excited about the launch of *CompositesWorld*, and we're confident that you will find its expanded focus and global perspective a key component of your continuing education program in the ever-expanding, ever-evolving composites industry.

Thanks for loyally reading *CT*, enjoy reading *CW* and, as always, let me know how we can serve your composites information needs most effectively.



Jeff Sloan

Beyond adaptation: Real metamorphosis



Bio | Jim Shobert

Jim Shobert is the CEO of Polygon Company (Walkerton, Ind.). He is a graduate of Indiana Wesleyan University. Polygon has been in the composites business for more than 64 years. The company has research and development and testing capabilities and two manufacturing facilities at its headquarters in Walkerton, near South Bend, Ind. — and maintains a third manufacturing facility in Xiamen, China.

It has been exciting to witness and experience, first-hand, the metamorphosis of our industry. As part of a second-generation composites family in the 1960s, I literally grew up running a pultrusion machine and doing something we called filament weaving, which was, in reality, braiding — a textile process we wanted to keep secret from potential competitors.

Our father had been part of a group of civilian scientists working at Wright-Patterson Air Force Base (Ohio) during WWII, developing cotton phenolic prepreg fabrics to mold into structural components for such things as nonmagnetic land mine detectors. We were the poster children for “Better Living through Creative Chemistry”: We had lunch perched on drums of methylene chloride after rinsing our hands in styrene. (Disposable gloves were for the faint of heart.) We even ruined a home oven or two curing some epoxy laminates. Afterward, mom couldn’t use them because subsequent cakes and pies all had that anhydrite aftertaste.

The word *metamorphosis* is typically used to convey the concepts of transformation, change or adaptation — all of which have been witnessed as we have watched the industry mature. However, if we probe the Greek a bit deeper, metamorphosis more precisely suggests evolving or changing into something uniquely *better*. If we think in terms of composites, there is a double meaning: In macro terms, as we review the past 50 to 60 years in the composite industry, we really are experiencing the *structural transformation* of an entire spectrum of processes, applications and markets served: What once was primarily an art has become a real science. All of this has been positive and good, as several large corporations learned in the 1970s after purchasing family-owned composites businesses only to discover that when the weather changed, so did their output of quality parts. Still more art than science, at that time.

Early on, most of us were chasing — at that time, under the moniker of *reinforced plastics* — the same applications, in recreational, insulated electrical or corrosion-resistant product markets. It’s clear, now, that we also were secretly inventing the same process technologies, vainly attempting to distinguish ourselves from our competitors and, in doing so, inadvertently slowing up the entire adaptation pro-

cess. Today, a plethora of markets and applications have developed, demonstrating the real possibilities and capabilities of composites. Growth in the numbers of market sectors and end-products continues to advance because the composites industry has learned that *cooperative* development is the better way to earn market acceptance. Now, public/private partnerships that include universities and input from trade associations are at the forefront of composites science.

We have always tried to be somewhat contrarian in our approach as we exploited these new possibilities. Early, most composite fabricators positioned their products as metal replacements. The real essence of composite manufacturing isn’t replacing metallic constituents, but radically re-imagining those constituents through the creative use and manipulation of individual fibers and polymer resin systems. But many found it difficult to see the composites enterprise as a transformational culture. This was manifested years ago when we exhibited at the Chicago Design Engineering Exposition. A visiting competitor came by our booth and asked why we were displaying at *that* trade show venue rather than seeking market share at the SPI (Society of the Plastics Industry) exposition. I replied that I merely wanted to be where people came looking for aluminum, stainless steel and other metals so we could capture a portion of their *mindshare*. The next year, this individual also had a booth at the Design Engineering Exposition. The more we can grasp, from an industry-wide perspective, that our mission is to provide solutions, not duplicate metal parts, the more successful we all will be.

An exciting but somewhat counterintuitive aspect of this metamorphosis is that electronic sensing technologies can be incorporated into the laminate cross section. These can range from sensing conductive changes in the polymer base to actual embedded circuitry in the form of conductive films or fibers, i.e., carbon fibers or — taking a page out of the competition’s playbook — metallic fibers. We, in fact, pioneered in composite tubing, a laminate in which there are alternating, discrete thicknesses of electrically conductive and insulating materials. In an insulated/conductive/insulated laminate, for example, insulating layers protect the conductive layer, allowing it to sense a metal object’s movement through the tube by measuring changes in the magnetic field within the tube. This is something the metals industry can do only by affixing or machining something into place externally — an *additional step*. In a world still immersed in metal paradigms, such capabilities represent real, essential change.

Today, we’ve eliminated the methylene chloride, we don’t bathe in styrene and only occasionally use the lunchroom microwave to postcure a part. A lot has changed, but one constant remains — an overwhelming opportunity for even greater composites metamorphosis. | CT |

The more we can grasp, from an industry-wide perspective, that our mission is to provide solutions, not duplicate metal parts, the more successful we all will be.



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Design for Producability and the Internet of Things (IoT) Push the Envelope of Production Efficiencies

EVENT DESCRIPTION:

Caught between increased production rates and growing cost pressures from the OEMs, manufacturers must improve part design and re-introduce the language of lean manufacturing in order to compete.

In this webinar, Dr. Leslie Cohen (HITCO), and Avner Ben-Bassat (Plataine) will review case studies demonstrating the impact of part design on production costs, and will introduce the opportunity of the Internet of Things (IoT) in manufacturing, leveraging state-of-the-art RFID and mobility technologies to better track and manage materials, kits, tooling, assemblies and staff on the production floor.

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PRIMARY TOPICS:

1. Managing the ingredients of a successful design process: customer requirements, engineering and manufacturing flexibilities and constraints
2. What is the Internet of Things (IoT) and how can it help to increase throughput, quality and quality control on the production floor
3. Establishing feedback cycles between engineering and manufacturing to support continuous improvement

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Aerospace and automotive: Convergence on the horizon?



Bio | Dale Brosius

Dale Brosius is the head of his own consulting company, which serves clients in the composites industry worldwide. Services include strategic planning, market analysis, assistance in mergers and acquisitions activities and technical support. His career has included a number of positions at Dow Chemical Co. (Midland, Mich.), Fiberite (Tempe, Ariz.) and then successor Cytec Industries Inc. (Woodland park, N.J.), and Quickstep Composites LLC (Dayton, Ohio). For

three years he also served as the general chair of the Society of Plastics Engineers' annual Automotive Composites Conference and Exhibition (ACCE). Brosius has a BS in chemical engineering from Texas A&M University and an MBA. Since 2000, he has been a regular contributing writer for *Composites Technology* and *High-Performance Composites*.

Most CT readers know that the American Composites Manufacturers Assn. (ACMA, Arlington, Va.) and the Society for the Advancement of Material and Process Engineering (SAMPE, Covina, Calif.) joined forces this past October to stage the CAMX conference and exhibition in Orlando, Fla. Historically, the SAMPE Convention & Exhibition was aerospace-dominated, while ACMA's trade show and conference focused on marine, automotive, construction and other "industrial" markets. I ran into one longtime colleague who lives mainly in the world of compression molding of chopped fiberglass compounds, and he was overwhelmed by the scope of materials, processes and applications represented at CAMX. It was, he told me, "almost too much to absorb." Those of us who have attended the JEC show in Paris for more than a decade have seen this melding of the extremes *and* the opportunities that flow from it.

Readers might not yet know that this is the final issue of *Composites Technology* before it is blended with sister publication *High-Performance Composites* to become *CompositesWorld* magazine — a merger that is further evidence the dividing lines have blurred.

In the late 1980s, I moved from the Dow Chemical Co. (Midland Mich.), where I pursued applications in automotive composites in Detroit, to a job in Salt Lake City, Utah, with Tempe, Ariz.-based Fiberite, where my work was focused mainly on composites applications in aerospace. One of Fiberite's top executives welcomed me to the "high-tech" world (based on his perception that automotive manufacturing — i.e., banging and welding sheet metal — was "low-tech").

At the time, airplanes were predominately metallic structures. Wing and stabilizer skins and other parts were made by *subtractive manufacturing*. That is, aircraft manufacturers took slabs of aluminum and milled 70 percent or more of the slab away to achieve the final part shape. A single aircraft took days or weeks to build, and a lot of guys with rivet guns put them together.

That didn't seem very high-tech to me. I had been in auto assembly plants, watching robots do welding and apply adhesives. I saw components come together as each customer ordered them — the proper seats (leather or cloth, heated or not, powered or not), the right instrument panel with the specified audio components, matching carpet, and the right exterior color (a red one followed by a white one followed by a blue one, etc.). And did I mention that the auto guys were doing this at the rate of *one every minute? That's high-tech.*

Fast forward. Today, Boeing's 787 and the Airbus A350 XWB are 50 and 52 percent advanced composites by structural weight. Although many in the public press want to call these all-composite or "plastic" aircraft, they are still roughly 40 to 45 percent metallic, including aluminum, titanium and steel. New commercial aircraft designs are truly *hybrid* structures and are likely to stay that way to achieve maximum structural efficiency.

In a race against the clock to meet fuel efficiency and emissions targets, automakers are aggressively exploring lighter weight materials. A growing consensus among the experts is that the future of

the automobile is in *hybrid structures* — a calculated mix of composites, steel and aluminum, exemplified by BMW's *i3* and *i8*, with their aluminum drive modules and carbon fiber passenger cells.

Hybrid structures require innovative joinery that accounts for thermal expansion and galvanic corrosion, yet enables disassembly and repair. This is an issue in both industries. We're moving toward a time when aerospace and automotive technical advances will be interchangeable and will extend well beyond the use of carbon fiber. Composite design and simulation software developed for the aerospace industry will find application in automotive structures design — especially useful for predicting fatigue, failure modes and, eventually, crash performance, as OEMs adopt increasing levels of continuous reinforcement to save weight. And if efforts to accelerate aircraft certification via simulation are successful (see <http://short.compositesworld.com/cdmHUB>), they could result in dramatically shorter car design cycles as well.

For their part, aeromanufacturers are increasing their use of automation, especially for composite structures, and as the auto industry increases fabrication rates for carbon fiber composites, via fast-cure resins and rapid lamination, expect to see some of that technology adapted for aerocomposites.

There are a number of additional areas where we will witness convergence — more than can be enumerated in this space. Who knows, maybe we will someday see a composites-intensive car that can take to the skies, just like in the old *Jetsons* cartoons. Oh wait ... a couple of companies — Terrafugia and Aeromobil — are already making this a reality today. | CT |

We're moving toward a time when aerospace and automotive technical advances will be interchangeable and will extend well beyond the use of carbon fiber.

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Composites Business Index 49.6: Virtually Flat Since July



Bio | Steve Kline

Steve Kline is the director of market intelligence for Gardner Business Media Inc. (Cincinnati, Ohio), the parent company and publisher of *Composites Technology* magazine. He started as a writing editor for another of the company's magazines before moving into his current role. Kline holds a BS in civil engineering from Vanderbilt University and an MBA from the University of Cincinnati.

Although September's U.S. Composites Business Index, 50.2, indicated a slight overall expansion, the industry remained flat for a fourth month. The rate of change was a mere 2.4 percent, the slowest month-over-month growth since August 2013.

New orders in the U.S. grew for a tenth consecutive month, at a rate virtually unchanged for three months. Production expanded for a ninth straight month, at a rate that ticked up after slowing since June. Backlogs contracted for the fourth month in a row, but remained 2.5 percent higher than one year earlier. Its annual growth rate — above 10 percent for four straight months — decelerated for

months, mid-sized plants contracted for the first time since December 2013 and plants with 19 or fewer employees contracted for a third month and at their second fastest rate since November 2013.

Regionally, the U.S. West was the best performer for a second month, and the Southeast was up for the first time since May. Contraction in the Northeast and North Central – East was moderate but accelerated in the North Central.

Future capital spending plans contracted at a rate that slowed for a third straight month. Although the annual rate of change was still growing, it did so at its slowest rate during the preceding year.

At 49.6 for October, the CBI continued its bounce between moderate growth and contraction, which began in July. Although the Index had been flat for four months, the month-over-month rate of change contracted for the first time since August 2013.

New orders grew for the eleventh consecutive month at a rate that had slowed somewhat the four previous months. Production expanded for a tenth month at a rate that had slowed since June, but remained virtually unchanged for a third month. Backlogs contracted for a fifth month in a row, running 1.3 percent below the backlog index of one year earlier. Its annual growth rate had

been above 10 percent for five straight months. Although it slowed for a second month, it was a strong sign that capacity utilization and capital equipment investment will increase at least into second quarter 2015. Employment continued to grow but its increase had been relatively weak three of the previous four months. Exports continued to contract significantly because of the rising dollar. Supplier deliveries lengthened again, but at their slowest rate since November 2013.

Material prices had increased at slower rates since June and were at their lowest since December 2013. Prices received fell, marginally, for the first time since March. Future business expectations fell back to a September 2013 low.

THE COMPOSITES BUSINESS INDEX						
Subindices	October	September	Change	Direction	Rate	Trend
New Orders	53.8	52.4	1.4	Growing	Faster	11
Production	52.9	53.2	-0.3	Growing	Slower	10
Backlog	44.1	44.7	-0.6	Contracting	Faster	5
Employment	50.4	53.6	-3.2	Growing	Slower	20
Exports	44.0	42.0	2.0	Contracting	Slower	4
Supplier Deliveries	52.2	54.6	-2.4	Lengthening	Less	35
Material Prices	62.2	64.5	-2.3	Increasing	Less	35
Prices Received	49.6	55.3	-5.7	Decreasing	From Increasing	1
Future Business Expectations	67.8	73.4	-5.6	Improving	Less	35
Composites Business Index	49.6	50.1	-0.5	Contracting	From Growing	1

the first time in 2014 but still strongly signaled that capacity utilization and capital equipment investment will increase throughout 2015. Employment growth accelerated and, for a second month, exports contracted at their fastest rate in CBI history. Supplier deliveries lengthened, as they had done at an accelerating rate since June.

Material prices continued to increase, but at their slowest rate of 2014. Prices received were up for a sixth month — their longest sustained increase since summer 2012 and the highest level reached since June 2012. After falling significantly for two months, future business expectations rebounded sharply.

Larger facilities (250+ employees) continued to see exceptional growth, and the growth rate accelerated as it had in previous

Facilities with more than 50 employees expanded but at a rate nearly 10 points lower — the prime reason the CBI moved from growth to contraction. Fabricators with fewer than 50 employees contracted at a slower rate than in September. For a second month, only two regions expanded. The West was the best performer and was the only one to grow in three consecutive months. The North Central – West showed the only other growth while the Northeast was flat and the North Central – East and Southeast both contracted significantly.

Future capital spending plans contracted, but at a slower rate for a fourth straight month. Although the annual rate of change was still up, it was growing at its slowest rate since the CBI began. | CT |

Composites WATCH

Multimaterial hybrids make automotive headlines in the European Union while fiber sources in the Middle East and Asia plan U.S. production facilities.

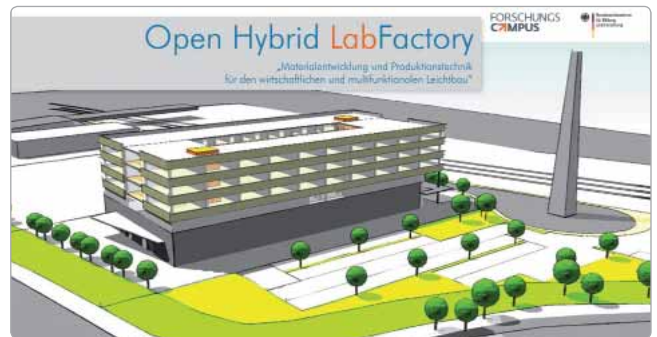


AUTOMOTIVE composite/metal/plastic hybrid research explodes in Germany

In the push to reduce vehicle weight, automotive designers in Germany are focusing on hybrid structures rather than choosing between metals and plastics/composites. Prof. Dr. Jürgen Lehold, the head of Volkswagen Group Research (Wolfsburg, Germany), explains: “Expensive lightweight materials, by themselves, aren’t enough. Rather, an intelligent multimaterial mix is required for success in the market, which enables new methods suitable for mass production.”

The hybrid trend, and the production methods they spawn, have exploded over the past three to four years in Germany. Volkswagen, which has proudly touted cutting 23 kg/51 lb from its *Golf VII* using high-strength steel — not carbon fiber — has formed the Open Hybrid LABfactory, in a new 7,000-m²/74,350-ft² facility located near Wolfsburg. “With our partners ... we are developing hybrid multimaterial structural components, made of plastic, metal and high-performance fibers in a single production step.” A public-private project, the lab is staffed by 200 employees from more than 30 companies, representing the entire value chain, from carbon fiber to finished part. Each company will contribute technology expertise via shared, cooperative R&D. The facility is expected to be operational in 2015.

The Open Hybrid LABfactory has announced its first three research programs: 1) ProVor, the designation for functional, integrated process technology used in prefabrication of FRP/metal hybrids; 2) Trophy, the project name for roll-formed components of hybrid construction for new vehicle concepts, which will involve development of a continuous production process for profiles with variable cross-sections and bends, made with hybrids of metal and fiber-reinforced plastic with a thermoplastic matrix; and 3) MultiMaK, a development program for methods and tools that will enable analysis and comprehensive evaluation (economic, ecological and technical) of product and process chains for lightweight multimaterial-based, high-volume production.



One of the lab’s partners, Technische Universität Braunschweig, is working on hybrid automotive hoods made with thin (0.2 mm/0.008 inch) steel plate as a jacket around a carbon fiber-reinforced plastic (CFRP) core — reportedly 30 percent lighter than steel alone.

Another example of the hybrid trend is the subject of this month’s “Inside Manufacturing” feature, titled “CAMISMA’s Car Seat Back: Hybrid Composite for High Volume.” Funded by the German Federal Ministry of Education and Research (BMBWF, Bonn and Berlin) and, like Volkswagen’s Open Hybrid LABfactory effort, a product of collaborative work on the part of a number of automotive supply chain representatives, CAMISMA’s complex seat back is a hybrid structure. It combines recycled discontinuous carbon fiber mat, continuous unidirectional carbon fiber tapes impregnated with polyamide 12 (polymerized *after* fiber impregnation), and injection molded glass fiber thermoplastic, in a one-shot, short-cycle fabrication process that combines thermoforming and injection molding. (Read the detailed account on p. 34).

A number of other collaborative projects with similar goals have sprung up elsewhere in Germany. Get the full story on them all online at the *CW Blog*: short.compositesworld.com/Hybridbau.

BIZ BRIEF

Resin filler and additive solutions supplier **R.J. Marshall Co.** (Southfield, Mich.) recently announced the acquisition of **Gruber Systems’** (Valencia, Calif.) “consumables” business. The new entity will do business as Gruber Supplies & Accessories. The acquisition includes all Gruber manufacturing activities in Mansfield, Texas, and its warehousing activities in Rockledge, Fla.. “We are very excited about this acquisition as it demonstrates our com-

mitment to the cast polymer and composites industries,” says R.J. Marshall cofounder Richard Marshall. “This will expand our current product offerings and will provide a platform for future products.” Founded by Richard and Joan Marshall in May 1978, the firm now has five manufacturing locations in the U.S. and also maintains a European stocking and distribution warehouse in Belgium.



INFRASTRUCTURE



Historic Ohio pedestrian BRIDGE upgraded with composite decking

During the 1920s, Sandy Beach Bridge connected the two sides of the Sandy Beach Amusement Park, in Indian Lake, Ohio. The pedestrian bridge supported heavy foot traffic for decades as part of what locals referred to as Ohio's Million Dollar Playground, but fell into disrepair along with the park in the 1960s. When the property was purchased in 1981 for development, the cost of restoring the bridge, updating it to building codes and providing insurance proved prohibitive. Earlier this year, however, a committee representing the Indian Lake Area Historical Society found a low-maintenance, non-skid solution in Composite Advantage's (Dayton, Ohio) FiberSPAN fiber-reinforced polymer (FRP) bridge decking.

The bridge's new FiberSPAN deck features panels 11.83 ft/3.6m wide, in lengths varying from 7 ft to 14.5 ft. (2.1m to 4.4m). Deck depth was calculated at 7.5 inches/191 mm to meet a deflection requirement of L/400 for the longest floor beam span. Adhesively bonded ship-lap joints were used to accommodate the high camber of the bridge along with a sliding expansion panel at the bridge's peak. Steel plate was embedded into the bridge deck to accommodate railing post attachments. Stainless steel cable railing was installed and an aluminum handrail hung from the bridge's top chord

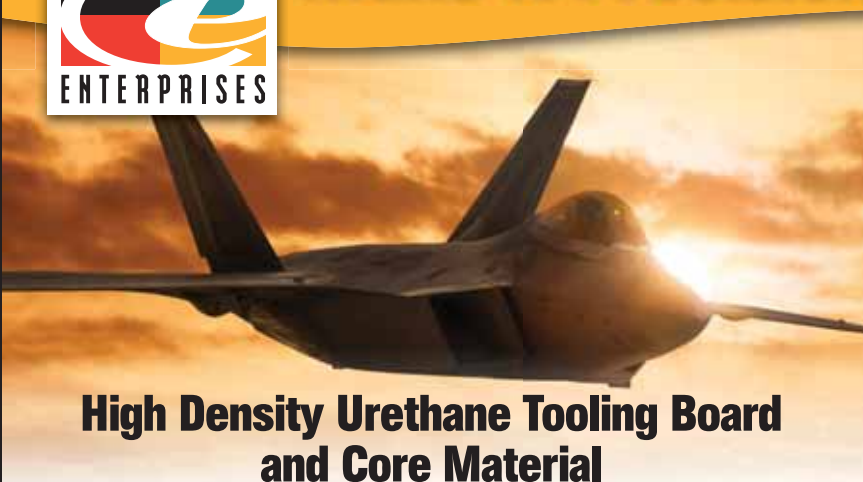


beams. A small-grit, nonslip wear surface makes the footing on the bridge deck safe yet also barefoot-friendly.

"The original renovation design called for galvanized steel flooring with a nonskid surface," says Composite Advantage VP Andy Loff. "We worked closely with the society to provide a bridge deck that met their requirements at a cost comparable to steel sheeting." The restoration project complements a new water recreation area and meets a live load requirement of 100 lb/ft². The bridge was re-opened to the public on Aug. 23, 2014.



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Composites | NEWS

DowAksa to establish U.S. carbon fiber manufacturing presence

Industrial carbon fiber manufacturer DowAksa (Istanbul, Turkey), announced on Oct. 28 at an event in Atlanta, Ga., that it plans to establish a large, industrial-grade carbon fiber manufacturing operation in the U.S. A joint venture of acrylic specialist AKSA (Istanbul, Turkey) and chemical giant Dow (Midland, Mich.), DowAksa will establish DowAksa USA in nearby Marietta, Ga. Led by recently appointed U.S. general manager Eric Coleman, the new outpost will begin the task of developing a carbon fiber production plant.

DowAksa CEO Kostas Katsoglou told CompositesWorld at the event that “the carbon fiber market in the U.S. is about to explode. It is essential for us to have a permanent presence in the U.S.” DowAksa is evaluating potential locations for the plant, and although the type and quantity of the prospective plant’s industrial-grade carbon fiber are not yet determined, Katsoglou said, “We will start with a prepreg line and, depending on market developments, we will continue with the manufacture of dry carbon fiber and, possibly, precursor.” The facility’s size and function will be determined by DowAksa’s strategy, which seeks to establish partnerships with potential customers — automotive OEMs — in which the customer’s applications help determine the type of product DowAksa produces. DowAksa’s intent, he said, is to be fully integrated into the supply chain, and AKSA’s ample supply of polyacrylonitrile (PAN) precursor reportedly offers DowAksa unusual scale-up flexibility. Noting that plant construction “will happen pretty soon,” he said, “we are working on multiple relationships, which will determine type of carbon fiber. Everything is on the table.”

Marco Barsacchi, DowAksa’s CTO, said the company plans, through the new facility, to address the full spectrum of composites manufacturing with its OEM customers, providing design, engineering, processing and technical services to help bring composite products to market quickly and efficiently. DowAksa already has one such partnership. In 2012, Dow established a joint development agreement with Ford Motor Co. (Dearborn, Mich.) to develop low-cost carbon fiber composites for high-volume automotive manufacturing use. Other automotive OEMs, in the U.S. and Europe, are being targeted by DowAksa as well, Katsoglou said.

Katsoglou’s belief in the promise of the carbon fiber market rests, in part, on fiber use triggered by U.S. fuel efficiency and European emissions regulations and enabled by a decrease in carbon fiber costs. In the past year, he noted, DowAksa has reduced fiber cost by 15 percent by optimizing its manufacturing process in Turkey. Further optimization, he predicted, will make carbon cost-competitive with legacy materials, including steel, thus removing a major hurdle to widespread automotive carbon fiber adoption. “The issue of cost is an industry issue that we will solve.”

DowAksa also has its eyes on the infrastructure and wind markets. In 2013, it acquired CarbonWrap Solutions (Tucson, Ariz.),



which provides dry and wet carbon fiber fabric and epoxy solutions and engineering services for bridge, building and pipe rehabilitation and reinforcement. And DowAksa is working with Energetx Composites (Holland, Mich.) to develop a material-enabled automated manufacturing process for carbon fiber wind blade spars, featuring the VIPER tape layer from Fives Cincinnati, (Hebron, Ky.).

Katsoglou acknowledged that DowAksa's plans are ambitious, but is convinced that the time is right for such a commitment. "On the one hand we are excited," he said. "On the other, we know we have a large mountain to climb."

BIZ BRIEF

Citadel Plastics Holdings Inc. (West Chicago, Ill.), a global provider of thermoplastic and engineered composite compounds, announced in mid-November that it had completed its acquisition of **The Composites Group** (TCG, Cleveland, Ohio), a manufacturer of engineered composite compounds, from Highlander Partners L.P. (Dallas, Texas). Terms were not disclosed. Citadel CEO Mike Huff notes that TCG "is a very strategic acquisition for Citadel" because it has differentiated itself through its ability to formulate a broad portfolio of proprietary products, including BMC, SMC, TMC, and high-performance composites, providing customers an integrated solution for demanding end-use needs. The acquisition will be the eighth plastics-related acquisition for Citadel since 2007.

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Jushi holds yearly gathering, announces U.S. glass fiber manufacturing facility

At its 20th annual International Conference on Fiberglass, Jushi Group Co. Ltd. (Tongxiang, Zhejiang, China) reported on the current state of its glass fiber manufacturing business, and announced that the company is close to selecting a site for a U.S. manufacturing plant.

Held Oct. 7-8 at its headquarters in Tongxiang, the conference's opening ceremony recognized, in part, the relocation of China Fiberglass Co. from Beijing to Tongxiang. China Fiberglass, a subsidiary of China National Building Materials Co., is a manufacturer of yarns and fabrics used to make pipe and other building and construction products. Zhang Yuqiang, Jushi CEO and president, revealed that the company had entered "the decision-making stage" for a U.S.-based fiberglass manufacturing facility at a news conference later in the day. He said the company has been researching sites and other business-related aspects for a potential U.S. plant for two years. A timeframe for the project was not provided.

The U.S. plant thrust was one of a number of new strategic initiatives and products that included strategic cooperation framework agreements with Guandong Shemma Electric Co., a circuit board manufacturer, Cathay Composites, a materials distributor based in the U.K., and an extension of its high-modulus/strength E7 E-glass product line. The latter now includes E7 568H chopped strands for



polyamide, E7 386T direct roving for weaving, pultrusion and filament winding, and E7 380 for weaving and filament winding. Read more about the Jushi Conference and the company's capacities and plans online at short.compositesworld.com/Jushi20th.

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Brazil's composites sector reports 2014 uptick

The Brazilian composites industry reported revenue of \$325 million (USD) in the third quarter of 2014, 9.8 percent higher than that recorded in the previous three months, but 2.4 percent lower than the figure for the same period last year. From July to September, Brazil produced 51,000 tons of composites, 4 percent more than in the previous quarter. Compared to the tonnage reported for the same period in 2013, however, performance was 5 percent lower. The figures are part of the latest survey conducted by consulting firm Maxiقيم (Porto Alegre, Brazil) for the Latin American Composite Materials Assn. (ALMACO, São Paulo, Brazil).

For the fourth quarter, Maxiقيم estimates a 6.5 percent revenue increase and a 3.2 percent increase in tonnage. For the year, Maxiقيم predicts that composites sector revenue will total \$1.3 billion (USD), 0.5 percent higher than in 2013, and processed tonnage will total 206,000 tons, 1.8 percent lower than in 2013.

The growth in the third quarter and projected fourth-quarter improvements are associated with increased demand in specific niches of the construction sector (schools and housing), infrastructure, sanitation, and wind energy, says Gilmar Lima, president of ALMACO, adding that the almost 10 percent revenue boost in the last quarter is a result of products of higher added value and price adjustments driven by the successive increases in raw material prices. For more data, visit www.almaco.org.br.

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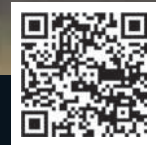
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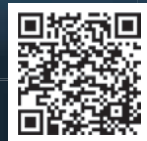


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As the CAMX general session venue filled up on day one, in anticipation of the inaugural show's first keynote address, it was abundantly clear that this new North American trade event was on its way to success. ■

Source | CT/Photo | Jeff Norgard

CAMX 2014

REPORT

ACMA and SAMPE come together to present a conference and exhibition of unprecedented scale and value to manufacturers from all segments of the composites industry.

Source | CT/Photo | Jeff Norgard



CAMX keynote speaker Kevin Mickey, the president of Scaled Composites (Mojave, Calif.), inspired the CAMX audience with his company's philosophy of finding composites programs that excite workers, make for a fun working environment, and involve taking risks. ■

The inaugural Composites & Advanced Materials Expo (CAMX) kicked off on Oct. 13 in Orlando, Fla. It represents a first-of-its-kind conference and trade show in North America: A single exhibition that unites the full spectrum of composites suppliers and fabricators, representing not only aerospace and other “advanced” applications, but also automotive, wind, marine, construction, oil and gas and other “industrial” end-markets. Jointly operated by the American Composites Manufacturers Assn. (ACMA, Arlington, Va.) and the Society for the Advancement of Material and Process Engineering (SAMPE, Covina, Calif.), CAMX offered a promising glimpse of the composites future, featuring materials, technology and software designed to meet the needs of the entire composites industry. The numbers alone — more than 7,100 attendees attracted by 550 exhibitors — made the show a success. The *CT* staff was out in force at CAMX and filed the following report of conference and show highlights that supported that view.

CAMX KEYNOTE

CAMX 2014 was officially launched on Tuesday, Oct. 14 with a presentation by Kevin Mickey, president of Scaled Composites (Mojave, Calif.). He was introduced by Kim Howard of Owens Corning (Toledo, Ohio), who emphasized the importance of innovation, risk-taking and a collaborative working environment — characteristics exemplified by Scaled Composites.

An engaging speaker, Mickey referred to CAMX attendees as the “world’s brightest people,” and reviewed the many groundbreaking milestones that Scaled Composites has passed since its beginnings in 1982. A notable one, in 2004, was its capture of the \$10 million Ansari X-Prize for development of a reusable, rocket-powered composite space vehicle that could transport three people into

CAMX exhibitor RocTool (Charlotte, N.C.) molded tablet computer cases on the show floor, using its 3iTech inductively heated tooling to curtail cycle times to well within the requirements of commercial mass-production operations. ■

suborbital space and return them safely to earth, built with funding from billionaire Paul Allen. Tongue firmly in cheek, Mickey elicited laughter when he said of the X-Prize, “Let me give you one piece of business advice: Do not spend \$30 million to win \$10 million.”

Mickey inspired the audience with his company’s philosophy of finding programs, like Virgin Galactic’s space tourism venture, that excite workers and make for a fun working environment. He stressed that risk-taking is important: “If you take chances, you might fail, but if you don’t take chances, you’ll never make any progress. Don’t be afraid of taking educated, calculated risks!” The success of Scaled Composites shows that being bold and taking risks, while celebrating results and learning from failures, is a winning combination. Concluded Mickey, “The process shouldn’t be the product — stop talking and start doing.”

TECHNOLOGY DEMOS

There was no shortage of actual manufacturing taking place at CAMX, often to educate composite professionals about new processing methods. Among the most notable, MarkForged (Somerville, Mass.) had almost continuous traffic at its booth, where the company demonstrated the capabilities of its Mark One additive manufacturing (AM) 3-D printer, which (so far) is unique in that it produces parts made with *continuous* carbon fiber in a thermoplastic resin. The Mark One uses fused deposition modeling (FDM), an extrusion-like process, to place resin and towpreg in the flat *x/y* plane of the part. The company says that the fiber can be oriented, or added selectively only where needed, in the *x/y* plane, but notes that, at present, vertical, or *z*-directional, orientations aren’t possible. Each build layer is approximately 200 microns thick. Notably, the Mark One has *two* print heads, both designed and built in-house. One dispenses polyamide (nylon) or polylactide (PLA) resin, and the other dispenses continuous carbon or glass towpreg (dispensing of aramid fiber is in development). The towpreg is made in a proprietary process: A single carbon filament is coated with a specially developed thermoplastic resin, designed specifically for the printer.

CAMX attendees were clearly enthralled and energized by the technology, which is in its infancy and certainly could prove to be highly disruptive.

AUTOCOMPOSITES: LOOKING AHEAD

A *CT* contributing writer and the principal of Composites Forecasts and Consulting (Mesa, Ariz.), market research specialist Chris Red walked CAMX conference attendees through his research into “The Automotive Market – Where is it Going and What’s Needed?” Noting that the auto industry in Europe and North America is only two model generations from the full extent of U.S. fuel economy and European CO₂ emissions regulations, and that something similar in China will likely follow, he argued that fines and other



RocTool’s molded tablet computer cases were reinforced with preforms fabricated from recycled carbon fiber supplied by Materials Innovation Technology – Reengineered Carbon Fiber (MIT-RCF, Fletcher, N.C.). ■

penalties that could accrue for models that do not comply will be prime motivators for change. In the U.S., by 2025, CAFE will require that subcompacts achieve about 61 mpg (miles per gal equivalent), and a car in the Mercedes S-class will need a 45-mpge rating. He noted, for example, that in Europe, failure to comply will result in fines that will raise the price of an Aston Martin by about \$20,000. In the U.S., General Motors (GM), for example, will pay \$5.50 per each vehicle, per 1/10th of a missed mile. “So, by 2025,” Red estimated for subcompacts, “if GM has got only 45 mpg, instead of what’s required, it could cost them \$2 billion.” Red wagers that automakers will not simply pass those penalties on to car buyers, who could be footing the bill for fines to the tune of up to *one-third* of a car’s purchase price. He believes, instead, that they adopt carbon fiber composites for lightweighting, at least in high-end vehicles. A carbon fiber passenger protection cell, for instance, will cost about \$10,000, he notes, but points out that the figure falls well within the penalty situation in the luxury car sector. “That,” Red points out, “buys a lot of technology.” The extra cost, will be passed long to the car buyer either way, but passing along the cost of technology ▶



that will pay for itself in increased fuel economy is far preferable to passing along fines for failure to comply.

Matthew Marks, the regulatory marketing manager for SABIC Innovative Plastics (Pittsfield, Mass.) followed Red to the podium. As the chairperson of the American Chemistry Council's (ACC, Washington, D.C.) Plastics Div., he presented a synopsis of the latter's new *Roadmap* for plastics and composites innovation in the automotive world, noting that it is "a strategy document to help us speak with one voice — something the metals industry has done for years." Marks drew special attention to several provisions: A prime concern is to "foster a culture of collaboration between ACC members, and governmental and auto industry players." Collaborative efforts, he added, should be directed at a Technology Demonstration Center; development of generic cost models that demonstrate plastics/composites advantages vs. metals; a focus on manufacturing speed and multiaxial joining and repair technologies; and development of a shared materials properties database, new CAE tools and design guidelines, and composites-specific models for crashworthiness.

Technical sessions also included a SAMPE panel headed by University of Alabama at Birmingham professor Uday Vaidya, which took on the topic of thermoplastic composites, as they attract increasing attention in aerospace, automotive, energy, sporting goods, defense and emerging applications, thanks to their toughness, rapid processability and recyclability. The six panelists, chosen in equal numbers from industry and academia, included (in addition to Vaidya) Dr. Mark Janney, chief scientist at recycling firm MIT-RCF (Lake City, S.C.), Shridhar Yarlalagadda, assistant director of research at the University of Delaware's Center for Composites Materials; Ed Pilpel, president of Polystrand (Englewood, Colo.); Mike Favaloro, president and CEO of CompositeTechs LLC (Amesbury, Mass.); and Dr. Brent Strong, professor emeritus at Brigham Young University and head of Strong and Associates LLC (Sandy, Utah).

Strong began with an overview of the thermoplastic (TP) resins space, comparing TPs to thermoset resins in terms of properties. He noted the differences between low-cost, commodity TPs (polyamide, etc.), which have existed for a century, and high-end, advanced thermoplastics, such as polyetheretherketone, which exhibit high

solvent resistance and operating temperatures and, with that, higher cost. Long and intertwined molecular structures gives thermoplastics their characteristic toughness and elongation.

Favaloro, who referred to TPs as "the first out-of-autoclave materials," reviewed some current technologies and markets, and noted some new approaches, including Firewind, developed by Fibrtec (Atlanta, Texas), a method of preheating the tool to help facilitate molding of continuous fiber-reinforced TPs. Yarlalagadda, however, looked critically at TP positives and negatives, pointing out that the very high processing temperatures required to melt advanced TPs have, in the past, made it difficult to combine them with fibers, especially carbon, because the fiber sizing is severely compromised at those high temperatures. Without adequate sizing, the fiber/resin bond can be a problem, making it impossible to "capture the high toughness" of the material. New sizing forms, he said, are helping.

He also stressed that computer modeling is necessary whenever a complex part geometry is planned, because broadgoods will shift and fiber direction and orientation will change during molding. Very fast cycle times are non-isothermal, further complicating the picture. His wish: a fully coupled design/analysis/process model that includes fiber orientation.

Finally, Janney discussed the issue of recycling thermoplastic composites, particularly those that contain carbon fiber. After noting that the short, discontinuous fibers that result from recycling will never match continuous carbon fiber performance, he went on to say that, nevertheless, there are opportunities to use them.

THE RISE OF RECYCLING

Recycling and reuse of composites was also a focus of the Green Composites conference track, headed by MIT-RCF's Janney and Dr. Brian Pillay of the University of Alabama at Birmingham. *CT* technical editor Sara Black was a part of the session, and spoke on the topic of lifecycle analysis (LCA). The session showcased some significant research into the fairly intransigent problems confronted by recyclers, particularly in processing thermoset composites.

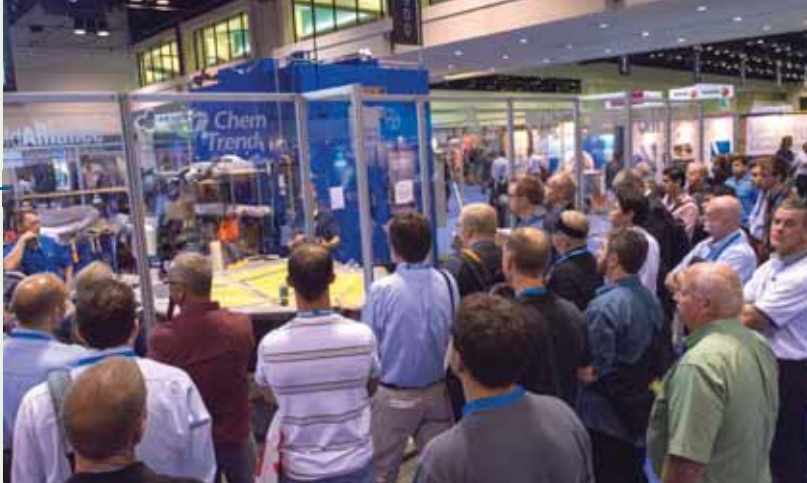
Polystrand's Pilpel, whose company is a subsidiary of thermoset fabricator Gordon Holdings Inc. (Englewood, Colo.), spoke about a possible approach for reusing waste products from his continuous fiber thermoplastic composites production. He discussed a project undertaken with the Materials Processing Applications Development (MPAD) center at the University of Alabama Birmingham (UAB), where an experiment was designed to test sample plaques made with Polystrand waste tape material mixed with new nylon resin. Tapes were chopped or shredded and mixed with dried resin, at varying fiber vol-

— Additive manufacturing equipment developer MarkForged (Somerville, Mass.) saw heavy traffic at its booth as the company demonstrated the capabilities of its Mark One 3-D printer, which produces composite parts made with continuous carbon fiber in a thermoplastic resin. ■



Source: *CT* Photo | Jeff Neigand

Composites One (Arlington Heights, Ill.) and the Closed Mold Alliance conducted tutorials in a glassed-in venue on the exhibit floor, focused on manufacturing processes, including infusion, resin transfer molding (RTM) and light RTM. ■



Source | CT / Photo | Jeff Nougard

umes, and then compression molded. Although the experiment showed some unexpected variations in the strength and modulus of the molded test plaques, depending on how the scrap material was handled and molded, it nevertheless proved that it is possible to collect and, with some value-added preparation, create a new molded product. Challenges include finding a viable end-user for the product, and maintaining consistent quality in new parts.

Presenter Pete George, an associate Technical Fellow at Boeing Research and Development (Tukwila, Wash.), touched on some of the major themes of composites and recycling, in a presentation titled, “Challenges to Successful Implementation of Composites Recycling, and Suggested Solutions.” There’s no question that carbon fiber composites use has grown dramatically over the past three decades, he said, pointing to data that show the energy required to recover carbon fiber is *one-tenth* that needed to make virgin fiber. George said that data generated in concert with partners MIT-RCF and RTP Co. (Winona, Minn.) showed that recovered aerospace carbon fiber waste performs better than virgin standard-modulus carbon fiber in typical molding compounds, which certainly offers an incentive for recycling these wastes. He cautioned, however, that current methods for recovering fibers from prepreg and cured laminates — in particular, pyrolysis — tend to reduce fiber performance and the resulting “fluffy” fibers aren’t easily conveyed and metered during compounding. So, much more needs to be done in the area of economical fiber recovery as well as waste material segregation to isolate these high-performance wastes.

Why not make composites easier to recycle from the get-go? That was the question asked by Rey Banatao of Connora Technologies (Hayward, Calif.), in his presentation, “Recyclable by Design: A Chemical Approach to Recyclable Epoxy Composites.” Reportedly, his company has developed high-performance epoxy curing agents called *recyclamines*, which can be combined with any di-epoxide molecule during standard part processing. The chemistry creates “cleavage points” in the molecular chains that permit the cured thermoset to be broken down, in the presence of an acid compound, into a *reusable thermoplastic*. Reinforcements, he claims, can be recovered without damage in their original form and easily recycled.

RESEARCH: MONOMER-FREE SMC

Sheet molding compound (SMC) has had a long but not always happy history in the auto industry. Championed as a lightweight replacement for semistructural steel members and Class A exterior body parts, SMC hit hard times in the early 2000s when the baking processes used to cure automotive paint caused cured SMCs to outgas through surface microcracks, causing eruptions in the paint finish that automakers dubbed “paint pops.” A flurry of research projects tackled the issue and by 2004, paint-pop-free formulations

were on the market. Today, SMC faces a second challenge: The U.S. Health and Human Services Department’s designation of styrene as a suspected carcinogen. SMCs variously contain four different reactive diluents: Styrene is the most common, but the vinyl toluene, divinyl benzene and acrylates that have been used recently as styrene replacements are also at risk because reactive diluents as a class could face future regulation. This risk has prompted efforts to develop reactive diluent-free resins, particularly for SMCs. Presenter Kurt Butler, polymer engineer – R&D in the Composite Group at Premix (North Kingsville, Ohio), addressed the subject, noting that there are two hurdles to development of SMCs without reactive diluents. The first is thickening of the SMC’s resin paste. The second is shrinkage control to ensure accurate finished-part dimensions. A reactive diluent has been crucial to both in the past. A commercially available magnesium oxide, in a 30- to 40-percent dispersion, has produced acceptable thickening, and Butler’s team also has tested proprietary formulations that improve performance. After the thickening hurdle was surmounted, the task was to develop reactive diluent-free shrinkage-control agents. A number of possibilities were tried, and Butler reports that his team has actually produced glass-reinforced formulations — ATH-filled and calcium carbonate-filled — in which flexural strength and modulus come close to the “control” SMC. For carbon fiber SMC, performance falls short, but Butler considers the combination of shrinkage control and thickening “promising.” He concluded that reactive diluent-free resin systems can be thickened successfully for SMC compounding and, although study must continue, both ATH and calcium carbonate can be used as fillers, with no wetting issues. Although temperature has to be elevated to accomplish thickening, standard peroxides are still used to catalyze the resins and the SMC compounding process is otherwise unchanged. Butler believes that, over time, the property short falls in the carbon fiber formulations will be overcome.

Editor’s note: CAMX generated much more of interest to CT’s readers than could be contained in this issue. Readers can peruse a more comprehensive review online (see “Learn More”) and review significant products introduced on the CAMX show floor in this issue and, in expanded format, online (see p. 43). | CT |

CW LEARN MORE
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Read a far more comprehensive review of CAMX 2014 happenings online | short.compositesworld.com/CAMX14Rpt.



Source | Bertel Schmitt

PRESSURE VESSELS for ALTERNATIVE FUELS, 2014-2023

Lower fuel costs and escalating emissions standards are driving a 10 percent annual growth in alternative-fuel pressure vessel sales.

High-pressure gas storage vessels represent one of the biggest and fastest-growing markets for advanced composites. In 2013, construction of pressure vessels of all types — metal, composite and metal/composite hybrids — represented more than \$2 billion in global sales. That same year, pressure vessel manufacturers accounted for 6 to 7 percent of the estimated 65,000 metric tonnes (143.3 million lb) of global demand for carbon fibers. Although they are used in self-contained breathing apparatuses and provide oxygen and gas storage on aerospace vehicles, the primary end-markets for *composite-reinforced* pressure vessels are bulk transportation of compressed natural gas (CNG) products, and fuel storage in passenger cars, buses and trucks with powertrains dependent on CNG and hydrogen alternatives to gasoline and diesel.



Low prices for compressed natural gas (CNG) are fueling orders for natural gas-powered buses and commercial trucks in developed economies. And since Toyota (Aichi, Japan) executive VP Mitsuhsisa Kato (top photo) introduced Toyota's FCV fuel-cell vehicles to the car-buying public in June and other auto OEMs signaled they will follow suit, the composite high-pressure storage tanks that hold the hydrogen that powers them could be in great demand by 2017. ■ Source | Hexagon Composites

GROWTH EQUATION

Demand for alternative fuels is growing, in large part, because the extraction of natural gas from shale reserves has contributed to lower prices in North America and parts of Europe. In the North American market, for example, the cost of natural gas fuels currently runs about 40 percent less than diesel per diesel gallon equivalent. In addition, increasingly stringent emissions regulations, including the European Union's (E.U.) Euro 6 Standard, which became effective earlier this year, are making diesel-powered buses and commercial vehicles more expensive for operators. Impending regulations are improving the marketability not only of CNG but also of hydrogen (H₂) gas — after a period of relative dormancy — for fuel-cell powered vehicles.

In addition, the current availability of postrecession, low-interest loans has helped create a surge in demand for these alternative fuels, accompanied by strengthening and expansion of the pressure-vessel manufacturing base.

CNG VEHICLES GROWING

Five years ago, the number of natural gas-powered vehicles (NGVs) in operation around the world — cars, trucks, buses, and other industrial vehicles — totaled about 10 million. Aggregate data offered by nearly 90 countries indicates that during 2013, the global NGV population exceeded 20 million vehicles. In the next three years, it is anticipated that this number will approach 35 million vehicles. By 2023, NGVs could number more than 65 million (see Fig. 1, top right).

In 2013 alone, it is estimated that nearly 5.1 million NGVs were delivered to customers. By way of comparison, the general automotive industry manufactured about 87 million vehicles (of all types). Based on strong demand in Argentina, Brazil, China, India, Iran, Italy and Pakistan, NGV deliveries are expected to reach nearly 5.8 million vehicles in 2014 and could realistically grow to nearly 11 million per year by 2023. Vehicle types vary from country to country (see Fig. 2, bottom right), but on the whole, about 94 percent of the total represents passenger vehicles; almost 4 percent are mass-transit buses and the remainder are medium- to heavy-duty trucks, forklifts and other industrial and commercial vehicles. Aggregately, over the 10-year forecast, there will be a market for 75 million NGVs. The vast majority of these, approximately 94 percent, are expected to be equipped with high-pressure (≥ 200 bar/ $\geq 2,900$ psi) fuel storage systems. The balance will be equipped with liquefied natural gas systems, wherein the natural gas is cooled to cryogenic temperatures ($-162^{\circ}\text{C}/-260^{\circ}\text{F}$) for storage at relatively low pressure (4 to 5 psi/0.28 bar) in a liquid state.

HYDROGEN FUELS ON THE RISE

Although CNG is commanding greater market share among global automotive OEMs, there has been a renewed push toward hydrogen fuel cell-powered electric vehicles (FCVs). Granted, past promises about the marketability of such systems were received with what was then well-deserved skepticism: If the predictions of policy makers and marketers had been accurate a decade ago, there would be more than 5 million FCVs on the road today (see “Learn More,” p. 26). In 2013, the actual number of transportation fuel cells

Global Natural Gas Vehicle (NGV) Population

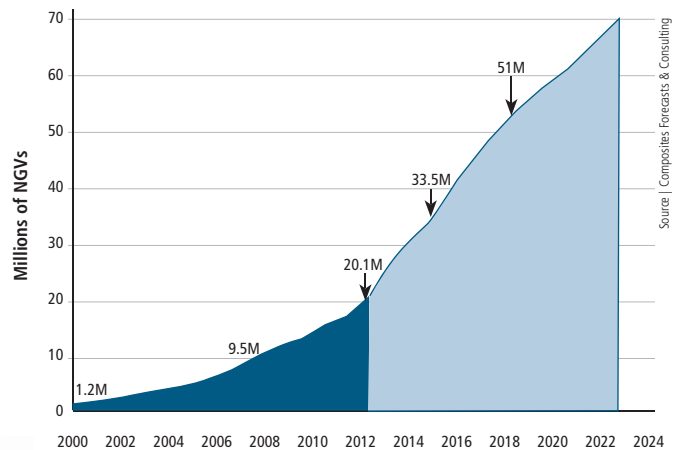
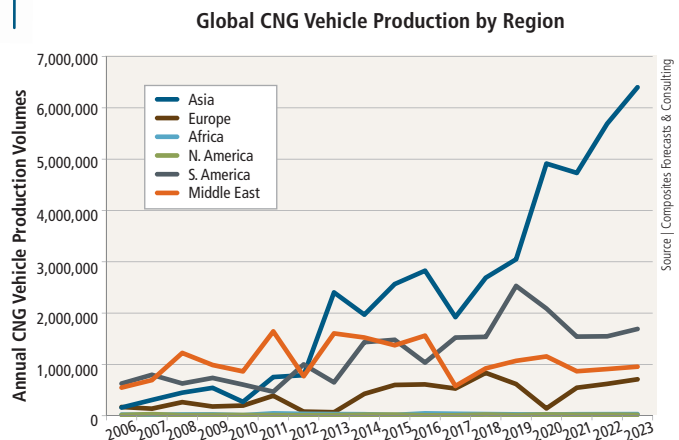


Fig. 1: By 2023, natural gas-powered vehicles (NGVs) could number more than 65 million.

delivered to customers *declined* to about 2,200 units, compared to approximately 2,700 units in 2012. Currently, the fielded fleet of FCVs around the globe stands at about 15,000, with a few hundred buses, trucks, and forklifts in commercial service. This situation, however, is beginning to change. Since 2007, 13 automotive OEMs have released FCV demonstrators and test fleets. These FCVs include the Chevrolet *Equinox Fuel Cell*, the Honda *FCX Clarity*, the Hyundai *ix35 Fuel Cell*, and the Mercedes-Benz *B-Class F-Cell*. Notably, in 2015, Toyota Motor Corp. (Aichi, Japan) expects to be the first company to offer a commercial FCV. Sales in Japan are expected to begin in April 2015 and open in Europe and the U.S. later in the year. Most importantly, Toyota won't be alone. Hyundai is expected to follow suit, and Honda, Nissan, Ford, BMW and others plan to join them no later than 2017. These passenger-vehicle brands, combined with mass-transit buses and limited volumes of commercial trucks, are poised to make hydrogen-powered vehicles — finally — a reality.

Fig. 2: Annual NGV deliveries could grow to nearly 11 million by 2023.



Source | Composites Forecasts & Consulting

Source | Composites Forecasts & Consulting

CT DECEMBER 2014



Source: Hexagon Composites



Composites manufacturers soon will be producing thousands of scaled-up composite-reinforced pressure vessels like these for gas transport. Some of the massive tank designs now under development will weigh in excess of 30,000 lb/13,607 kg each. ■

Encouragingly, the number of refueling stations needed to support these vehicles is beginning to grow rapidly throughout Japan, Germany, the U.K. and other early adopters (the U.S. among them but, so far, only in California). Globally there are approximately

325 hydrogen refueling stations. Only 25 were added in 2013. During the next two years, however, Japan and California are planning to bring online a combined 100 new hydrogen refueling stations. Germany expects to add about 400 refueling stations by 2023. This analysis forecasts that at least 2,500 refueling stations will be operational globally by 2023. Using the CNG industry as a model, these hydrogen refueling stations have the potential to support between 10 million and 20 million vehicles.

Based on a fairly conservative view of how fuel cell manufacturing capacity will scale up, the number of new-build FCVs was expected to double this year compared to 2013, totaling about 4,000 vehicles. Despite this relatively small number as a starting point, it is plausible that annual production could climb to approximately 200,000 vehicles per year by 2023. This would create sizeable demand for high-pressure hydrogen storage tanks (CNG Type III, IV, and V pressure vessels, described in the sidebar, below).

In addition to the above, there is a compelling outlier: A number of small companies are developing products and technologies that could help existing operators of medium- and heavy-duty trucks *convert their diesel engines to use either natural gas or hy-*

CNG TANKS: PRESSURE VESSEL EPICENTER

In the pressure vessel market, there are a number of competing designs offered around the world, including a small number of new CNG Type V “linerless” designs, which have recently received regulatory approval for use in vehicle applications. A brief description of today’s five design types follows:

- **CNG Type I:** All-metal construction, generally steel.
- **CNG Type II:** Mostly steel or aluminum with a fiber-reinforced polymer overwrap in the hoop direction, featuring glass, carbon or basalt fiber; the metal vessel and wound composite materials share about equal structural loading.
- **CNG Type III:** Metal liner (typically aluminum) with full carbon fiber composite overwrap; the composite materials carry the structural loads.
- **CNG Type IV:** Metal-free construction. A carbon fiber or hybrid carbon/glass fiber composite is filament wound over a thermoplastic polymer (typically HDPE or polyamide) liner; the composite materials carry the structural loads.
- **CNG Type V:** An all-composite construction. The vessel is linerless, and features a carbon fiber or hybrid carbon/glass fiber composite wound over a collapsible or sacrificial mandrel; the composite materials carry all the loads.

Each type of pressure vessel has its benefits and liabilities. CNG Type I vessels are the least expensive, with estimated production costs of roughly \$5 per liter of volume. The metalworking skills and equipment needed to produce them are widely available internationally. To their detriment, Type I vessels also are the heaviest, weighing approximately 3.0 lb/liter (1.4 kg/liter). By comparison, CNG Type II vessels cost about 50 percent more to manufacture but can reduce the weight of the storage containers by 30 to 40 percent. Type III and Type IV vessels take the weight savings even further, weighing between 0.75 and 1.0 lb/liter (0.3 to 0.45 kg/liter). The cost of Type III and IV vessels, however, is roughly

twice that of Type II vessels and 3.5 times greater than Type I tanks. Types III and IV, moreover, are keys to the current growth equation for three reasons. First, constructing pressure vessels, in whole or in part, from composites reduces fuel system and vehicle weight. On a typical transit bus or commercial truck, for example, the use of Type III and Type IV vessels easily could reduce the weight of the gas containment system by more than 1,000 lb (454 kg). This weight reduction would not only improve fuel economy but also increase load-carrying capacity and introduce other operational benefits, making it possible for the more expensive tanks to buy their way onto vehicles. Second, composite vessels extend the practical limit for gas containment pressures and provide better energy storage density. For many high-pressure applications — requiring cylinders rated at 5,000 psi (344.7 bar) or greater — Type III and Type IV vessels represent the most practical solution. Third, composite materials significantly improve a pressure vessel’s corrosion resistance and overall safety. For composite vessels that incorporate carbon fiber tow as reinforcement, the excellent fatigue resistance of these fibers also extends the vessel’s service life. Carbon fiber-reinforced Type III and Type IV pressure vessels can remain in use for as many as 30 years before they require replacement — *twice* the interval allowed for Type I and Type II vessels.

New to the fray are Type V vessels. Certified in 2013, they represent the current state-of-the-art in terms of weight-to-pressure ratio. Composite Technology Development (Lafayette, Colo.) and Clean NG (Tulsa, Okla.) are reported to offer an additional 10 to 20 percent weight reduction compared to CNG Type IV vessels (See “Learn More,” p. 26). By virtue of the simplified laminate, it is believed, Type V vessels will eventually become less expensive options than the CNG Type III and IV vessels. And this is expected to be true despite some higher materials costs, owing to new toughened epoxy resin systems and the nanocomposites needed to prevent gas leakage in the absence of a liner.

drogen fuels. Truck operators would be offered systems that include new fuel injector systems, fuel storage and conditioning systems and new electronic control units. Adoption of such “retrofit kits” could enable owners of 310 million in-service medium- and heavy-duty trucks to meet increasingly stringent emissions requirements.



— CNG Type V pressure vessels, filament or tape wound directly over collapsible or dissolvable mandrels, don't need liners, could potentially reduce pressure vessel weight by 10 to 20 percent, and might, eventually, reduce manufacturing costs, compared to Type III and Type IV vessels. ■

Source | Clean NG

VALUE IN GAS TRANSPORT

Gas transport systems also have been an area of recent new growth. These systems are designed either to transport gaseous fuels from stranded production fields or to deliver these fuels to markets in which building a pipeline transport system is not feasible. Compared to the tanks used in NGVs and FCVs (typically 30 to 200 liters/8 to 53 gal in capacity), this new generation of pressure vessels is much larger. The first to market, manufactured by Hexagon Lincoln (Lincoln, Neb.) under the trademark Titan, have an internal volume of more than 6,000 liters/1,585 gal (see the photo on p. 24).

Development of gaseous fuel transport systems has been underway since 2006. Lincoln Composites opened its first dedicated facility for manufacturing these vessels in 2009. Initial certifications for the Lincoln products were awarded in 2010 and first customer deliveries followed soon thereafter. Other companies, Luxfer Gas Cylinders (Salford, U.K.), through its acquisition of Dynetek Industries in 2012, and Quantum Technologies Worldwide Inc. (Lake Forest, Calif.) among them, have developed similarly sized pressure vessel products.

Potentially bigger than the market for mammoth ground-transport cylinders is the prospect of shipping large volumes of CNG over the world's waterways. Although gas transport ships equipped with carbon fiber composite containment vessels have not yet made it into service, there are several development teams engaged in active pursuit of this opportunity.

So what is bigger than mammoth? Imagine 100, 200 or more CFRP pressure vessels on a single ship — each vessel at least as large and, in some cases, several times larger than the Titan.

These types of vessels and transport ships are under consideration for a number of markets. Candidates include island nations in Asia, such as Indonesia, and coastal population centers around the world. Although such projects are still in early-stage design and development, this forecast includes the possibility that at least a few pressure-vessel-equipped transport ships will be commissioned to serve South American and island-bound markets.

PRESSURE VESSEL DEMAND

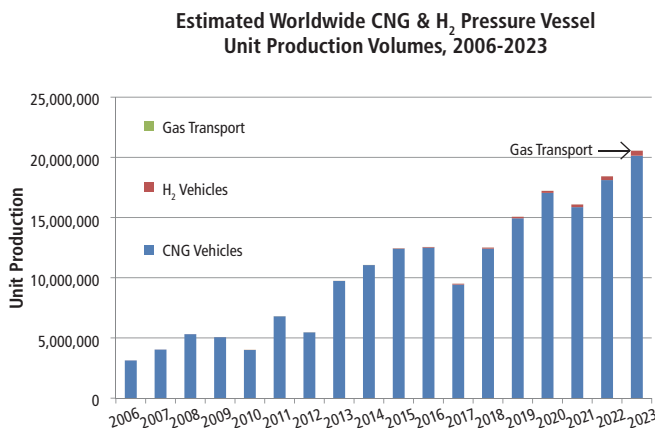
Over the past two years, this collective demand has prompted a dramatic increase in pressure vessel production numbers. Overall annual production (all vessel types) stood at approximately 5.5 million units in 2012, valued at \$1.1 billion. With increasing demand in 2013, the global market rose to 9.7 million units, worth \$2.3 billion. The rush in demand motivated a number of vessel fabricators to significantly expand their capacity — much of which

became operational this year. By 2016, this analysis forecasts that production will approach 12.5 million pressure vessels and could grow to more than 20 million units by the end of the forecast (see Fig. 3, below). Over the entire 2014-2023 period, predicted production of pressure vessels represents about \$45 billion in potential sales, broken down regionally as follows:

- Europe.....14%
- North America.....<1%
- Asia-Pacific.....61%
- Latin & South America.....12%
- Africa<1%
- Middle East12%

Our research into the activities of the world's growing number of pressure vessel manufacturers uncovered some intriguing trends. A decade ago, only a dozen or so companies offered CNG Type III and Type IV pressure vessels. As the market has grown, so has the supply base. At least 30 companies now compete in this space. Further, many of them offer a wide range of products, suitable for virtually every conceivable vehicle application (see a sampling of this diversity in Fig. 4, at left). Many new entrants are still, comparatively, quite small, but their formation nevertheless lends credence to the observed trend: clearly greater market acceptance of carbon fiber composite cylinder systems.

Fig. 3: Overall vehicle pressure vessel production (all vessel types) could reach 20 million units in 2023. Growth will be dominated by CNG-powered vehicles (see lower chart for estimated vehicle numbers (M = million)). ■



Source | Composites Forecasts & Consulting

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Source | Composites Forecasts & Consulting

Comparison of 20 Key Composite Pressure Vessel Manufacturers						
Company	Type I	Type II	Type III	Type IV	Type V	Est. 2013 CNG Market Share
3M/Xperion				✓		1.0%
Beijing ChinaTank Industry Co. Ltd.			✓			0.1%
Cilbras (subsidiary of Praxair)	✓	✓				5.5%
CleanNG					✓	0.0%
CNG Cylinders International			✓			0.2%
Cobham Composites			✓	✓		<0.1%
COMAT GmbH				✓		<0.1%
Composite Technology Development					✓	0.1%
Composites Aquitaine		✓	✓	✓		<0.1%
Faber Industrie SpA	✓	✓	✓	✓		28.4%
GASTANK AB				✓		0.2%
Hexagon Lincoln				✓		6.3%
INFLEX-Argentoil S.A.	✓	✓		✓		8.8%
Luxfer Gas Cylinder (includes Dynetek & Vexxel)		✓	✓	✓		11.4%
MCS Technologies GmbH	✓	✓		✓		0.7%
Pressed Steel Tank	✓	✓	✓	✓		<0.1%
Quantum Technologies Worldwide			✓			1.0%
Ullit				✓		0.7%
Worthington Cylinders (including SCI)	✓	✓	✓			3.3%
Xperion				✓		1.0%
Combined Market Share of Global Vehicle Pressure Vessel Business						68.8%

Fig. 4: At least 30 companies now offer pressure vessels suitable for vehicle applications. The 20 listed here are key players that demonstrate the broad product diversity and the availability of Types III and IV. ■

Source | Composites Forecasts & Consulting

Change in Pressure Vessel Demand by Vessel Type									
CNG Vessel Type	2007	2009	2011	2013	2015	2017	2019	2021	2023
Type I	89%	88%	84%	82%	72%	67%	65%	56%	54%
Type II	9%	11%	14%	16%	25%	26%	24%	30%	31%
Type III	2%	1%	1%	1%	2%	5%	5%	7%	8%
Type IV	1%	1%	1%	<1%	1%	2%	5%	7%	7%
Type V	-	-	-	-	<1%	<1%	<1%	<1%	<1%

Estimated Pressure Vessel Unit Production									
Market Segment	2007	2009	2011	2013	2015	2017	2019	2021	2023
CNG Vehicles	4.03M	5.06M	6.79M	9.73M	12.41M	9.43M	15.87M	14.94M	20.14M
H ₂ Vehicles	1,000	5,000	4,000	5,500	32,000	73,200	125,000	219,800	412,000
Gas Transport	0	0	40	400	1,200	2,000	2,650	3,500	4,600

Fig. 5: Going forward, growth in the demand for CNG Type 1 (all-metal) vessels will be outstripped by growth in the demand for vessels that incorporate composites (CNG Types II, III, IV and V). ■

Estimated Pressure Vessel Composite Material Requirements, 2006-2023

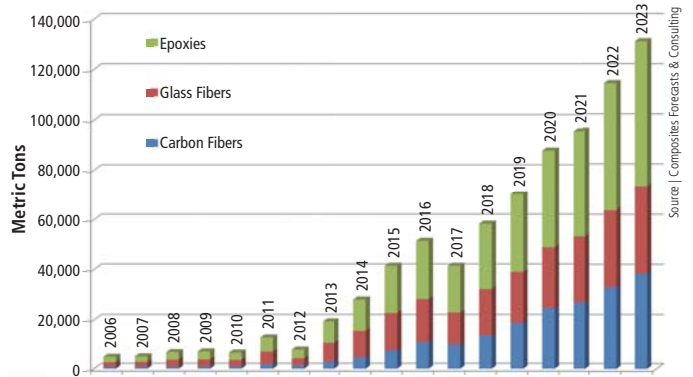


Fig. 6: By 2023, carbon fiber will account for up to 26 percent of pressure vessel materials, while glass and basalt fibers, combined, will make up slightly less than 30 percent. ■

DOING THE MARKET MATH

The developing markets, which place heavy emphasis on passenger vehicles, continue to demand large volumes of CNG Type I and II (metal-centric) pressure vessels. But the number of all-metal Type I pressure vessels is only expected to grow at an average annual rate of about 3 percent over the forecast. Unit production volumes on the whole, however, are rising about 10 percent each year. That means the proportional market shares of vessels that incorporate composites — CNG Types II, III, IV and V — are growing at a much faster rate (see Fig. 5, bottom left).

CNG Type III and IV vessels, which consume the greatest volumes of carbon fiber composites, are growing largely as a result of demand from OEMs of mass-transit busses and commercial trucks (Class 6 to Class 8). For these medium- and heavy-duty vehicles, the higher fuel density and low mass of these vessels can enable greater range and fuel economy, increase the operational interval between refueling stops, and help to reduce maintenance costs.



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

Read more about the recent history of hydrogen fuel-cell power and the pressure vessels those applications require in the following:

“The markets: Fuels cells and batteries (2014) online | short.compositesworld.com/M-FCandB14.

“Fuel cells (finally) set to power composites growth,” (CT December 2010, p. 5) | short.compositesworld.com/FCGrowth.

Read more about the genesis and performance capabilities of Composite Technology Development’s CNG Type V vessel in “Next-generation pressure vessels,” in CT’s sister magazine *High-Performance Composites (HPC July 2012, p. 40)* | short.compositesworld.com/1hQ7I5mz.

Historically, these high-performance pressure vessel types have been sold primarily into European, North American, and well-developed Asian economies. When the E.U.'s Euro 6 Standard went into effect earlier this year, the economics that support CNG- and hydrogen-powered buses and trucks became even more compelling and, therefore, should significantly expand the demand. In North America, the availability of shale gas now gives the operators of high-use, and formerly diesel-powered, vehicles a return on their \$20,000 to \$30,000 cost premium for their investment in CNG-powered vehicles in about *one year*. After that, the less expensive CNG enhances bottomline profit. South Korea, China, India, Turkey, Argentina, Russia and Brazil also are seeing a notable increase in demand for the Type III and Type IV vessels. This increase has been a boon to established pressure-vessel manufacturers and has provided the impetus for expanded domestic production.

GROWING MARKET FOR COMPOSITES

In step with the market for pressure vessels, demand for the raw materials necessary to produce those vessels is growing. Delivery of more than 150 million pressure vessels is forecast between 2014 and 2023. During this forecast period, vessel fabricators will need to procure approximately 15 billion lb (6.84 million metric tonnes) of raw materials to support the predicted production volumes. Of this total, about 11 percent will be composed of composite materials (epoxy resins and glass, basalt and carbon fibers, etc.).

During 2013, the estimated total volume of composite raw materials delivered to vessel manufacturers was 42.7 million lb (8,768 metric tonnes). Epoxy resin systems make up the largest component of this volume, at 45 percent. High-tensile-strength carbon fiber currently accounts for 15 percent, but as the pressure vessel market continues to move toward greater adoption of Type II, III and IV cylinders, carbon fiber's relative share of the materials market is expected to grow dramatically. By the end of the forecast, carbon fiber is expected to account for as much as 26 percent of the materials total.

In applications where weight is less critical (for example, already small, light-weight passenger vehicles), for which the upfront purchase price is a significant issue, high-performance glass fiber and basalt fibers could see significant adoption. Despite their lower cost, however, glass and basalt fibers will co-own slightly less than a 30 percent share (see Fig. 6, top right on p. 26).

As a result, annual demand for raw carbon fiber will grow from 4,684 metric tonnes (more than 10.3 million lb) of fiber in 2014 to as much as 38,638 metric tonnes

(nearly 85.2 million lb) by 2023 — an average annual growth rate of nearly 30 percent. Over the 10-year outlook, these figures equate to more than \$12 billion in total composite raw material sales, including about \$5.8 billion in carbon fibers (primarily 12K, 24K, and large-tow formats).

To keep up with demand, carbon fiber suppliers will likely need to add 30,000 metric tonnes (more than 66.1 million lb) of low-cost, standard-modulus, high-strength product. This is considered a key reason why Toray Industries (Tokyo, Japan) acquired Zoltek (St. Louis, Mo.) in 2013 and Mitsubishi Rayon Carbon Fiber and Composites recently announced plans to double carbon fiber production capacity at its existing site in Sacramento, Calif. Because much of the market demand for *and* many emerging suppliers of pressure vessels will come from South Korea and China, domestic fiber suppliers there will likely see considerable growth as well. If this analysis and its predictions are accurate, use of carbon fiber in pressure vessel manufacturing could rival carbon fiber use by fabricators in today's leading segments for carbon composite applications: wind turbine blades, automobiles and aircraft. | CT |



Contributing Writer

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The CFRP lifecycle loop is indeed closing: Carbon fiber reclaimed from end-of-life sources — aging aircraft and, eventually, scrapped automobiles — can be repurposed for use in automotive composites applications. But current RCF production outpaces uptake from commercial applications. ■

Source | MIFRCF

Recycled carbon fiber update: CLOSING THE CFRP LIFECYCLE LOOP

Commercial production of recycled carbon fiber currently outpaces applications for it, but materials characterization and new technology demonstrations promise to close the gap.

In the automotive industry, carbon fiber is big news. Despite grumblings about its cost, most auto OEMs are, at a minimum, privately conducting R&D efforts in active pursuit of carbon fiber-reinforced polymers (CFRP) — a key means to lightweight production passenger vehicles and light trucks — as they seek to comply with impending CO₂ emission and fuel-economy regulations. European automakers are leading the way. Some have already fielded commercial vehicles with significant CFRP content, creating quite a stir, both in the trade press and public media.

AN INCONVENIENT TRUTH

Largely absent from these discussions until recently has been the cost of, and the means for, compliance with the European Union (EU) end-of-life-vehicle (ELV) directive. It requires that 85 percent, by weight, of the materials used in each car and light truck built for the 2015 model year and beyond must be reusable or recyclable. Metals and neat plastics — amorphous materials — have proven recycling track records. But CFRP does not. Yes, the ELV does permit some disposal — up to 10 percent of the

Fig. 1: Current commercial RCF production uses pyrolysis and outputs milled and chopped fiber, reinforced thermoplastic pellets for injection molding, nonwoven roll goods and more advanced 3-D and aligned preforms. ■

vehicle's weight can be incinerated and the remaining 5 percent can find its way into a landfill. But the math doesn't work: If carbon fiber is to become a significant tool in the automaker's lightweighting toolbox, *recycling* of CFRP from ELVs is an imperative. The good news is that this problem, once considered almost intractable, is proceeding apace toward solution, thanks to a determined and growing effort to develop CFRP recycling technologies.

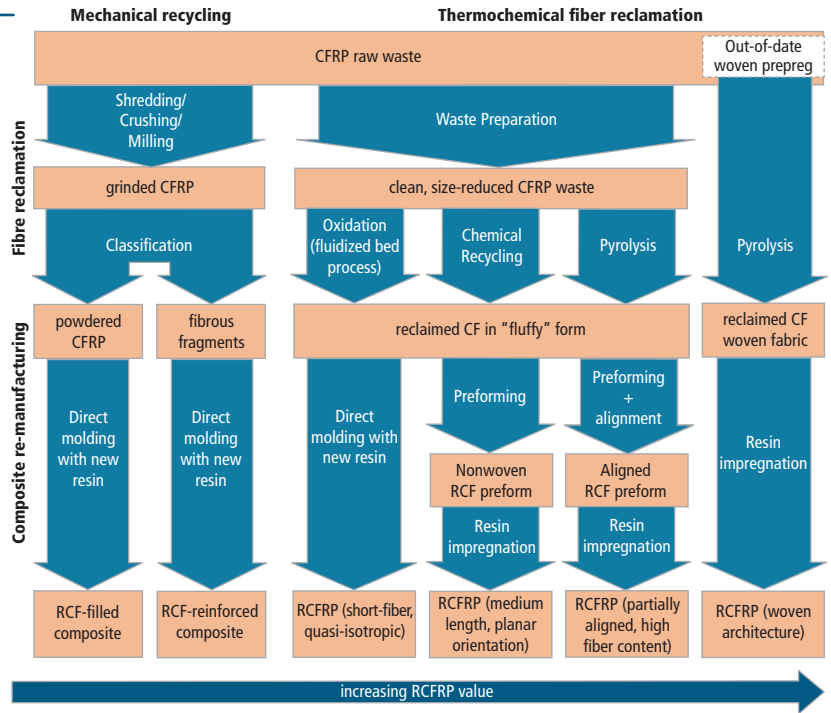
TWO-PRONGED ATTACK

Recycling strategies are focused on two fronts. The first is the reclamation and repurposing of CFRP waste streams (off-spec material, scrap from cutting/trimming operations, etc.) in the form of dry fiber and prepreg.

Tim Rademacker, a managing director at CFK Valley Recycling (Stade, Germany), cites an estimated demand for virgin fiber in 2014 (See Fig. 3, p. 30) of 50,000 metric tonnes (110 million lb), noting that if 30 percent of that ends up as production waste — a commonly quoted figure — the result is ~10,000 metric tonnes/~22 million lb of commercial recycled carbon fiber (RCF) *before* end-of-life (EOL) structures are considered. Recyclers predict that automakers will be big beneficiaries of fibers reclaimed from carbon fiber waste streams generated by fabricators in *other* industries. "We can receive up to 50 metric tonnes of CF waste in a given month from wind," claims Alex Edge, sales and business development manager for recycler ELG Carbon Fibre (Coseley, U.K.), noting that much of it is generated when materials are kitted for turbine blade layup.

"Most of *our* incoming waste is from aerospace and automotive," says Rademacker, who, unlike Edge, says, "We are not seeing much from wind yet, which still uses mostly glass fiber."

The RCF from aircraft sources is especially promising. "Aerospace generates tons of waste," says Edge," but it has to be used in *other*



Source | Handbook of Recycling: State-of-the-art for Practitioners, Analysts, and Scientists by Ernst Worrell & Markus Reuter, Elsevier BV (Amsterdam, The Netherlands), © 2014

markets." One big reason is that fiber reclaimed by current means is chopped. Currently unusable in wind turbine and aircraft structures (aircraft *interiors* are the one exception), discontinuous fiber has long been a staple of automotive composites, particularly in auto interiors and under the hood. "We have been doing a lot of work over the past few years with large OEMs, both in aerospace waste supply and automotive end-use of recycled products," says Edge.

Given this, the recycler's feedstock today is primarily from waste. Recyclers, however, don't see waste processing as an end in itself. In the longer term, they want to help users of CFRP "close the loop": If automakers must ensure that automotive materials are recyclable, then it is to their great advantage to *reuse* fiber reclaimed from EOL vehicles in the production of new vehicles. Waste processing, then, is seen as an important first step as recyclers gear up to process the increasing number of CFRP parts that will reach EOL every year. ►

Fig. 2: Recycler ELG Carbon Fibre (Coseley, U.K.) produces milled fiber (left, with average length of 100µ); chopped fiber (center, with random lengths (6 to 60 mm)); and lightly compacted thermoplastic pellets (right) made with milled or chopped fiber and matrix-compatible binders. ■



Source | ELG Carbon Fibre

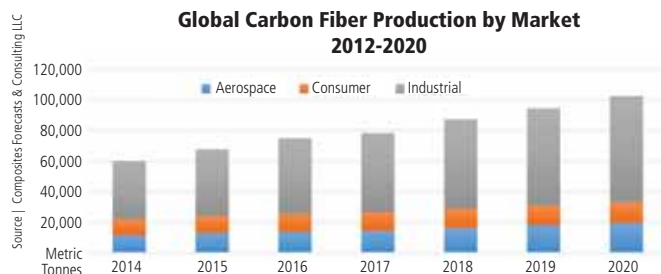


Fig. 3: Forecast sales growth from one carbon fiber producer aligns well with RCF potential in consumer and industrial applications. ■

Although several methods have been conceived for recycling carbon fiber, including some that maintain long fibers and even preserve fabric weaves, all of the current *commercial* RCF is subjected to *pyrolysis* (See Fig. 1, p. 29, and “Learn More” for more information about *solvolysis* and other alternatives.) Incoming waste is sorted by type (dry fiber, prepreg, EOL parts) and, in some cases, by fiber type. EOL parts are crushed or chopped, and all materials are shredded to a homogeneous size, which increases bulk for pyrolyzation. Pyrolysis vaporizes the remaining matrix material on crushed EOL parts and prepreg waste (which is then drawn off via ventilation), but, importantly, leaves the fiber intact. It also removes sizings and binders from the fibers. After pyrolysis, as noted below, custom conditioning may include tailored fiber sizing and/or binders applied to the reclaimed fiber’s surface for a customer’s specific reuse.

COMMERCIAL CAPACITY

In a few short years, recycling operations have progressed from pilot projects to commercial production facilities. Although their names have changed and others have joined the fray, the major players remain the same.

In 2011, German metals recycler ELG Haniel (Duisburg, Germany) acquired Recycled Carbon Fibre Ltd. (Coseley, U.K.; previously Milled Carbon Group) and its commercial-scale recycling plant (commissioned in 2009), renaming it ELG Carbon Fibre.

Why would a *metals* recycler enter the RCF market? “They saw more and more metals contaminated with carbon fiber and an opportunity to capture high value out of aerospace waste,” explains ELG Carbon Fibre’s Edge. “We process 2,000 metric tonnes [4.4 million lb] of waste and generate 1,000 metric tonnes of reclaimed CF per year using a patented pyrolysis process and a 21m/69-ft long belt furnace.”

ELG CF sorts the waste and shreds it. “We then use an automated system to call out a selected waste volume from one of four storage bunkers,” Edge details, “which is then transported to the furnace.” Fibers are then processed to produce chopped, milled or pelletized fiber products, and a needle-punched mat is in development.

Edge says interest in both milled-fiber and long-fiber pellets used in long fiber thermoplastics (LFTs) has increased. ELG CF is working with 10 to 20 LFT industry suppliers and offers a standard 6-mm/0.24-inch diameter pellet using 6-mm to 10-mm (roughly 0.2-inch to 0.4-inch) long fibers (see Fig. 2, p. 29.) The company says it can tailor formulations, such as a PEEK-compatible binder vs. the standard system for nylon (polyamide or PA) and polypropylene (PP) thermoplastics. “There is a big push for long-fiber injected parts,” Edge observes, “and CF has a real benefit vs. talc and silica fillers. We are well-matched to that outlet and have only recently started looking at the opportunity in thermoset compounds.”

Founded in 2005, Materials Innovation Technologies LLC (MIT LLC, Fletcher, N.C.) began reclaiming carbon fiber in 2009 and opened its Lake City, S.C., commercial recycling facility, MIT-RCF, on the strength of equity investments from South Carolina Research Authority (SCRA, Columbia, S.C.) and Toyota Tsusho America (Maryville, Tenn.). MIT-RCF processes streams from multiple sources: dry scrap from fiber manufacturers, braiders and weavers; uncured prepreg from prepreggers, Tier 1s and OEMs; and fully cured parts. Sorting is a priority. “Customers want a defined input for the preform or roll goods they will use,” explains MIT-RCF president and COO Mark Mauhar. “There is one type of part and one type of fiber per batch. We track the material pedigree very closely.”

After pyrolysis, MIT-RCF sells the resulting chopped RCF directly or converts it into LFT pellets or into rolls of chopped fiber mat. Mat weights range from 50 to 1,000 g/m² (1.5 to 29.5 oz/yd²), and in widths up to 49 inches/1.2m. Value-added products include blends of chopped carbon and thermoplastic fibers — e.g., 60 percent polyphenylene sulfide (PPS)/40 percent CF — produced by the firm’s proprietary Co-DEP process (see Fig. 4, below). MIT-RCF also fabricates net-shape preforms as large as 1.8m by 1.8m/5.9 ft by 5.9 ft, using its patented 3-DEP slurry forming process (see “Learn More”), which offers high uniformity (areal weight standard deviation of 1 to 3 percent) and cycle times of one to two minutes, regardless of size. Mauhar summarizes, “We have very flexible processes that can tailor materials and produce uniform thickness and weight with low variation in properties.”

Indeed, the company has multiple automotive parts on the path to adoption and is working to validate new high-speed processes to transform its RCF products into cost-effective automotive parts. MIT-RCF’s growth plan is to expand facilities once the market catches up. According to Mauhar, “We need to hit 3 [million] to 5 million lb/yr of reclaimed fiber sold before we expand capacity.”

Environmental and disposal services group Karl Meyer AG began work on recycling with CFK Valley e.V. (Stade, Germany) in 2005, establishing an industrial-scale RCF facility called CFK Valley Recycling, in 2007. In 2010, the company moved to Wischhafen, Germany. Today, its plant can yield up to 1,000 metric tonnes (more than 2.2 million lb) of RCF per year and has long-term disposal contracts with airframer Airbus (Toulouse, France), automakers



Fig. 4: Recycler MIT-RCF (Lake City, S.C.) converts chopped RCF into 3-DEP preforms, continuous nonwoven roll goods and pellets for LFT. Applications successfully demonstrated include automotive parts like the door bolster support for the Ford *Escape* and the 2014 *C7 Corvette*’s upper plenum (pictured here). ■

Bugatti (Molsheim, France) and BMW (Munich, Germany) and other CFRP market leaders, to guarantee its raw material supply. It also founded carboNXT GmbH as the distributor for its chopped and milled RCF products.

CFK Valley Recycling sees preparation of fiber for customer reuse as an important value-added feature of the recycler's mission (see Fig. 5, at right). The focus is fiber-to-matrix adhesion. "We have modified our process so that we have no bonding issues, in response to market demand," explains CFK's Rademacker. "For thermosets, we can reapply sizing, and for thermoplastics we can add a specific binder in order to maximize matrix adhesion." Fiber length also can be customized, for example, to meet compounding needs.

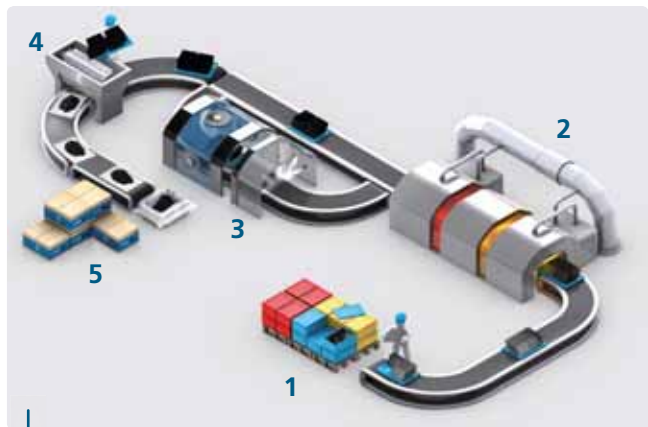
"We have invested in textile machinery and can produce nonwovens," adds Rademacker. These range in width from 1,100 to 1,300 mm (43 to 51 inches) at weights from 10 g/m² (0.3 oz/yd²), using a wet-lay process, to 600 g/m² (18 oz/yd²) using an air-lay method.

FROM PULL TO PUSH

Scaled up to deliver commercial quantities of customer-friendly RCF, the major players' footing is more firm, but the road ahead is not yet straight and smooth. Four years ago, the recyclers' big concern was the security of their raw material supply (see "Learn More"). But MIT-RCF's Mauhar says that's no longer the case: "Aircraft manufacturers are generating so much waste as they ramp production rates that the volume of scrap is ahead of the market for the reclaimed products." And there is no doubt that there will be a sufficient supply of EOL feedstocks: 35 million vehicles enter the recycling infrastructure each year — 13 million in North America and 11 million in Western Europe. Further, the earliest aircraft that were built with CFRP components are likely to reach EOL within the next 10 years, and more than 12,000 aircraft will be retired worldwide over the next two decades, just before the first CFRP-laden Boeing 787 and Airbus A350 XWB aircraft are ready to retire.

For fiber reclamation specialists, then, the present concern is reselling what they are already capable of processing. Current estimates of combined RCF capacity run from 3,500 to 5,000 metric tonnes (>7.5 million to 11 million lb) per year.

The greatest sales potential lies with high-volume automotive applications. Mauhar believes reuse of RCF could be accelerated if waste generators, recyclers and automotive users worked *together*

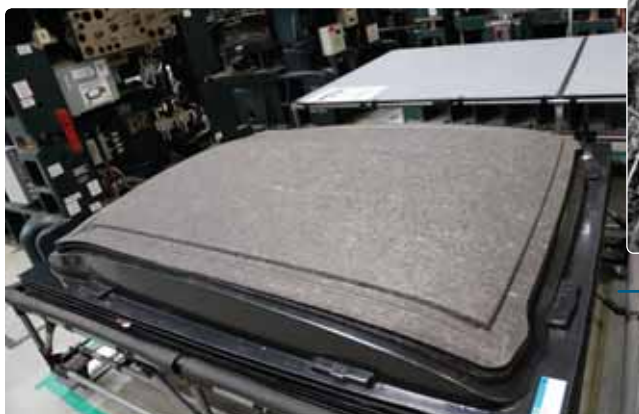


Source | CFK Valley Recycling

Fig. 5: CFK Valley Recycling touts an automated process that enables the company to offer RCF customers high-quality, customizable products, such as mats and veils. Process steps include: (1) sorting, (2) pyrolysis, (3) tailored surface treatment (4) cutting to tailored length and (5) distribution. ■

to complete required development. Although some fiber and textile producers (see "Learn More") and some OEMs are recycling their *own* waste — most notably, BMW — few players within the CFRP supply chain have committed to using RCF produced by commercial recyclers.

Recyclers admit that the market for RCF *applications* is lagging but claim that the issue is *not* mechanical performance: RCF studies reportedly show tensile strength and modulus well within fiber producers' targets for virgin products in industrial applications (see Figs. 6 & 7, p. 32). Further, reclamation of longer fibers is a possibility. According to a 2014 report by Hitachi Chemical (Tokyo, Japan), the Japan Carbon Fiber Manufacturers Assn. (JCMA) recycling plant now jointly managed by Toray Industries and the Teijin Group (both based in Tokyo, Japan) and Mitsubishi Rayon Co. (Osaka, Japan), has been expanded to include a pyrolysis process that, unlike JCMA's older 1,000 metric tonnes/yr (2.2 million lb/yr) line, *does not require preshredding*. Developed by Takayasu Co. Ltd. (Kakamigahara City, Japan), this new process reportedly has a capacity of 60 metric tonnes/yr (132,000 lb/yr). And even newer recycling methods, designed to reclaim *continuous* fibers (see "Learn More") and methods for aligning discontinuous RCF (e.g., oriented vs. ►



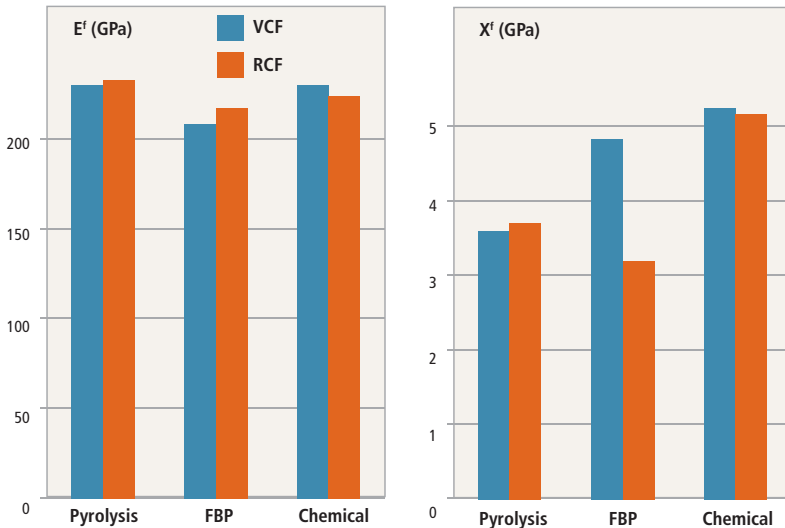
Source (both photos) | BMW

SGL Automotive Carbon Fibers (Wackersdorf, Germany) processes CF scrap from weaving and preform kitting operations for reuse in the BMW *i*-series CFRP Life Module. Reclaimed fiber is incorporated into stitched nonwoven materials (above), which are then molded into the *i3*'s rear seat structure and roof sections for both the BMW *i3* (left) and *i8*. ■



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Recycled Fiber vs. Virgin Fiber



*FBP = Fluidized Bed Process (see "Learn More," p. 33)

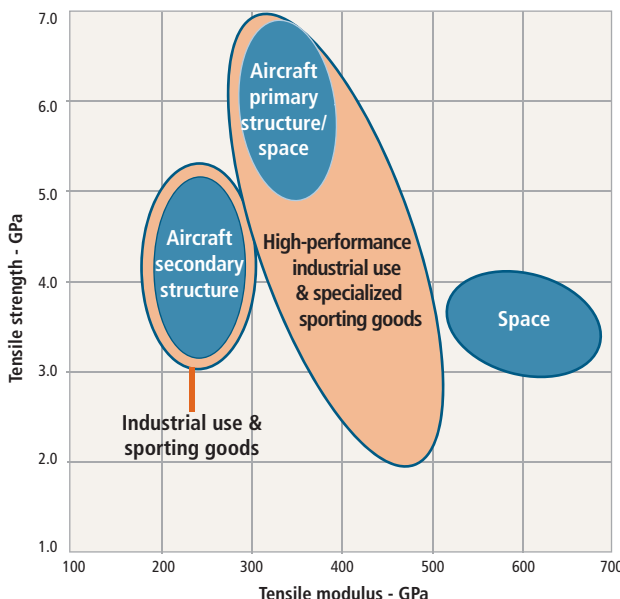
Fig. 6: Comparison of recycled carbon fiber (RCF) vs. virgin carbon fiber (VCF) in terms of modulus (E) and strength (X).

random) indicate that, sometime soon, recyclers might be able to offer RCF products capable of performance near aerospace targets.

Commercial recyclers also point out that RCF offers a 20 to 40 percent cost savings vs. virgin fiber. That's no empty claim. The Carbon fiber/Amid (short for polyamide)/Metal Interior Structure using Multi-material System Approach (CAMISMA) project recently demonstrated the potential for RCF in thermoplastic processes. Tier 1 automotive seat supplier Johnson Controls Inc. (JCI, Burscheid, Germany) and partners successfully molded a CFRP seat back us-

Fig 7: When it is reused in new parts, pyrolysis-produced RCF can reach the carbon fiber producer-defined industrial envelope of 200 to 300 GPa for tensile modulus and minimum 3 GPa for tensile strength.

Classification by Mechanical Characteristics of Conventional Carbon Fiber



PROVING RCFRP PRODUCIBILITY

Those looking for an educational demonstration of this sort, however, need look no further than the high-profile BMW *i3* and *i8* vehicles (see "Learn More"). Somewhat obscured by the publicity surrounding BMW's development of its vertically integrated supply chain for *virgin* heavy tow, is the automaker's reuse of production scrap in the roofs for the *i3* and *i8* and in the *i3*'s rear seat structure. SGL Automotive Carbon Fibers (SGL ACF, Wackersdorf, Germany) collects weaving and preform-kitting scraps from production of the *i* vehicles' CFRP Life Modules and cuts them into chips, which are then processed to open the constituent fibers, followed by mechanical carding to disentangle and align the fibers (see "Learn More"). The fibers are then layered in different angles — according to where the final part will be used — and stitched to form nonwoven textiles (mats or fleece). The nonwovens for the roof structures are molded using high-pressure RTM (HP-RTM) and Araldite epoxy resin from Huntsman Advanced Materials (The Woodlands, Texas and Basel, Switzerland), while the self-supporting rear seat shell uses BASF's (Ludwigshafen, Germany) Elastolit polyurethane (PUR), reportedly the first CF/PUR part in series production. Molded by automotive seating specialist F.S. Fehrer (Kitzingen, Germany), the part also integrates a cupholder attachment and a storage tray. This reduces assembly steps and part weight, *and* the part meets crash requirements with a mere 1.4-mm/0.6-inch wall thickness.

MIT-RCF also sees the necessity for demonstrating that RCF products can meet automaker needs (Fig. 8, p. 33, compares RCF materials with legacy materials). Mauhar says, "We are working with RocTool North America [Charlotte, N.C.] to demonstrate our materials in its fast-cycle-time molding processes." Toward that end, RocTool is seeking to improve the speed of RCF thermoforming via its Light Induction Tooling (LIT). LIT uses an induction-heated (no fluids) and cooled steel cavity tool and *silicone* core with vacuum assist to mold parts *without preform preheating* and only 8 bar of air pressure. RocTool says the tools cost one-fifth that of those used in traditional methods with cycle times as short as 105 seconds.

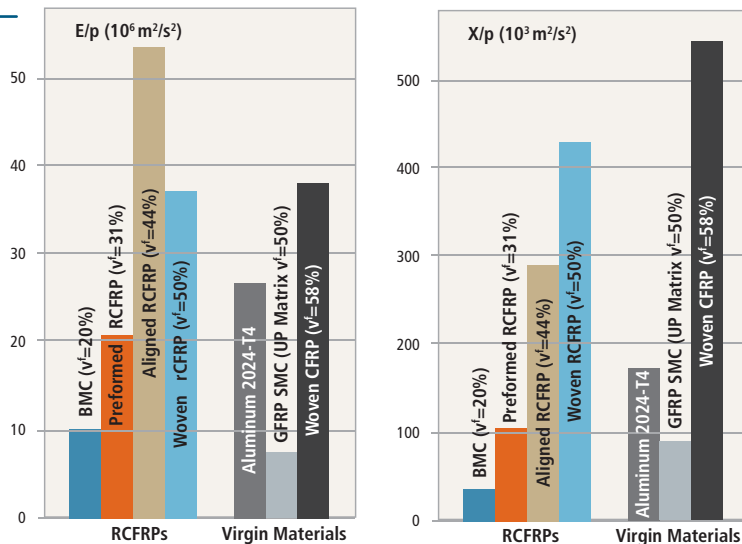
Trialed materials include PP, PET and PA12 with RCF and other

Fig 8: Specific mechanical properties (divided by density, (ρ) including tensile modulus (E) and tensile strength (X) of typical RCFRP vs. virgin structural materials. ■

fibers, and, according to RocTool North America president Mathieu Boulanger, LIT offers both textured and glossy surfaces. Capabilities can include inmold decoration, and postmold results reportedly include zero warpage, even with thin (1-mm/0.04-inch) laminates. “The opportunity to mold thousands of parts per day using RCF materials could really change the current landscape,” he says. Mauhar adds that volume production is a *must* if significant percentages of recycled CFRP waste are to be reused successfully and complete the circle for carbon composites sustainability.

REAL PROGRESS = REAL PARTS

CFK’s Rademacker believes that CF use will increase, especially in autocomposites, where BMW has clearly demonstrated the value of both virgin fiber and recycled production waste, each optimized accordingly. “They will transfer this into their series products for use in partial structures,” Rademacker predicts. Indeed, SGL ACF says 10 percent of the CFRP used in the BMW *i* vehicles is recycled, and BMW has already declared that it will apply its CFRP technology beyond its *i* and *M* models. “Here is where there is opportunity for recycled carbon fiber as well.” He also sees others in the auto industry looking increasingly to thermoplastic applications. Quoted widely by the auto industry press, BMW’s lightweight construction manager Franz Storckenmaier has listed seat frames, instrument panel frames and spare wheels as RCF targets and recently told *Auto Express* magazine: “Carbon fiber



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is an expensive material to work with, but if you are using production waste, then it’s a different cost structure from working up raw carbon fiber.”

Indeed, MIT-RCF has developed a hood inner for a mid-volume vehicle that is completing OEM demonstration. The company sees potential for more applications in luxury models. It also has submitted a quote to a Tier 1 supplier for an SUV produced at 500,000 vehicles/year. “This is an interior part, using our Co-DEP process and thermoplastic fibers, which can be mixed with RCF and other fibers,” Mauhar explains, claiming that MIT-RCF offers a 30 percent lighter, cost-neutral replacement for the natural fiber/thermoplastic used for door inners and interior backing structures in Europe, and a 40 percent lighter, cost-neutral replacement for the injection molded acrylonitrile butadiene styrene (ABS) used in the U.S.

But Rademacker says several issues still hinder widespread adoption of RCF. Working only with large CF waste producers, he contends, isn’t beneficial because they already have established supplier bases that they are not interested in disrupting because the materials and suppliers are already qualified. He suggests that opportunities lie, instead, with large waste sources that also need new forms of raw CF materials — forms that still need to be refined and qualified. This is one big reason why recyclers are targeting the auto industry. Further, virgin fiber customers are accustomed to specifying strength and modulus. “I can sort the incoming waste and affect the RCF properties,” Rademacker explains, “but the industry needs applications that fit the products we can supply, based on the waste streams already established. The designers need to think about where these products can be used,” he adds. “We still must develop a better understanding of what RCF products will produce in the final parts.” | CT |

CW LEARN MORE
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Read this article online | <http://short.compositesworld.com/RCFUpdate>.

Read more about solvolysis and other alternatives for reclaiming carbon fibers in “Recycling carbon fibre reinforced polymers for structural applications: Technology review and market outlook,” authored by Soraia Pimenta and Silvestre Pinho | Copies may be requested at www.sciencedirect.com/science/article/pii/S0956053X10004976.

Read more about MIT-RCF’s effort to introduce RCF processed by its 3-Dep system into auto parts | short.compositesworld.com/4f4j9pzn.

Four years ago, our previous coverage of this subject in *CT*’s sister publication *High-Performance Composites* highlighted recycler concern about raw material availability. See “Carbon fiber reclamation: Going commercial” | *HPC* March 2010 (p. 32) | short.compositesworld.com/Ah8s0EcZ.

Read about recycling continuous carbon fiber, and potential applications, in the *CW Blog* | short.compositesworld.com/RCFBlog.

Read more about the impact of recycled fiber alignment in the online sidebar “Recycled carbon fiber: Comparing Cost and Properties” | short.compositesworld.com/RCF-CvP.

Read about recycling-proactive textile producers online in “Recycled carbon fiber update: The supply side” | short.compositesworld.com/RCF-Supply.



Senior Editor

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CAMISMA's car seat back



Johnson Controls Inc. (Burscheid, Germany) and its CAMISMA collaborators combined the best features of two short-cycle molding processes, thermoforming and injection molding, and three distinct material forms to fabricate a complex, ribbed automotive seat back with metal inserts in an automated, one-shot, 90-second cycle. The seat back design cut weight by 40 percent vs. conventional metal construction by integrating parts and functions into a unitized, mass-producible multimaterial structure. ■

HYBRID COMPOSITE FOR HIGH VOLUME

Recycled fibers, in-situ polymerized PA12 and steel inserts combined in one-shot process to cut weight 40 percent at competitive cost, cycle time and safety.

Carbon fiber-reinforced plastic (CFRP) is an attractive solution for automotive lightweighting, but the material and manufacturing costs can exceed 10 times that of steel. The Carbon fiber/Amid (short for polyamide)/Metal Interior Structure using Multi-material System Approach (CAMISMA) collaborative aims to change that equation. Funded by the German Federal Ministry of Education and Research (BMBF, Bonn and Berlin), CAMISMA's goals include:

- Reuse of byproducts from carbon fiber production and/or recycled fibers to help limit incremental component cost (i.e., cost due to new materials and manufacturing) to <\$5/kg (≈\$2/lb) and help reduce CO₂ emissions for CFRP structures.

Source (both photos) | Johnson Controls & HBW-Gubisch



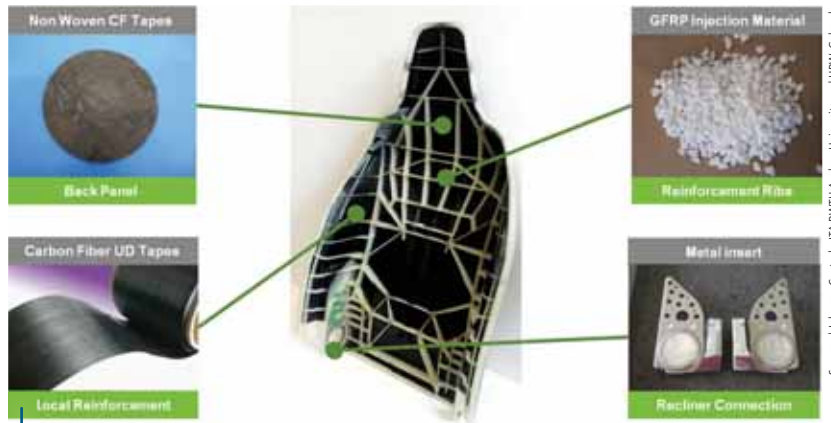
- Enable low-cost, short-cycle manufacturing by combining thermoforming with injection overmolding and attachment of metal inserts in a one-shot process.
- Develop an automobile seat design that reduces weight 40 percent vs. conventional metallic constructions.
- Meet front and rear impact safety requirements.

Johnson Controls Inc. (JCI, Burscheid, Germany) supplies integrated automotive seating modules to OEMs and has led CAMISMA's simulation and design efforts with team members noted below. The CAMISMA team began work in 2011 and is scheduled to conclude manufacture and crash testing of a full-scale seat back structure in early 2015.

BUILDING ON PAST SUCCESS

CAMISMA takes advantage of three recently developed technologies. The first is a new type of unidirectional (UD) polyamide (PA) prepreg tape, developed by Evonik Industries AG (Marl, Germany) and Toho Tenax Europe GmbH (Heinsberg, Germany). Dr. Eleonore Moeller, project manager at Evonik's Science-to-Business division, Creavis, acknowledges that continuous-fiber PA6 and PA12 tapes are already available, but points out that they are expensive because highly-viscous PA polymers require melting and solvent-reduction before they will thoroughly impregnate carbon fiber. To make the new tapes, continuous carbon fiber is saturated with a monomer, laurolactam (a low-viscosity constituent of PA), rather than a polyamide polymer. Prior to wetout, the monomer is mixed with catalyst and an anionic initiator/activator, which enable polymerization into PA *in situ*, that is, during the tapemaking process. "We polymerize that matrix into PA12 *around the fibers*," Moeller explains, claiming, "The low-viscosity monomer achieves impregnation very quickly, but with a high quality that improves fiber-to-resin adhesion." The monomer is not only less expensive than an already processed PA but its use also eliminates steps and solvents from processing. Fast wet out and polymerizing after impregnation also boost the PA12's mechanical properties, Moeller adds, noting that the latter does so "because it builds higher molecular weight."

For CAMISMA, Evonik used Tenax-E HTS45 12K fiber, with a sizing tailored for thermoplastic matrices. The fibers were supplied to a pilot plant installed by Evonik at, and operated by, the Institute for Textile Technology (ITA, RWTH Aachen University, Aachen Germany). Tapemaking begins with heat treatment of incoming fiber to remove residual moisture prior to impregnation. Fibers are then wet out with the monomer mix, heated and compacted, after which the PA12 tape is ready for molding.



This graphic illustrates where the CAMISMA design team used its three composite material types and metal inserts (bottom right) to fashion a seat back with optimized wall thicknesses and mechanical properties, tailored to meet precise loads yet also hit cost and weight targets. ■

The second technology helped CAMISMA meet its material cost-reduction goal. PA12-powder-impregnated nonwoven mats were made for this project from recycled carbon fiber by Materials Innovation Technologies Reengineered Carbon Fiber (MIT-RCF, Lake City, S.C.). These mats can be impregnated with monomer and in-situ polymerized like the UD tapes to form PA12 organosheets that are thermoformed during the CAMISMA process. Notably, ITA is also working on an alternative: Forming such mats from nascent fibers not collected by rollers during the spinning of polyacrylonitrile (PAN) precursor fibers for carbon fiber production. Supplied to ITA, these PAN fiber segments, which would otherwise be waste, are cut into 2-inch/50.1-mm lengths, carbonized and formed into homogeneous mats, using ITA's newly developed continuous air-lay process, which prevents the fiber damage and breakage usually associated with mechanical processes (carding and roller carding).

The third technology, a hybrid injection molding/thermoforming process developed during the BMBF-funded SpriForm project, enabled forming of the PA12 tapes and mats, overmolding of plastic features and incorporation of metal inserts in one step. ►



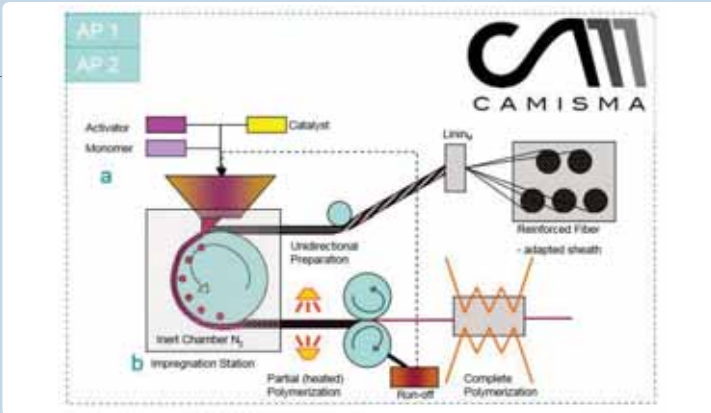
CAMISMA's automated production line includes (from background right to left foreground) an oven for preheating preforms, robotic transfer to SpriForm tool, conveyor transport of SpriForm tool to thermoforming press (white), and injection molding unit (green and gray, near left). ■

Source: | Johnson Controls, ITA, RWTH Aachen University and HBW-Gubersch

Source: | Johnson Controls



Source | Evonik Crawis



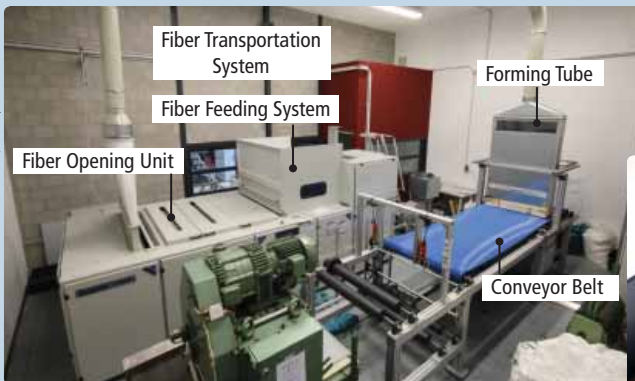
1 Evonik's innovative in-situ polymerization process includes removal of residual moisture, impregnation with laurolactam monomer (mixed with catalyst and anionic initiator/activator), and heating/compaction to complete polymerization into PA12 unidirectional tapes. ■



Source | Johnson Controls

3 Unidirectional carbon fiber/PA12 tapes and nonwoven mats were assembled into this tailored preform and tacked together using an ultrasonic welder. ■

Source (both photos) | ITA - RWTH Aachen



2 Continuous carbon fiber/PA12 unidirectional tapes were produced at Evonik's pilot plant (pictured) operated by ITA Aachen. For the nonwovens (inset at right), ITA has developed an innovative continuous air-lay process, using recycled fibers. ■



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SpriForm's Germany-based working group was headed by Jacob Plastics GmbH — now HBW-Gubesch Thermoforming GmbH (Wilhelmsdorf) — and included automaker Audi AG (Ingolstadt), organosheet supplier Bond-Laminates (Brilon), thermoplastics formulator Lanxess (Cologne), injection molding equipment source KraussMaffei (Munich) and the Institute for Composite Materials (IVW, Kaiserslautern). The SpriForm process unites injection molding and thermoforming in a fully automated production cell in which continuous-fiber-reinforced organosheets are preheated by an infrared oven and robotically placed in an injection mold, fixed in place by hydraulic needles, thermoformed and then back-injected with a short-fiber-reinforced thermoplastic that fills the mold cavity to fully overmold edges, ribs and other functional elements. To facilitate overmolding, the KraussMaffei injection system features a compounder that enables customization of fiber length and content.

A key to SpriForm development was understanding the strain-rate-dependent material properties of both short-fiber-reinforced and continuous-fiber-reinforced plastics so that process tooling and parameters could be optimized both for the hybrid materials and hybrid molding. In 2012, *Compounding World* magazine reported that SpriForm partners believed the process capable of producing parts with high strength and energy absorption at reduced weight vs. metal equivalents and at a lower cost vs. metal hybrids (e.g., steel-aluminum). Audi estimated a SpriForm bumper beam could reduce part weight by 20 percent vs. aluminum designs.

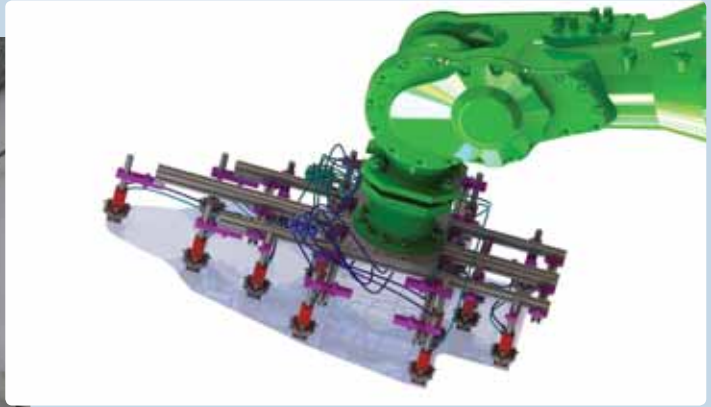
DESIGNING A MULTIMATERIAL SEAT

Armed with materials and a process, CAMISMA focused on an optimized design. "The basic task was to develop a lightweight seat back with additional functions integrated into it," says Axel Koeber,

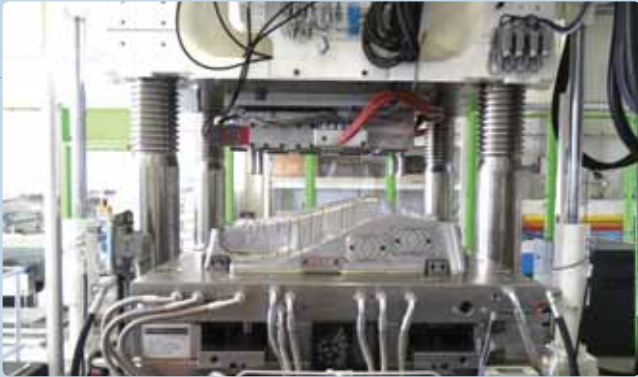
Source: (both photos) | HBW-Gubesch Thermofforming



4 The tailored preform was preheated in a convection oven to between 260°C and 280°C and then robotically transferred by this pick-and-place robot to the SpriForm tool. Inset at right shows how the preform is oriented with respect to the robot's head. ■



Source | HBW-Gubesch



5 In this photo, metal inserts and the preheated preform have been positioned on the SpriForm tool (at center of press). The preform was then thermoformed into its final shape as the press closed the tool. ■



Source | HBW-Gubesch

Source | Johnson Controls & HBW-Gubesch

6 Thermoforming was immediately followed by injection of Vestamid L-GF PA12 compound, which formed the stiffener ribs and attachment features for air bags and trim, and also overmolded the edges and metal inserts. Then the mold cooled the part and ejected it, finished (left), with a total molding cycle approaching 90 seconds. ■

manager of new technology at JCI Automotive Seating. “We had already demonstrated rear seat concepts, so we chose a front seat, which has higher loads and where carbon fiber has opportunity,” he recounts. “We then identified a reference seat in production so that we could compare our results to a meaningful benchmark.”

Working with the Institute of Automotive Engineering (IKA, RWTH Aachen University) and JCI’s Structural Simulations Dept., Koever’s team completed dimensioning and design, using HyperWorks from Altair Engineering (Troy, Mich.) and LSDyna from Livermore Software Technology Corp. (LSTC, Livermore, Calif.). “We used the three different materials in a smart way,” Koever explains, “chosen not only because they offered different mechanical and lightweight properties but also different costs.” Because optimized cost was a key goal, the design had to minimize expensive, high-strength material. That was accomplished with the “injection

molding material — which is the lightest and also most cost-effective — to support the other materials,” he notes. The nonwoven mat provided a common surface on which the design team, based on the results of its topology optimization, placed and oriented the least amount of material that would meet specified loads. “In the end,” Koever recounts, “we achieved an integrated structure with different wall thicknesses and different mechanical properties where desired, tailored to meet precise loads.”

The computer models were validated by significant materials testing (tensile, compression, flexure, etc.). In the beginning, the in-situ-polymerized UD tapes and nonwoven mats were not yet fully developed, so the design team used comparable UD tapes impregnated with PA by conventional means, and nonwoven mats that were commercially available. “We compared these test properties with our simulations to verify the models,” Koever relates, “and ▶



then simplified the HyperWorks output slightly to optimize manufacturability and reduce cycle time.”

Metal content was a design necessity in the reclining mechanism, which also functions to connect the seat back to the rest of the seat. “But because it is the heaviest material, we wanted it minimized,” says Koever. Crash impact requirements, however, required that load transfer between the metal and composite be optimal. The key innovation here was a special coating for the metal inserts, also from Evonik. Numerous lap shear tests were performed, where metal plates overmolded with plastic were pulled and load transfer between the two measured. They also tested for climatic and temperature effects on this connection, cycling from -30°C/-22°F to 80°C/176°F.

Koever concludes, “We wanted to make sure that combining the different materials would not produce any long-term weakening.” The team’s efforts in that regard were positive: The coating ensured good metal-to-composite bonding, and the overmolding step achieved mechanical locking of the metal inserts. “Now we had a connection strong enough to handle the loads transferred between the seat back and bottom during a crash.”

ONE-STEP THERMOFORMING/ INJECTION MOLDING

For the CAMISMA project, the SpriForm process began by integrating the PA12-impregnated nonwoven mats and UD tapes into preforms. “We placed the mats and tapes in the right direc-

tion in the right place and built the layers of the preform with the nonwoven typically across the bottom of the layup,” reports HBW-Gubesch R&D director, Dr. Marcus Schuck. An ultrasonic welder melted the PA matrix and adhered the layers together (see Step 3, p. 36). Then, the preform was transferred by a robot with needle grippers into a convection oven where it was heated to between 260°C/500°F and 280°C/536°F. After sufficient heating, a robot moved the preform from the oven to the SpriForm tool, where elements inside helped to locate and hold it in place. Metal inlays for the recliner mechanism had already been robotically placed in the tool and positioned by built-in elements.

As the mold closed, the preform was pulled and draped over the tool die (pictured in Step 5, p. 37) and subjected to heat sufficient to ensure good formability as the part assumed its final shape. In the overmolding stage, Evonik’s Vestamid L-GF grade of 30 percent glass fiber-reinforced PA12 compound was injection molded into the closed tool, filling the cavity to form the seat back’s reinforcing ribs as well as functional features like the air bag attachment and trim channel. It also encapsulated the edges and metal inserts. The mold then cooled and ejected the part, with a total molding cycle approaching 90 seconds.

When asked what CAMISMA had to do to adapt or enhance the SpriForm process for its purposes, Schuck responds, “The process was the same, but the materials were new. Our biggest issue was material handling and draping. The heating, picking up and moving of the materials had to be developed for these new materi-



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als.” Handling time, in fact, had to be minimized because material temperature was the key to achieving good bond strength between components in the integrated structure. Thus, the preform could not be allowed to cool between the preheat oven and heated SpriForm tool.

The result? According to JCI’s Koever, “The first time we put the SpriForm tool on the injection machine and pulled parts, they looked very good and well-designed.” Weight savings vs. the steel benchmark actually exceeded the 40 percent goal for the structure plus mechanism. For the structure alone, weight was reduced by more than 50 percent. The CAMISMA team began crash-testing full-size seat backs, using test dummies, in September. The first completed test simulated rear-end impact by a car traveling at 30 kmh/19 mph. Koever says there were no failures that presented serious issues and deformation was in line with expectations. “We are comparing the results now to our simulations,” he notes, “but overall, the demonstrator took the loads well.”

HARD QUESTIONS, REAL-WORLD ANSWERS

But is the process viable for real-world auto production? Koever says *yes*. Currently, the process is configured for two robots. One takes a finished part out of the tool and places new metal inserts into the tool while the other takes a preheated preform out of the oven and places it into the tool. Schuck states that synchronizing the various transfer and placement operations basically simulates an inline process. Although automated preforming wasn’t available for the project, Koever points out that the equipment for it exists, developed by Fiberforge (Glenwood Springs, Colo., see “Learn More,” p. 40) and subsequently acquired by Dieffenbacher (Eppingen, Germany). “We have investigated this with Dieffenbacher to see if target cycle times could be achieved,” says Koever. “Their proposals are very close, which balances with our forming/molding equipment. So the equipment to make this process feasible for mass production is already available, and just a matter of combining the technologies in one place.”

What about auto OEM cost targets? Koever claims the seat back “is reaching the goal of not more than \$5 additional cost per saved kg of vehicle weight, which is considered the lightweight indicator in the auto industry. “We think we can stay below this,” he explains, “because we mini-

mized the expense of material. For example, lower-cost injection molding material makes up half of the seat back mass. After 90 seconds, you have a completed part with no secondary operations and the materials are also produced in a continuous way. So this is much more viable to an OEM vs. RTM where one part takes 5 to 15 minutes, making high volume difficult.” Koever adds that although some automakers are using very specialized machines in their development of composites, CAMISMA is using standard injection molding equipment in its process, and although they have used a vertical machine, which has advantages, this is not a requirement for successful processing. ▶



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What about performance? Planned lifecycle analysis is still in process, but Koeber anticipates that the team will have data that compares the full-scale demonstrator seat back to standard metal seats as well as a full analysis and complete results by early 2015.

When asked about the future of using recycled carbon fiber (RCF) and how that compares to virgin fiber, Koeber replies, “For CAMISMA, the recycled material, as far as short fibers, is the same, and the issue with waste in composites production is one that must be solved.” He notes there are viable industrial-scale RCF suppliers, but observes, “You can also use glass fabric organosheet, so there are a lot of possibilities. However, this CF nonwoven has benefits

if you consider surface quality and planarity [flatness]. It also aids in impact performance. With CAMISMA, we are now looking at integrating the seat back structure into the visible part of the seat, but this surface must be attractive and also hold up to use inside the vehicle.”

WHERE TO FROM HERE?

The big question, of course, is, Will this technology bear fruit in series production? HBW-Gubesch’s Schuck sees a future for the CAMISMA technology and will continue to explore seat systems and crash-absorbing structures. He adds, “As a molder of composite

parts, this was a good opportunity to learn about the manufacturing of new materials, specifically the in situ polymerized thermoplastic tapes and mats, which we believe is the future to achieve good performance and reduce material cost, which is still a barrier to composite parts entering the mass market.”

Evonik’s Moeller concurs, noting, “CAMISMA could allow a breakthrough in polyamide composites for automotive, enabling lower cost, high-performance structures.”

For its part, JCI’s product development engineers “now have this technology in their strategy options,” says Koeber. “We are making presentations to OEMs, with availability for 2019 models in high volume production.”

“Taking composites to production is not easy,” he admits, “but we have a good story, and this works.” | CT |



Senior Editor

Ginger Gardiner has more than 20 years in the composites industry.

She joined the CT team in 2013 after seven years as a regular contributor. ginger@compositesworld.com

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Applications

BUOYANT BUILDINGS | Modular design relies on cored composites

Arquitectura en el Agua's (AEEA, Santa Cruz, Tenerife, Canary Islands) architects and engineers design and construct *floating* modular structures for marinas, harbors, restaurants, hotels and leisure centers. The flotation concept was envisioned by company founder/CEO Antonio Arderius for a new marina conceived by a client faced with limited land area. Since then, floating modules have been built to customer-specified sizes using aluminum and other metals, and reportedly can be adapted to uses as diverse as temporary concert stages and hospital buildings erected after natural disasters.

Interested in the possibilities of composite solutions, AEEA contracted with **Composites Consulting Group** (CCG, Laholm, Sweden) for a preliminary feasibility study. CCG carried out initial tests on floating designs that incorporated a variety of core materials supplied by sister company **DIAB**. CCG senior engineer Jose Cristos describes the proposed composite design as octagonal, flat-bottomed pontoons, essentially small hulls with flat upper decks. Similar to boat hulls, they are fabricated as single parts in one-piece molds. The hulls support cored sandwich panel bulkheads on lami-



nated frames. Multiple pontoons are joined to support larger structures.

Panel faceskins feature a marine-grade, highly UV-resistant gel coat backed by fiberglass infused with either isophthalic polyester or vinyl ester resin and cored with DIAB Divinycell P or H foam. Says Cristos, "The support deck spreads loads onto the bottom pontoon structure, which creates

independent, watertight volumes inside for extra safety. The sandwich panel concept provides the required stiffness to cope with the demanding loads imposed by the sea environment as well as service loads." Pontoon hulls and decks are adhesively bonded together, eliminating the risk of corrosion with metal fasteners.

The AEEA composite solution offers rapid design and installation, and its modular design facilitates easy reconstruction or expansion to meet changing demands. Further, the composites minimize environmental impact in protected marine areas.

Among other projects, the concept was used in support of an extension of the Nautical Club (Santander, Spain) to provide dock space for the more than 1,400 sailors and 1,000 boats from 80 nations in attendance at the 2014 Sailing World Championships. ■

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 - Dec. 9-11, 2014** **CW Carbon Fiber 2014**
La Jolla, Calif. | www.compositesworld.com/conferences/compositesworld-2014-carbon-fiber-conference
 - Dec. 10-12, 2014** **India Composites Show 2014**
Mumbai, India | www.indiacompositesshow.com
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 - Feb. 3, 2015** **International CompIC Conference**
Amsterdam, The Netherlands | www.netcomposites.com/calendar/compic-2015/1410
 - Feb. 25-27, 2015** **COMPOSITE-EXPO-2015**
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- MAR**
 - Mar. 2-4, 2015** **SpeedNews 29th Annual Commercial Aviation Industry Suppliers Conference**
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- APR**
 - April 13-15, 2015** **8th International Conference on Bio-Based Materials**
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- MAY**
 - May 14-16, 2015** **Composites Pavilion – American Institute of Architects Convention 2015**
Atlanta, Ga. | <http://convention.aia.org/event/homepage.aspx>
 - May 18-21, 2015** **SAMPE Baltimore Conference and Exhibition**
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 - Sept. 8-10, 2015** **SPE Automotive Composites Conference and Exhibition (ACCE)**
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At the 2014 editions of three trade events — the Composites & Advanced Materials Expo (CAMX), the International Boatbuilders Exhibition (IBEX) and Society of Plastics Engineers' Automotive Composites Conference and Exhibition (ACCE), exhibiting suppliers offered a wide array of new technologies. The following is a mere sampling from CAMX (see many more online, throughout the month of December, at <http://www.compositesworld.com/articles/ct>).

Self-contained, adhesively applied fastener studs

At CAMX 2014, **Click Bond** (Carson City, Nev.) focused on new-generation versions of its adhesively bonded fastener technology that eliminate the need to drill holes in composite structures to accommodate fasteners. The classic system uses an adhesively bonded standoff and a positioning fixture that applies pressure to the adhesive bondline, and holds the standoff in



position until the adhesive cures. The positioning fixture is then discarded. To avoid fixture waste and reduce material usage during stand-off/fixture manufacture, Click Bond has redesigned some of its standoffs with internal rather than external fixturing devices (center and left-most images in photo). The smaller unit on the left contains its own *internal* positioning and pressure-application feature (the "dot" in the center is coated with pressure-sensitive adhesive, and fulfills the role once performed by the larger fixture on the right). The only discarded component in the new design is the thin plastic film that covers the adhesive on the "dot." www.clickbond.com

Phenolics for FST applications

At CAMX, **Mektech Composites** (Hillsdale, N.J.), a distributor of user-friendly phenolic resins from **Momentive Specialty Chemicals Inc.** (Columbus, Ohio), showcased trademarked Cellobond, for fire-retardant applications that require low smoke/low toxicity. Mektech president Aram Mekjian points out that phenolic resins, without fire-retardant fillers, provide parts with much better flame/smoke/toxicity (FST) performance than polyester, vinyl ester, modar and epoxy parts, and, absent the fillers, achieve a 20 to 30 percent weight reduction. Mekjian also discussed his patented passive reactor device for customers who use phenolic resins, which handles the phenol and formaldehyde off-gassed during processing. The reactor reportedly can be used with any styrenated resin, to control volatile organic compounds (VOCs). www.cellobond.com | www.momentive.com

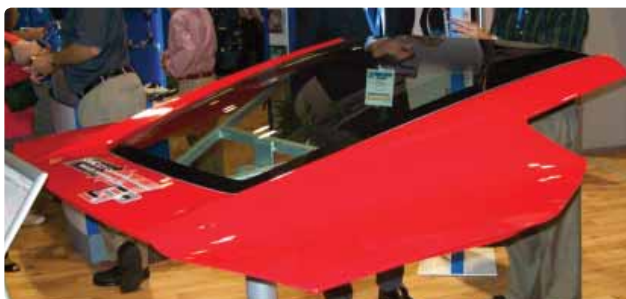
Reformable epoxy

L&L Products (Romeo, Mich.) spent much of CAMX 2014 explaining to attendees what its L-F610 *reformable* epoxy adhesive film is and how it works. It reportedly combines the adhesion and mechanical properties of an epoxy with the processing ease of a thermoplastic. L&L says it will facilitate new opportunities for the manufacture of composite parts, panels and laminates. With a tensile elongation of 40 percent, the reformable film is said to offer high toughness, with better strength and better adhesion than traditional thermoplastic adhesive systems. It adheres to many different substrates (metals, epoxy composites, plastics and wood) and can join *dissimilar* substrates. It can be debonded and reformed with heat, allowing parts and components to be modified in existing structures. L&L featured in its booth a police shield molded by **Hardwire LLC** (Pocomoke City, Md.), featuring L-F610 as part of the material stackup (see photo). www.llproducts.com | www.hardwirellc.com



Low-density SMC

On display at the **AOC LLC** (Collierville Tenn.) CAMX 2014 exhibit were demonstrator products compression molded with low-density (specific gravity of 1.2) sheet molding compound (SMC) that reduces the weight of comparable steel parts by as much as 46 percent and is comparable in weight to alumi-



num. Formulated with AOC's Atryl TCA resin for Class A finishes, the SMC produced this Chevrolet Corvette tonneau (pictured here, and expected to appear on production models later this year). www.aoc-resins.com

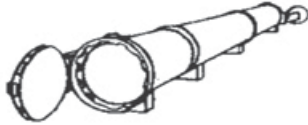


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Pavilion Canopy

GRACEFUL LINES, STRENGTH OF STEEL

All-GFRP design eschews steel framing but can withstand wind and elements.

The Irish city of Cork is hoping that its newly redesigned Mardyke Gardens in the city's Fitzgerald Park will become an iconic attraction for tourists. The garden's centerpiece is a new pavilion with a strikingly modern canopy, where the city will host musical and theatrical performances as well as outdoor cinema.

The canopy was conceived by Cunnane Stratton Reynolds (Cork, U.K.), a multidisciplinary consulting firm that handles urban and landscape planning. Its unique shape was informed by the park's heritage, specifically its role as a venue for the 1902 Cork International Exhibition, a showcase for emerging 20th Century technologies and industries. Cunnane Stratton Reynolds' design team says it "reimagined the gardens as a venue and destination fit for the 21st Century."

RE-IMAGINING THE MATERIALS

"A shape like that just *calls* for advanced composites," says Dr. Mark Hobbs, senior engineer, Gurit (UK) Ltd. (Isle of Wight, U.K.). But the initial design from Darmody Architects (Dublin, Ireland) called for a steel framework clad in either wood paneling or a fiber-reinforced plastic (FRP) shell.

Given that mandate, Isle of Wight-based AM Structures Ltd., a specialist in large-scale composite structure fabrication, subcontracted Gurit to engineer the shell's materials solution. Having previously worked with AM Structures on large canopy structures, Gurit developed several glass FRP cladding solutions for the steel superstructure. "But we also began to consider a fully composite solution," Hobbs recalls, noting, "Analysis on the composite shell showed that it possessed nearly enough strength and stiffness on its own, without the large steel work underneath to meet the structural requirements." Several studies were performed to see if carbon reinforcement would be necessary, but in the end, it was clear, says Hobbs, "we could achieve sufficient strength and stiffness using just glass."

Darmody and the team's general contractor agreed that an all-composite solution would be beneficial. It not only eliminated the steel work and the associated bolts and connections, but it also reduced the canopy's complexity, simplified its installation and ensured a longer service life. "With the GFRP solution, the entire structure was fabricated off site, requiring only minimum onsite installation," says Hobbs. And, although the structure is large, its light weight al-



This uniquely shaped pavilion canopy in Cork, Ireland's Mardyke Gardens, the centerpiece of the city's Fitzgerald Park, is constructed of glass-reinforced epoxy and designed to stand up to high wind loads and inclement weather. ■

Source (both photos) | Gurit

AM STRUCTURES' MARDYKE GARDENS PAVILION CANOPY

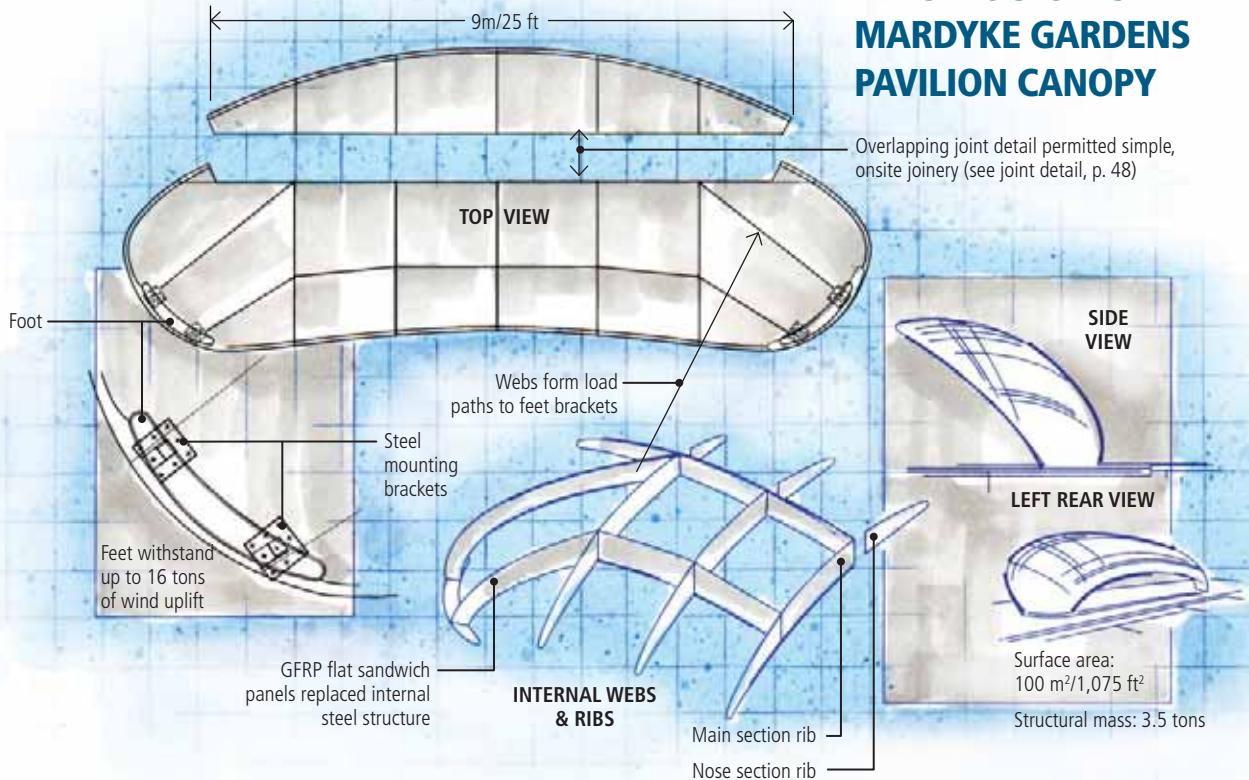


Illustration | Karl Reque

ENGINEERING CHALLENGE:

Ensure that the pavilion canopy has high stiffness and global strength to withstand strong wind loads, yet minimize weight and provide for practical transport of the oversized structure to the installation site.

DESIGN SOLUTION:

A sandwich construction shell supported by a simple internal web structure, with a longitudinal joint that enables canopy fabrication and transportation in two pieces but minimizes onsite finishing.

lows for easy handling. “Overall, the FRP surface is cleaner, free of joints that would’ve been necessary with cladding, and the FRP provides excellent resistance to corrosion.”

MANAGING GLOBAL AND LOCAL LOADS

The composite solution was not without its challenges, however. “We had some reasonably tight stiffness and global-strength criteria to meet on the structure,” says Hobbs.

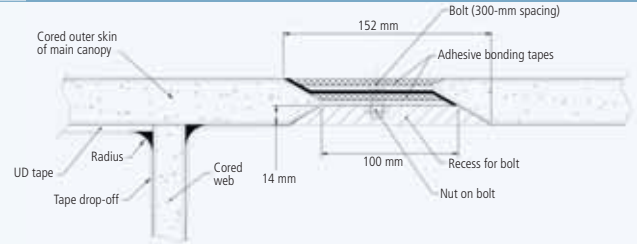
“We used the Eurocode standards to define the load and stiffness criteria,” explains Gurit design engineer Francois Hilary. “Stiffness criteria is a maximum deflection of 1:200 over the serviceability limit states, and the strength criteria are checked over a variety of different envelope load cases for short-term and long-term loading.”

Gurit relied heavily on analysis tools in Hyperworks from Altair Engineering Inc. (Troy, Mich.) to define the load paths and ensure that reinforcements would be properly placed to get the loads to the base. “FEA permitted us to have a clear view of how the structure was responding to the different loading from the first simple models, so we were pretty confident regarding the load paths,” says Hilary. Using Altair’s Hypermesh, the structure was optimized for global deflections and natural frequency, strains under serviceabil-

ity limit state (to avoid microcracking of the resin) and strength under ultimate limit states.

The primary load, however, was aerodynamic. “We had a global wind load of 1.8 kN/m², which is suction load,” says Hobbs. “Because the structure is essentially shaped like a parasail, it has a tendency to want to lift up off the base. And since it’s a very light structure, we needed to consider not just the uplift, but also the downward weight on the structure,” he adds. The GFRP structure’s surface area is just under 100m²/1,076 ft² with a total mass of 3.5 tons. “At a maximum, we’re dealing with approximately 16 tons of uplift, which is quite a lot of load,” explains Hobbs. “We wanted to move that load down to two “feet,” each fitted with two steel brackets, on either side of the shell, that are fixed into the concrete.” The four brackets bear both uplift energy and downward loads.

The inner and outer shells ultimately were conceived as quadraxial laminate-skinned sandwich constructions. Quadraxial reinforcements would compare well to the initial design, providing equal strength in all directions in the same way as steel, and offered good performance predictability. Skins were formed with Gurit’s Ampreg 21 FR epoxy and glass fibers at 0°, 90°, +45°, and -45° on either side of Gurit’s trademarked Corecell M80 SAN foam core. Corecell M, ▶



Too big to transport in one piece, the canopy was built in two sections. A longitudinal joint detail (see joint cross section above) was incorporated, allowing separation of a 9m/29.5 ft section from the tip. The overlaps between the nose section and main canopy were then bonded and bolted at the installation site, with minor finishing work, in less than six hours. ■

says Gurit, combines high shear strength (1.09 MPa/158 psi) with low density (81 to 89 kg/m³/5.1 to 5.6 lb/ft³), high elongation, high-temperature resistance, and low resin uptake. Additional UD tapes placed inside the outer skins would add global stiffness to the structure. The number of UD tapes and tape drop-offs were optimized using FE analysis.

Inside, the shell would feature a set of internal ribs and webs. “These were mainly for support of the shell itself under panel deflection, but they also direct the global loads from the shell down towards the two steel feet on either side of the structure,” explains Hobbs. Those “feet” — via the steel brackets (see foot detail in drawing, p. 47) — would be bolted to the webs and then connected to the concrete plinth that forms the foundation for the canopy. Core in the internal web was replaced by solid E-glass laminate locally, at the bolting points, to provide bearing strength in the laminate sufficient to transfer load into the bolts.

“To keep the internal structure simple, we decided to make the webs out of flat panels rather than having to mold a curved structural beam,” says Hobbs (see drawing). “By simplifying the internal support structure, it was easier and quicker to manufacture the components, and saved the cost of tooling.” Rhino 3D modeling software from McNeel America (Seattle, Wash.) was used, says Hobbs, “to complete work within the 3-D geometry in order to achieve these simple, but effective webs.” Further, he says, “Geometry and laminate of internal webs was also optimized using FEA to achieve a good balance between structural efficiency and ease of manufacture.”

The biggest issue, according to Hobbs, was to maintain the orientation of the internal webs as they neared ground level, says Hobbs, “to ensure that the base plate holes in the steel feet would match up to the anchors in the concrete slab.” The steel feet would be bolted into the structure in the factory, which meant that early communication between Gurit and AM Structures and the contractor laying the concrete base was critical.

“Simple preliminary FE models were run and compared until we were happy with the internal structure disposition,” says Hilary. “Then the final laminate and UD reinforcements were optimized using FEA as well to ensure compliance with Eurocode.”

One complication was that a one-piece canopy would be too massive to move by truck. “We looked at a number of ways to split up the structure,” says Hobbs. Eventually, it was determined that a 9m/29.5-ft section from the forward uppermost curve of the cano-

py would be fabricated separately. It and the main canopy structure would have molded-in overlaps at the joint line, to facilitate bonding and mechanical fastening.

DESIGN FOR “SIMPLE” MANUFACTURE

After design approval, its components were wet laminated, vacuum consolidated and cured on very simple tooling. “Both the upper and lower shells were manufactured alongside each other over a timber-and-ply former, with care taken to assemble the longitudinal accurately to match the precast foundation already on site,” says Downer. Webs were formed on flat tables and then cut and bolted into the structure. The outer shells, with UD tapes in place, were then bonded onto the web structure to form the completed canopy.

“Incorporating a longitudinal joint detail that enabled the transportation of the pavilion from AMS to the job site with a minimum amount of onsite finishing work was a *definite* challenge,” quips AM Structures director Mark Downer, but he points out that the joint enabled onsite joinery in less than six hours. The structure was finished with International Interthane 990 acrylic polyurethane, from AkzoNobel Marine & Protective Coatings (Gateshead, U.K.).

Hilary likens the canopy design and engineering process to that used in previous sailboat and tidal and wind turbine projects. “The beautifully curved shape made the study interesting,” he says. “However, the overall construction methods and design were standard,” he adds. “The sandwich construction permitted us to use a very simple internal structure design, and it was easy to build and assemble.”

“In fact,” Hilary concludes, “this is a school case of how switching to composites saves money and time *and* solves potential problems.” | CT |



Contributing Writer

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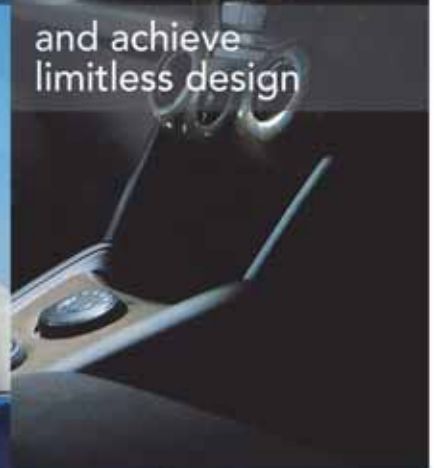


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