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OCTOBER 2016




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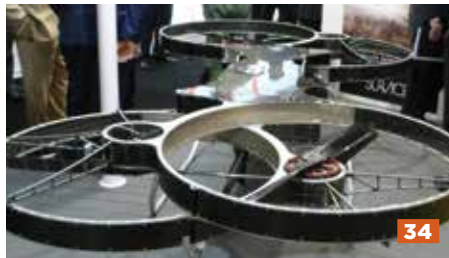


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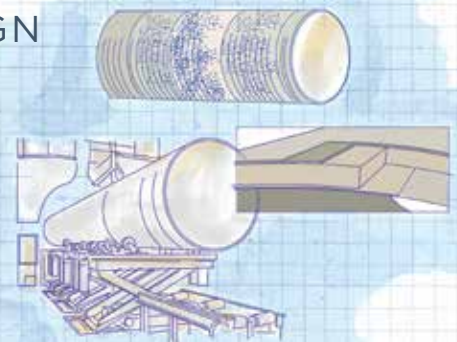
Source / Onne Van der Wal Photography

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60 Engineered Large-diameter Underground Pipe

A combination of design and new materials enhances pipe performance without adding cost.

By Sara Black



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» I am attending this week (Sept. 7-9) the Society of Plastics Engineers' (SPE) Automotive Composites Conference and Exhibition (ACCE) in the Detroit suburb of Novi, MI, US. The first time I attended this event, in 2007, there were — maybe — 300 people

How do we integrate composites into the auto supply chain?

in attendance. By 2009, with the Great Recession in full swing, it seemed like those who gathered at ACCE were glad to be producing vehicles at all, much less ones that incorporated composites. By

2012, conference participants were seeing some light at the end of the automotive tunnel, and it was not unreasonable to think that composites had a future in automotive, particularly given new and aggressive corporate average fuel economy (CAFE) standards.

Today, ACCE is, without doubt, the largest automotive composites event in the world, attracting more than 900 people and 75 exhibitors, and featuring more than 90 technical paper presentations. And all of us, including me, are here learning about new bonding technologies, sheet molding compound innovation, fiber reinforcement draping simulation . . . and much more.

The people here represent the entire automotive supply chain, ranging from resin suppliers to composites fabricators to (yes!) OEMs — 130 or so, from what I hear. They represent some of the best automotive engineering minds the world has to offer, and they ask excellent questions of highly qualified, thoroughly vetted speakers who present well-researched papers.

There is one question, however, that seems to generate a different answer for each person to whom I put it. The question is this: If the growth of ACCE is symptomatic of the overall growth of composites in automotive, then all those really great composite parts that result must be integrated into the automotive supply chain. *How is that going to work?*

I ask this question for two reasons: First, the automotive supply chain is a world unto itself, full of rules, traditions and expectations found nowhere else in the manufacturing world. Second, except for a very small handful of companies, there are none in the composites world that have experience serving that supply chain. And although this handful of companies might be able to serve a few customers' needs, they alone cannot serve the entire industry.

So, if, in fact, automotive OEMs not named BMW are serious about using composites in quantities that — to us — might represent the next Great Composites Expansion, who is going to do the actual work required to make it happen? Where will the technical brainpower and manpower come from? Who can provide parts in the quantities the auto industry requires? Which processes will be used? How will all this be integrated into the automotive supply chain?

I used to think that the automotive Tier 1 suppliers would be handed the job, but aside from activity at companies such as Magna, Continental Structural Plastics and Faurecia, it's difficult to tell how much legwork Tier 1s are doing. That leaves a few possibilities, as far as I can see.

First, maybe it's too much to expect that one type of supplier can meet the automotive industry's composites needs. Perhaps a cooperative venture is required, involving resin suppliers, fiber suppliers, fabricators *and* Tier 1s. There is some evidence to support this, particularly on the materials side, where resin and fiber suppliers already supply technical know-how to a variety of automotive OEMs.

Second, perhaps we are on the verge of the emergence of a disruptive technology — like, for example, liquid compression molding — that will make composites unbelievably attractive to automotive OEMs. Or, perhaps Google or Apple are developing disruptive vehicles that will transform how we think about transportation, and manufacturing for transportation.

Third, we might be on the cusp of a Pretty Good Composites Expansion, one in which we'll see composites consumed in moderate volumes and only in mid-level to high-end cars. Not the end of the world, but definitely lacking the satisfaction of that full-blown Great Composites Expansion.

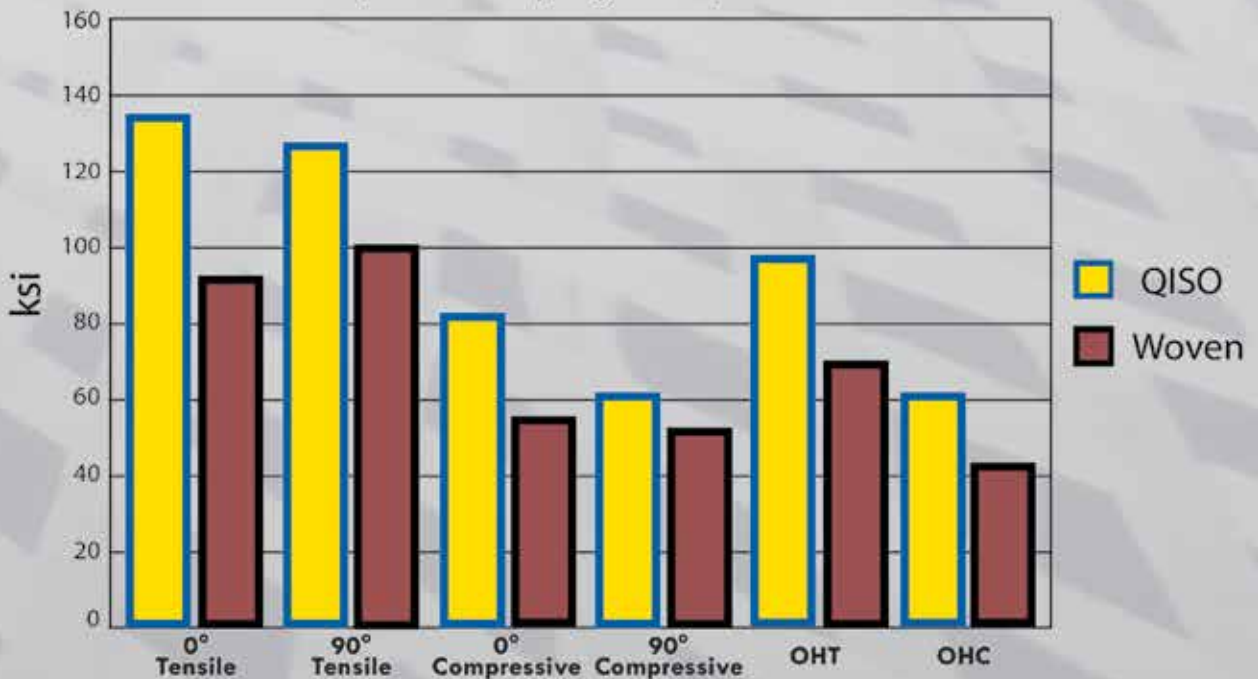
So, there you have it — three speculative answers to one question from one person. I'm all ears if you have your own ideas about what the future might hold. E-mail me at jeff@compositesworld.com.

JEFF SLOAN — Editor-In-Chief



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Composite repair: Lessons learned, challenges and opportunities, Part I

» Over three decades, the aerospace industry has collaborated successfully to produce standard composite repair designs, materials and methods and foster confidence in the ability to repair composite structure. As aerospace companies look to increase the scope and quality of repairs, through standardized training and increased automation, their lessons learned (outlined here in Part I of a two-part examination) can smooth the repair path for other industries. The opportunity to avoid costly repair issues, however, could be missed if the OEMs and owner/operators in these industries resist collaboration and the resulting standards and technology necessary for an effective repair supply chain.

From bolted doublers to bonded repair. At Lear Fan Ltd. in the early 1980s, the common repair method for composite structures was bolted doubler repair, because this was the way metal structures were repaired. Applying CFRP doublers to CFRP structures, we quickly learned that the common aluminum alloy fasteners experienced galvanic corrosion in contact with carbon fiber. So we switched to stainless steel, and later, titanium fasteners.

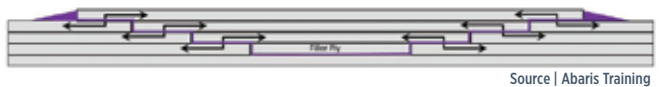
The bonded patch step repair followed soon thereafter, which was the standard approach used for a *multi-layered* metal structure. The damaged material from each layer was removed in progressively larger diameters, creating a stepped surface in which to replace plies (Fig. 1). For composites, this posed serious challenges. The first was to remove the damaged material down to the undamaged layer *without* intruding into that ply, which would make the repair larger, and require more time, labor and risk to return the structure to acceptable performance. The second was to actually make repair plies fit into each stepped recess without overlap or gaps — an extremely difficult, operator-dependent task.

The transition from step repairs to tapered scarf repairs began around 1984-1987. These were easier to perform and provided better results. Boeing specified them in its aircraft structural repair manuals (SRMs). Without the steps, you no longer had to worry if you were 1.0 mm off in the repair ply location (Fig. 2).

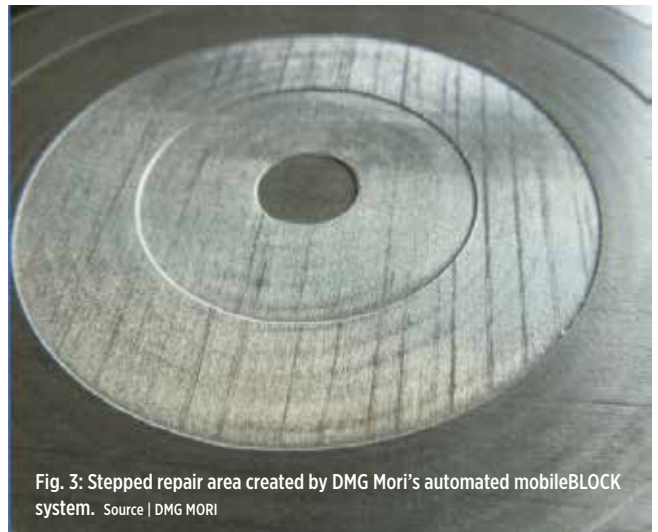
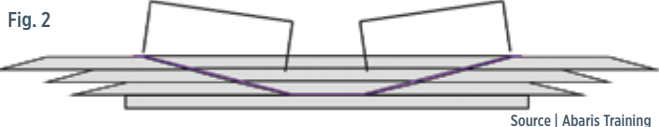
However, companies making general aviation (GA) aircraft and Airbus were still prescribing step repairs, or alternately, upside-down “wedding cake” taper-scarf repair patches — i.e., the largest diameter ply at the bottom and smallest at the top, covered by a final layer that seals the repaired area. This technique came from the marine industry, which typically used heavy woven roving, where the thick exposed edges were easily accessed later for removal of trapped air and ease of finishing. The approach became unnecessary in the aerospace industry, when thin harness-satin and plain-weave fabrics were used, vacuum bagging was employed for compaction and gas removal, and portable hot bonder equipment monitored and logged repair patch vacuum and cure temperatures. Through the 1990s, the “big ply down” vs.

Loads are distributed through the repair via a lap joint into the underlying layers

Fig. 1 The resulting repair sits above the surface



Uniform shear stress distributed through a tapered scarf joint



“little ply down” debate continued. Airlines and repair-station technicians were frustrated with the inconsistency in repair methods, and sought simple, efficient techniques. (Note: the big-ply-down method is still employed in some GA repair schemes.)

Bonded and bolted doublers on thin-skin laminates also were prescribed. However, in the early days, there weren't a lot of fasteners specifically developed for composites, and it was common for wear around the holes to cause fastener pull-out failure. Huck (now Alcoa) and others eventually introduced now common fasteners with larger heads, which dramatically improved performance. Bolted doublers have been used on thick laminates since the 1980s and are often used in non-aerodynamic, flight-critical areas today. The common rule of thumb is to use bolted doublers on thick laminates (>13 mm) and bonded, tapered scarf repair on thin laminates (<3.2 mm), with sufficient analysis to substantiate the appropriate repair design. »

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Automation, training and increasing allowable bonded repair limits. Since the 1990s, taper-scarfed repairs have become the method of choice on thin laminate structures, using the small-ply-down-first approach, ensuring a flush overall final ply for an aerodynamic surface. The focus now is on developing standardized repair technician training and adapting repair patch preparation methods, including double vacuum debulk (DVD) processing and automation to extend bonded repairs to increasingly larger areas of damage and flight-critical primary structures (see endnote). The goal is reduced human error and increased precision in nondestructive inspection, damage removal, adhesive bond preparation and repair patch application and cure.

Today's robotic systems can, indeed, CNC mill each damaged ply from the digitally scanned and verified repair area with precision. Some systems, such as mobileBLOCK from DGM Mori (Bielefeld, Germany) can mill both step and taper scarf surfaces (Fig. 3, p. 6). However, many of these automated systems still create a stepped repair area, which ironically brings back the old issue of matching the repair plies — although more precision is possible with digital ply cutting capabilities — because repair patch application is typically still done *manually*. Obviously, the next objective is to automate the patch application and cure.

The increased standardization in requirements for repair technicians and their training has largely been the result of collaboration

through the Commercial Aircraft Composite Repair Committee (CACRC), which is administered by SAE International (Warrendale, PA, US), with technician certification provided through the Performance Review Institute (PRI). This group, along with OEMs, operators, suppliers and service providers, has provided a forum for discussion, research and dissemination of repair knowledge (and archiving), and serves as a model for development in other areas.

In Part II, Dorworth will discuss how the automotive and wind energy industries can and are benefitting from aerospace industry experience. He also will treat this topic in detail at CompositesWorld's Carbon Fiber 2016 conference (Nov. 9-11, Scottsdale, AZ, US). CW



ABOUT THE AUTHOR

Lou Dorworth has been involved with the advanced composites industry since 1978 and has worked with Abaris Training (Reno, NV, US) since 1983, where he currently manages the Direct Services Division. Lou's experience includes composite material and process (M&P) engineering, manufacturing engineering, tool engineering/design and tool fabrication. He is a member of the Society for the Advancement of Material & Process Engineering (SAMPE, Covina, CA, US), the Society of Manufacturing Engineers (SME, Dearborn, MI, US) and the Society of Plastics Engineers (SPE, Bethel, CT, US), as well as a frequent conference presenter and co-author of the popular textbook, *Essentials of Advanced Composite Fabrication & Repair*, published by Aviation Supplies & Academics, Inc.

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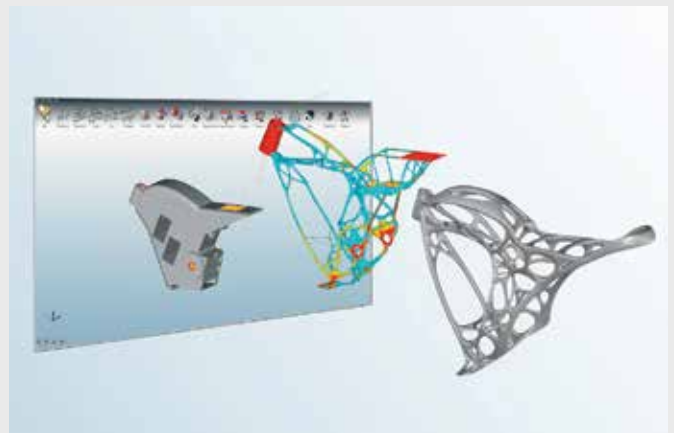
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» A recent announcement by Fibergrate (Dallas, TX, US) that it was celebrating its 50th year in operation, really caught my eye. My first reaction was, “Wow, fiberglass grating has been around for 50 years, already?” I had always thought of it as a more recent invention. Then, it struck me that here was a small company that had managed to make it 50 years in the composites industry. Around the same time, I received an invitation to attend the 50th-year celebration of IDI Composites International (Noblesville, IN, US), a producer of thermoset sheet and bulk molding compounds.

Many small companies like these have operations in small towns, or at least they were small when established. Fibergrate manufactures in Stephenville, TX, which had a population of 9,000

In a time known for owner “exit strategies,” longevity in family-owned composites businesses is heartening.

in 1972, but has grown to 19,000 today. Noblesville, IN was a rural community of about 7,500 in 1966, and today is a bustling Indianapolis suburb of 56,000. However, it still

retains small-town charm. Although Fibergrate is now an independent subsidiary of a larger company, IDI remains a family-owned business. In a world where many owners are encouraged to think about “exit strategies,” seeing such longevity is heartening. Speaking of family-owned, Dieffenbacher GmbH (Eppingen, Germany, population 22,000) was founded in 1873 and started producing presses used to mold Bakelite compounds in 1928. Today, under the fifth generation of family ownership, it is one of the world’s largest producers of composites molding equipment.

I worked for a dozen years for one such small company with an outsized influence on the composites industry, called Fiberite, started in 1948 in Winona, MN, US, by two brothers, Ben and Rudy Miller. The two ran a family business, Miller Waste Mills, which recycled cuttings from clothing manufacturers, particularly those using denim fabrics. Such scraps found use as a lubricant for train wheels, among other applications. Looking for a new outlet for these waste textiles, they created a cotton fabric-reinforced phenolic molding compound, and established Fiberite to manufacture and sell it into applications such as timing gears for automobiles. The product line expanded to include melamine resin compounds for food trays, then fiberglass-reinforced phenolics, melamines and epoxy compounds. Given this expertise in “putting glue on string,” Fiberite entered the continuous-fiber prepreg business, first with glass fabrics, then carbon fiber fabrics and unidirectional tapes (and some carbon fiber molding compounds as well). They expanded from Winona, adding a molding compound facility in Delano, PA, US, and a prepreg line in Orange, CA, US, to serve the aerospace industry along the US west coast.

Having become major materials suppliers to the composites industry, the Millers added glass-reinforced engineered thermoplastic molding compounds to their portfolio in the 1970s. They were among the first to offer a long glass (6- to 12-mm) pellet form for structural applications. In 1980, the Millers sold Fiberite to Beatrice Foods, where it became a wholly owned yet independent subsidiary. Because Beatrice already held a dominant position in engineering thermoplastic compounds through another subsidiary (LNP, now part of SABIC), they were forced to sell the thermoplastic operations of Fiberite back to Miller Waste Mills. The Millers established the business as RTP Company, which remains in Winona and is still held by the Miller family.

Beyond its role as a major player in the advanced composites industry, Fiberite had a big influence on the city of Winona, and the local composites community. A number of composites companies thrive today in Winona, some arising out of the entrepreneurial efforts of former Fiberite employees. These include not only RTP but Composite Products Inc. (now part of Core Molding Technologies), PlastiComp, Wenonah Canoe, Coda Composites and a compounding plant of Celanese Corp. (Irving, TX, US) as well. The overall population of Winona hasn’t changed much, growing from 25,000 in 1950 to about 28,000 today, but given this local concentration, Winona State University offers the *only* accredited undergraduate degree in composites engineering in the US, with 32 graduates in 2015.

After the divestiture of RTP, Beatrice sold Fiberite to Imperial Chemical Industries (ICI) in 1985, which established additional facilities in Texas, Arizona and Europe. In 1995, with the overall company at about 750 employees, ICI sold the company to an investment firm. Throughout these transitions, Fiberite retained its identity as a wholly owned subsidiary. In 1997, in its 49th year of operation, a major competitor, Woodland Park, NJ-based Cytec Industries (now part of Solvay, Brussels, Belgium), purchased the company and integrated it into its operations. As employees of Fiberite, we didn’t get the chance to celebrate 50 years of independent operation, which makes the Fibergrate and IDI anniversaries all the more special. **cw**



ABOUT THE AUTHOR

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

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Damage-resistance testing of composites

» An important consideration for many composite structures, damage assessment targets two primary components: damage *resistance* and damage *tolerance*. Damage resistance refers to the ability of a composite laminate or structure to resist damage formation. Of particular concern is damage produced due to impacts, which may cause extensive internal damage that is difficult to detect by visual inspection. Because the types and extent of damage produced by an impact depend on the layup and thickness of the laminate, as well as the material used, damage resistance is considered a *structural* rather than a *material* property.

In contrast, damage tolerance refers to the capability of an impact-damaged composite laminate or structure to maintain its strength and stiffness. The most common method of assessing damage tolerance is to perform an in-plane compression test using impacted composite specimens, referred to as Compression After Impact (CAI) testing. The focus here, however, will be on testing to assess the damage resistance of a composite laminate.

A damage resistance test has two phases: 1) impacting a composite specimen and 2) assessment of the damage produced. The most common procedure for specimen impact is the instrumented drop-weight impact test method, specified in ASTM D 7136¹. Although a variety of composite laminates may be tested, the use of $[45^\circ/90^\circ/-45^\circ/0^\circ]_{ns}$ quasi-isotropic laminates of 4- to 6-mm thickness is suggested for comparisons among different materials. The 100-mm by 150-mm specimen is clamped to a support plate that features a centrally located, 75-mm by 125-mm rectangular hole. This plate provides support for the specimen around its perimeter, but permits deflection of the specimen's center section during impact (Fig. 1). A 16-mm hemispherical tip impactor is specified. However, a different tip diameter and shape may be used to represent an identified impact threat for a particular application.

The impact energy, E , may be calculated based on the potential energy of the impacting mass, m , from the equation

$$E = m g h,$$

where h is the drop height and g is the gravitational constant (9.8 m/sec²). Alternatively, the impact energy may be calculated based on the kinetic energy at the point of impact using the equation

$$E = \frac{1}{2} m v^2,$$

where v is the impactor velocity just prior to specimen contact. The use of kinetic energy in the second equation is typically considered more accurate, because friction as the weight is dropped results in less impact energy than that calculated using the potential energy expression in the first equation. But when an accurate measurement of the impactor velocity at impact is not available, the potential energy expression is considered acceptable.

The impact energy and the resulting level of impact damage are determined based on the purpose for testing. For material comparisons, ASTM D 7136 specifies a value of impact energy per specimen thickness of 6.7 J/mm to produce visual damage in the central region of the specimen. To identify the impact energy

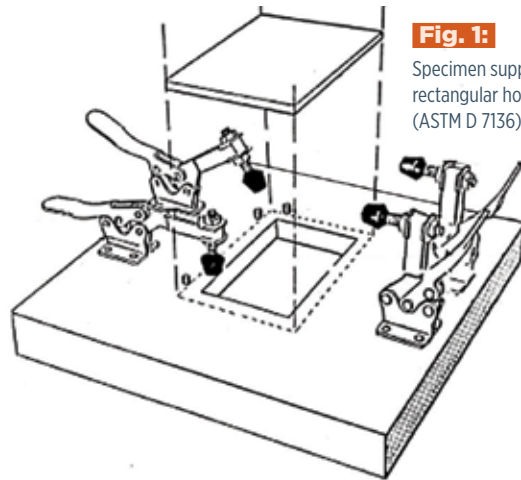


Fig. 1:

Specimen support plate with rectangular hole for impacting (ASTM D 7136). Source | Dan Adams

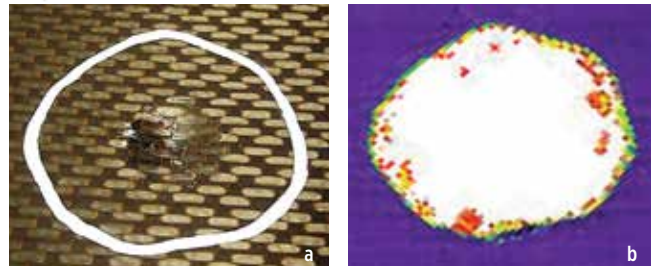


Fig. 2:

Impact damage produced in woven carbon/epoxy composite specimen:

- a) Visual impact damage and outline of C-scan damage area
- b) Ultrasonic C-scan image of internal damage area

Source | Dan Adams

associated with barely visible impact damage (BVID), however, a series of impacts typically are performed with increasing impact energy, produced by increasing the drop height of the impactor.

A less commonly used method of damage resistance testing is the quasi-static indentation test, during which an indenter of the desired size and shape is *pressed* into the panel using a mechanical testing machine. ASTM D 6264² specifies the use of a 150-mm by 150-mm specimen and two support conditions: 1) edge supported on a support plate with a 125-mm diameter circular cutout and 2) rigidly backed on a solid support plate. Because neither of these support conditions are the same as the rectangular cutout specified for drop-weight impacting in ASTM D 7136, they would not be expected to produce the same damage formations. But research studies have shown that if the same specimens and support conditions are used, comparable damage formations will be produced when the maximum force applied during indentation testing is the same as the peak force produced during drop-weight impacting³.

The extent of the damage produced in the composite specimen can be measured by nondestructive and destructive inspection methods. Note, however, that if impacted specimens are to be »

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used for follow-on damage tolerance testing, only nondestructive methods should be used.

Common nondestructive measures of impact damage include surface indentation depth, measured with a depth gage micrometer. ASTM D 7136 specifies that this depth measurement be made immediately after specimen impact because the indentation depth might decrease over time. In some cases, an additional depth measurement is made from one to seven days afterward, to better assess the indentation that would be present during visual inspection in service. Unfortunately, considerable scatter is common in indentation depth measurement data and, therefore, they are of limited use. Measurement of visually observable surface damage, such as cracks, also can provide a simple damage metric and can be used to establish impact energy levels associated with BVID (Fig. 2a, p. 12). But the most commonly used damage metric is the planar damage area, produced using ultrasonic C-scan inspection. Using the pulse-echo method, an ultrasonic pulse is sent through the specimen thickness. The pulse reflects back to the probe when it reaches either the panel's back surface or internal damage, such as delaminations. The planar damage area thus can be identified and measured, as the probe scans the region of impact (Fig. 2b).

If destructive inspection is permissible, specimens can be sectioned through the impacted region, polished and examined using optical microscopy. Additionally, the impacted region may

be cut from the larger specimen and X-ray microCT scanned to produce a three-dimensional image of the internal damage. Because both methods are more time-consuming and costly, they tend to be used less frequently. **CW**

REFERENCES

¹ASTM D7136-15, "Measuring the Damage Resistance of a Fiber-Reinforced Polymer Matrix Composite to a Drop-Weight Impact Event," ASTM International (W. Conshohocken, PA, US), 2015 (originally published 2005).

²ASTM D6264-12, "Measuring the Damage Resistance of a Fiber-Reinforced Polymer Matrix Composite to a Concentrated Quasi-Static Indentation Force," ASTM International (W. Conshohocken, PA, US), 2012 (originally published 1998).

³A.T. Nettles and M.J. Douglas, "A Comparison of Quasi-Static Indentation to Low-Velocity Impact," NASA Technical Report TP-2000-210481, 2000.



ABOUT THE AUTHOR

Dr. Daniel O. Adams is a professor of mechanical engineering and has been the director for 19 years of the Composite Mechanics Laboratory at the University of Utah and vice president of Wyoming Test Fixtures Inc. (Salt Lake City, UT, US). He holds a BS in mechanical engineering and an MS and Ph.D in engineering mechanics. Adams has a combined 36 years of academic/industry experience in the composite materials field. He has published more than 120 technical papers, presents seminars and chairs both the Research and Mechanics Divisions of ASTM Committee D30 on Composite Materials and the Testing Committee of the *Composite Materials Handbook (CMH-17)*. He regularly provides testing seminars and consulting services to the composites industry.

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August 2016 — 51.9

New orders, production and key target markets are up.

» With a reading of 51.9, the Gardner Business Index showed in August that the US composites industry had expanded for the first time since February of this year. Also, in August the Index reached its highest level since March 2015, jumping significantly from 43.3, the level recorded just two months previously, in June.

New orders grew for the second month in a row. That subindex reached in August its second highest level since June 2014. Production increased for the first time since May. August's was by far the highest level for the production subindex since March 2015. And other than one month, the backlog subindex,

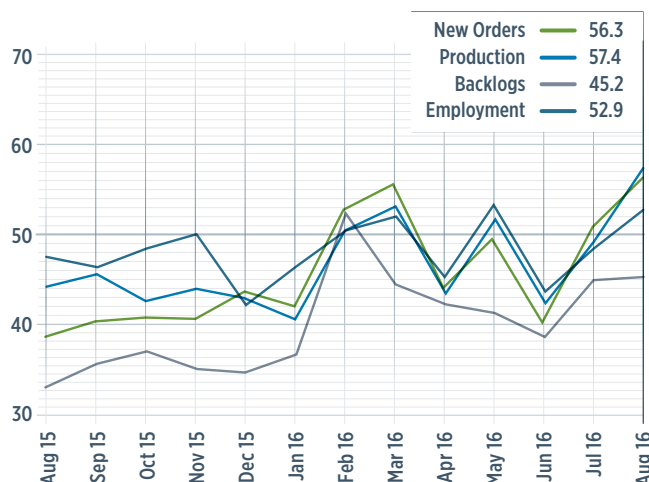
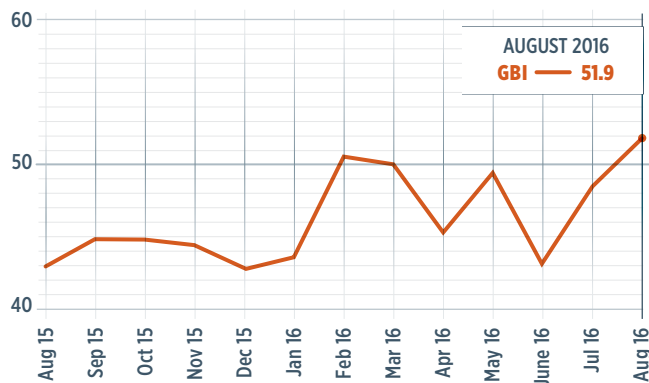
as August closed out, had contracted since December 2014. That said, the backlog subindex had shown dramatic improvement since January of this year. Employment increased in August. Its subindex had bounced, alternating between growth and contraction since February. Exports continued to contract in August. However, the trend in that subindex had been positive since November 2015. Supplier deliveries lengthened for the fourth time in five months.

Material prices increased for the seventh month in a row. The rate of increase accelerated in August, pushing the subindex to its highest level since July 2015 and its second highest level since November 2014. Prices received increased for the first time since August 2015. In August, that subindex jumped sharply from the number recorded in July. Similarly, the future business expectations subindex increased dramatically in the space of a month. In the case of the latter, the number rose to its highest level since October 2015.

The US aerospace industry grew for the fifth time in seven months. And, in one of the other two months, it was flat. In August, the aerospace subindex was 57.4, which was its highest level since March and second highest since May 2012. The US automotive industry grew for the first time since October 2015. The power generation industry appears to have been quite strong in the past four months. Although not as strong, the computer/electronics industry has grown every month but one in 2016.

Future capital spending plans for the coming 12 months were above average in August, and that was the case for the first time since August 2015. Compared with the figure recorded at that earlier date, future spending plans in August 2016 were down 2.2%. However, at the end of August, future capital spending plans had increased compared with one year earlier in four of the previous six months. Although the annual rate of change continued to contract, it did so at a decelerating rate from February through August. This indicated that the weakest part of the capital equipment cycle was likely in the past. **CW**

A GBI reading of >50.0 indicates expansion; values <50.0 indicate contraction.



ABOUT THE AUTHOR

Steve Kline, Jr. is the director of market intelligence for Gardner Business Media Inc. (Cincinnati, OH, US), the publisher of *CompositesWorld* magazine. He began his career 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.
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The Impact of the “Future Car” on Engineering Software

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As the car of the future becomes a reality, there will be new demands on what is expected of engineering software. A shift will occur in engineering efforts towards software/electronics, lightweight materials and interiors.

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An Integrated Approach to
Achieving Widespread Adoption
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Presented by: Dale Brosius / IACMI

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CFRP Manufacturing:
Rethinking the Process

Friday, November 11

Carbon Fiber Recycling:

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Offshore wind in US promises a blade bonanza, a promising composite-cored transmission cable wins an award, and fiber-metal laminate automation promises 50x panel output.



ENERGY

Block Island: Beginning of a second big blade boom?

The completion of the offshore Block Island Wind Farm about 5 km southeast of Block Island, near New Shoreham, RI, US, is in the grand scheme of the growing global wind energy industry a small drop in a very large ocean. But when the 15 massive composite wind blades installed on those five 6-MW Halide turbines began to capture the power of the wind off the US East Coast in late August, the key had finally turned in what had been a very sticky lock. Since then, a chorus of voices in industry, media and in governmental circles have joined the American Wind Energy Assn. (AWEA, Washington, D.C.) in proclaiming the US offshore wind door open. The *New York Times*, for example, in an article heralding the new offshore push, reported that Massachusetts governor Charlie Baker, in late August, signed a bipartisan bill *ordering* the state's utilities to develop contracts with offshore wind farms for more than 1.5 GW — 50 times the expected output of the Block Island Wind Farm. (That would be ± 750 composite blades, if you're counting.) Gov. Andrew M. Cuomo of densely populated New York, the article noted, had previously set a goal of getting 50% of the state's power from renewable sources by 2030, an unlikely outcome without resort to offshore wind power.

USA Today reported that Block Island's developer, Providence, RI-based Deepwater Wind, was working on a

deal for 200 turbines with 1 GW of capacity in 256 miles² of federal waters 30 miles southeast of Montauk, NY and that the Long Island Power Authority recently announced plans to acquire 90 MW of capacity from 15 Deepwater Wind turbines in the area, although the financial terms still need to be worked out. Further, the US Bureau of Ocean Energy Management (BOEM) has awarded 11 commercial wind energy leases off the Atlantic coast. And according to the latter, there are 13 offshore wind projects now at some stage of development, totaling about 6 GW of capacity, intended for shallow waters off 10 states on the US East and West Coasts and in the Great Lakes region.

What's remarkable is the potential: As European research has demonstrated, offshore winds are steadier and, therefore, offshore turbines turn more hours and produce more power per day than their onshore counterparts. The US government classifies winds on a scale of 0 to 7 (7 is best), based on power density, and more than 66% of offshore wind accessible from US territorial waters is in class 6 or 7. Moreover, the National Renewable Energy Laboratory (NREL, Golden, CO, US) estimates the US has 4,200 GW of developable offshore wind resources. Figuring roughly three blades per current state-of-the-art 6-MW turbine, that could amount to 2,100,000 blades. *All new business*. That's what might be called a windfall.

CompositesWorld announces media partnership with IACMI

CW's parent company Gardner Business Media (Cincinnati, OH, US) announced an August agreement with the Institute for Advanced Composites Manufacturing Innovation (IACMI, Knoxville, TN, US) that names CompositesWorld as IACMI's Preferred Media Partner.

"CompositesWorld is recognized as the leading media source in the composites industry," said Craig Blue, IACMI's CEO. "Our partnership ... will help us spread the word of the good work that IACMI is doing as a collaboration of industry, research institutions and state partners committed to accelerating development and adoption of cutting-edge manufacturing technologies for low-cost, energy-efficient manufacturing of advanced polymer composites for vehicles, wind turbines and compressed gas storage."

Ryan Delahanty, publisher of *CompositesWorld* magazine, commented, "Our partnership with IACMI will allow

CompositesWorld an even deeper reach into the important work being done by this outstanding organization, thereby allowing us unique early access to information for our readers. We look forward to working with IACMI to help expand our readers' composites knowledge base."

IACMI, a public/private consortium operated by Knoxville-based Collaborative Composite Solutions Corp., is the fifth Institute in the National Network of Manufacturing Innovation, supported by the US Department of Energy's Advanced Manufacturing Office. Learn more about IACMI through the Web site, www.IACMI.org

CompositesWorld is the publisher of the *CompositesWorld Weekly* and *CompositesWorld EXTRA* newsletters, as well as *CompositesWorld* magazine, the *SourceBook* composites industry B2B buyer's directory and the CW Web site | www.CompositesWorld.com



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How to Make Great (Ti/CFRP) Joints: The Story of the Robot Bike Co. R160 Development

EVENT DESCRIPTION:

“The right material in the right place” is an oft-used mantra but in practice the benefits of hybrid construction are difficult to realize due to the weight of the joint. This story starts with the increasing take-up of carbon fiber composite construction in high performance bicycles motivated by weight saving. An unintended consequence of this, however, is reduced consumer choice due to the high up-front capital investment in tooling required. HIETA Technologies, in collaboration with Altair and Renishaw PLC, has worked with Robot Bike Company to address this problem with a combination of metallic Additive Manufacturing, topology optimization, cost-effective out-of-autoclave composite manufacturing and parametric design. The result is the recently launched Robot Bike Company R160 Enduro-style suspension frame.

PARTICIPANTS WILL LEARN:

- Integration of the titanium and carbon composite parts through the use of double lap shear (pi) joints
- Structural and economic drivers, detailed design, manufacturing, assembly processes and testing associated with the double lap shear joints
- Insight into how HIETA Technologies is pursuing alternative applications of this technology in other ‘hybrid truss’ applications.

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AUTOMOTIVE

Carbon fiber wheels the subject at automotive lightweighting conference

Lacks Wheel Trim Systems LLC (Grand Rapids, MI, US, a business unit of Lacks Enterprises Inc.) was a featured sponsor at the 5th Annual Global Automotive Lightweight Materials (GALM) 2016 Summit held Aug. 23-25, 2016, in Detroit, MI, US, and the company unveiled a new composite wheel technology at the event.

"We are very excited to once again be a sponsor at the GALM Summit in Detroit, a conference that, for five years now, has been at the forefront of the increasingly important lightweighting movement."

Ryan O'Toole, director of sales and marketing at Lacks Wheel Trim Systems, described a new hybrid aluminum/carbon fiber wheel, an outgrowth of his company's ongoing partnership with Plasan Carbon Composites (Wixom, MI, US). The Lacks and Plasan wheel reportedly has significant carbon fiber content, and will be ready for OEM production in third-quarter 2017, at wheel shipment volumes not previously possible says O'Toole.

"This is a movement that we continue to support by providing automakers with advanced composite wheel technologies that provide ... immediate savings of ... weight,



Source | Lacks Wheel Trim Systems LLC

ranging from 4-10 lb [1.8-4.5 kg] per wheel depending on size," says James Ardern, general manager at Lacks Wheel. "Along with Plasan Carbon Composites, we are excited and proud to introduce our latest lightweight wheel property to the automotive industry." Lacks Wheel has established long-term relationships with global automotive partners that include Audi, Mercedes-Benz, Toyota, Nissan, Ford, FCA, General Motors and Volkswagen. For more information, visit www.lacksenterprises.com/wheels.html

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RICHARD MITCHELL
Lead Product Marketing Manager
for Structures
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EVENT DESCRIPTION:

Composites provide new solutions for manufacturers looking for stronger, lighter and more cost-effective materials. At the same time, they pose new modeling and manufacturing challenges due to curing, springback and residual stresses. With the right simulation tools, designers can account for residual stresses, predict performance, analyze reliability and potential failures, optimize construction and export accurate information to manufacturing, all before a physical prototype is built. This webinar demonstrates how ANSYS simulation tools can help you engineer lighter, better and higher performing composites using simulation.

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BIZ BRIEF

Private equity firm Sorenson Capital (Lehi, UT, US) and Yukon Partners (Bloomington, MN, US), a provider of mezzanine capital for middle-market private equity transactions, have invested in **Axiom Materials Inc.** (Orange County, CA, US). Axiom is a manufacturer of proprietary advanced composite materials and related products for customers in the aerospace and defense, industrial, automotive, medical device and electronics industries.

Sorenson sponsored the transaction in which it, Yukon and other institutional co-investors facilitated the recapitalization of Axiom. NXT Capital (Chicago, IL, US) provided the senior credit facility, and mezzanine capital was provided by Yukon. Chicago-based Schiff Hardin LLP served as legal counsel to Yukon.

"We are delighted to partner with Sorenson Capital and Yukon Partners to co-author the next major chapter in the Axiom Materials story," says Johnny Lincoln, founder and president of Axiom Materials. "With the combined capabilities of Axiom, Sorenson Capital and Yukon Partners, the company's future has never been brighter. We are now aligned and capitalized to accelerate our long-term strategic goals and ultimately reach our highest potential."



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CW / MONTH IN REVIEW

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

SpaceX rocket explodes on launch pad in Cape Canaveral

The company says an anomaly on the pad resulted in the loss of its *Falcon 9* launch vehicle and a Facebook-owned satellite payload intended for low Earth orbit.

09/01/16 | short.compositesworld.com/SpaceXexp

American Industrial Partners buys Gerber Technology

The private equity firm bought Gerber from Vector Capital.

09/01/16 | short.compositesworld.com/AIPGerber

Newly formed LeMond Composites signs agreement with ORNL

The company's "breakthrough" process will reportedly reduce production costs by more than 50% relative to the lowest cost industrial grade carbon fiber.

08/29/16 | short.compositesworld.com/LemondORNL

New composites technology center opens in Turkey

Center anchors Kordsa Global (Istanbul) and Sabanci University seek a new, high-tech hub, driven by collaborative research and production.

08/29/16 | short.compositesworld.com/TurkeyCtr

Owens Corning to invest US\$110 million in India composites operations

The investment includes the installation of an 80,000-ton glass melter at the company's existing facility in Taloja, India.

08/26/16 | short.compositesworld.com/OCIndia

IACMI, University of Tennessee opens revamped facility

The newly named Fibers and Composites Manufacturing Facility and Engineering Annex serves as a complementary resource to area facilities.

08/26/16 | short.compositesworld.com/IACMI-UT

Solvay doubles carbon fiber manufacturing capacity in the US

The company adds a new carbon fiber line to its facility in Piedmont, SC, US, to produce standard-modulus PAN fiber used to make aerospace prepreps.

08/25/16 | short.compositesworld.com/SolvayCFUS

Stratasys debuts Robotic Composite and Infinite-Build 3D printers

The Minneapolis, MN, US-based company says this new 3D printing technology produces larger, lighter production parts for aerospace and automotive.

08/25/16 | short.compositesworld.com/Robo3D

Hexagon Composites produces new-gen cylinders for Mercedes-Benz GLC F-CELL

The compressed hydrogen gas cylinders are the result of years of R&D and testing with Mercedes-Benz parent Daimler's wholly owned subsidiary NuCellSy.

08/22/16 | short.compositesworld.com/Tanks4FCV

Gurit provides full structural design for new Qatar Coastguard boats

Gurit also undertook FEA on the composite waterjet for the 48m vessel to ensure that the intake avoids the natural frequencies from the waterjet's impeller.

08/22/16 | short.compositesworld.com/GuritQatar



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FORECAST

Market for core material to grow

Research and Markets (Dublin, Ireland) is forecasting that the market for structural core materials will grow significantly from US\$142.2 million today to US\$220.2 million by the year 2021, driven largely by aerospace demand, and specifically, the use of core in aircraft interiors. So says the company's new report, "Structural Core Material Market in Aerospace Interior by Type, Aircraft Type, Application and by Region — Global Forecast to 2021," dated July 2016. It contends that structural core materials, which include honeycombs, foam and balsa wood, are now widely used in a variety of interior aircraft cabin applications, including sidewall and ceiling panels, floor panels, galley areas and bulkheads. The growth is largely associated with the overall increasing use of composites, both structural and nonstructural, in commercial aircraft. High production build rates are driving the increase, as well as rising demand for new materials that both reduce aircraft weight and allow the passenger more personal and luggage space.

Use of structural core materials in the Asia-Pacific region is expected to grow at a high rate both in terms of value and volume, and the trend is expected to continue into the future, driven by an improving economy and industrial and technological development in the region, including in Japan, China and Malaysia. North America also is one of the major regions in terms of impact on the structural core material market in the realm of aerospace interiors due to the presence of large aircraft manufacturers in the US.

The report further explores the core market by type of core, by aircraft, by application and by geographic region, and presents supplier company profiles as well as a look at the overall competitive landscape.

To preview or acquire the full report, visit www.researchandmarkets.com/research/jsbwfq/structural_core

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INFRASTRUCTURE

Composite-cored electrical transmission lines win award

American Electric Power (AEP, Columbus, OH, US) recently received the Edison Electric Institute's (EEI, Washington, DC, US) 2016 Edison Award, the electric power industry's most prestigious honor, for its Energized Reconductor Project in the Rio Grande Valley, in the US state of Texas. A panel of former electric company chief executives selected AEP for the 89th annual award from a group of distinguished finalists. The project incorporated hybrid carbon/fiberglass Aluminum Composite Core Conductors (ACCCs), supplied by CTC Global (Irvine, CA, US).

AEP made the decision to upgrade the two 345-kV transmission lines the company uses to deliver power from Corpus Christi to the lower Rio Grande. Taking the transmission lines out of service was not an option, because the two power lines were the only source of power in the region, says Bob Bradish, AEP vice president, transmission grid development. "If we had taken one line out of service for replacement, there was a good chance the remaining line would overload," he points out. AEP was able to replace all 240 miles of line while they were in an energized state, using existing structures and rights of way, thus negating the need for alternative generation

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sources and completing the project at a savings of more than US\$43 million.

With the help of Quanta Energized Services (Houston, TX, US), a specialist in maintaining large transmission lines while they carry power, AEP replaced more than 1,440 miles of traditional aluminum conductor steel-reinforced (ACSR) line with high-performance, high-efficiency ACCC conductor while the line remained energized. This was not only the largest live-line reconductoring project ever undertaken but also the largest single deployment of CTC's ACCC conductor in history. In addition to doubling the capacity of the existing circuits, the ACCC conductor is more efficient, reducing line losses by 30% compared to the ACSR conductor.

The ACCC conductor consists of a pultruded hybrid carbon/glass fiber/epoxy core in an epoxy matrix, surrounded by aluminum strands. The glass overlay creates a barrier between the carbon fiber and the aluminum conductor, preventing galvanic corrosion. Read more about how the ACCC cable is made and how it has contributed to the electrical industry, in "Composite cored conductors holding the line" |

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Watch a video presentation about the energized reconductor project |

www.youtube.com/watch?v=aPaNHawldFA&feature=youtu.be

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AEROSPACE

New chance for fiber metal laminates — GLARE production amped by automation

In a 2014 SAMPE Europe presentation, Christian Ruckert, head of Airbus R&T Materials & Process in Bremen, Germany, cautioned that the cost to develop and implement new composites technologies on upcoming aircraft will have to be much lower than what was seen on the most recent models. He then predicted



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that titanium-based additive layer manufacturing (ALM) and glass laminate aluminum-reinforced epoxy (GLARE) will see growth in future aircraft, including narrowbody models, such as the Airbus (Toulouse, France) A320.

GLARE is a specific type of fiber metal laminate (FML) made from interleaved thin sheets of aluminum and unidirectional S2-glass prepreg. The material first came to the attention of the aviation and composites industries' news reporters when it cut part weight by 30% vs. aluminum in 27 fuselage panels on the 20% composite Airbus A380 jumbo passenger jet. Although Ruckert acknowledged that GLARE was dropped for models after the A380, he also asserted that recent innovations in automation will reduce its cost vs. non-metal based composites. His predictions were bolstered by Premium AEROTEC's (Augsburg, Germany) recent conference technical presentation, "New Chance for Fibre-Metal-Laminates as Hybrid Material for Mobility." (Note: Premium Aerotec has also announced serial production of 3D-printed titanium parts, fulfilling Ruckert's predictions concerning ALM.)

According to the presentation, Premium AEROTEC's current production rate — including 5 of the 27 A380 panels — is 200 m²/month, and relies on myriad manual steps, including trimming, pre-treatment of, and primer application on, aluminum sheets, followed by layup with glass prepreg into a mold, vacuum bagging, autoclave cure (see photo, above) and nondestructive testing (NDT). The cured GLARE skin is then milled and layed again into a mold for

an *additional* bonding step necessary to apply stringers and doublers, followed by a *second* vacuum bag, cure and NDT cycle.

Now, however, the company has a development program to automate its GLARE production, aimed at a rate of 10,000 m²/month — an ambitious 50x increase — and a single-shot bonding process in which sheet metal, prepreg, doublers and stringers are co-autoclave-cured. An ATL head has been developed, which is capable of laying 460-mm-wide material, with a full roll of prepreg mounted on a standard robot for positioning and a second end-effector with linear actuators to handle the aluminum sheets. Part geometry and final positioning of all materials is guided digitally, directly from the part's CAD model.

For automated application of stringers, doublers and other parts, Premium AEROTEC has worked with an automation partner experienced in Airbus A350 stringer integration control, using sensors.

The team has demonstrated production of 2m by 2m cylindrical and spherical parts, including all of the splice geometries likely to occur in current aircraft designs. Coming developmental milestones include a 2m by 6m panel, yet this year, and a 4m by 10m panel in 2017. Stringer integration and single-shot bonding also will be demonstrated, and investigation of new designs for fuselage shells is on the agenda as well. Premium AEROTEC is working with partners Fokker Technologies (Papendrecht, The Netherlands), Toulouse-based Stelia Aerospace and others from the R&D sector, and reports it will soon be able to meet production rates of up to 70 aircraft per month.

For its part, Fokker, which already produces 22 of the A380 panels, signed an agreement earlier this year with Airbus, entering into a strategic partnership to address research, development and automation of FML production.

Read more about the resurgence of GLARE in Airbus commercial aircraft production online at the CW Web site | short.compositesworld.com/REGLare

BIZ BRIEF

Bang & Bonsomer Group (Helsinki, Finland), a distributor of a wide range of raw materials and additives to the composites industry, will open a new gel coat manufacturing unit in its Kokkola warehouse site in Finland by the fourth quarter of 2016. This will enable the manufacture and sale of Polycor QuickMix gel coats, a product line developed by **Polynt Composites** (Carpentersville, IL, US). Available in spray or brush grade, Polycor QuickMix is said to provide a durable, porosity-free surface on molded composite parts.



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AEROSPACE

GAMA reports downturn in general aviation in second quarter



Source | Bombardier

The General Aviation Manufacturers Assn.'s (GAMA, Washington, DC, US) worldwide general aviation (GA) aircraft shipment and billing figures for the first half of 2016 show GA airplane shipments declined 4.5% to 970 units and billings fell 11% from US\$10.4 billion to US\$9.3 billion. GA rotorcraft shipments also dropped 16.1%, from 467 units during the same period a year ago to 392 units in 2016. Billings fell 32.5%, from US\$2.1 billion to US\$1.4 billion.

Piston airplane deliveries were down 4.5%, from 464 units to 443 units. Turboprop shipments declined 4.9%, from 247 units to 235 units. Additionally, 292 business jets were shipped in the first half of 2016, a 4.3% dip from the 305 units shipped during the same period in 2015. Piston rotorcraft fell 10.1%, from 129 units to 116 units, and turbine shipments were down 18.3%, from 338 units in 2015 to 276 units in the first six months of this year.

"In a challenging global climate, every segment of the fixed-wing and rotorcraft market showed declines," says GAMA president and CEO Pete Bunce, citing the failure of the US Congress to reform what he called outdated, overly prescriptive certification processes in the recently passed Federal Aviation Admin. (FAA) extension: "We hope to see greater commitment by policymakers around the globe to give manufacturers the regulatory environment they need to succeed and allow our industry to continue to move forward."

3D printing harnesses ceramic-matrix composites

Swansea, Wales, UK-based 3Dynamic Systems Ltd. says it has harnessed what it terms a revolutionary new 3D Printing platform for producing ceramic-matrix composites (CMCs). Adapted from fused deposition modeling (FDM), but operating at a higher temperature than conventional FDM, the new 3Dynamic Systems printer extrudes material at 315°C. The printing filament is made by suspending fine ceramic micro-fibers in a special thermoplastic polymer that is stable up to 325°C. The ductile 3D printed structure is then heat-treated in a furnace to 1450°C, transforming it into a CMC component.

This pyrolysis process must be carried out in a vacuum (i.e., absence of oxygen) to eliminate porosity. Although a turbine blade structure can be printed in roughly 5 hours, heat treatment requires another 24. "The annealing and complex heating cycles required are crucial for making our form of CMC," notes lead scientist Dr. Daniel J. Thomas. "If the material is placed straight into a high-temperature furnace, then it cracks. Care has to be taken in order to achieve the appropriate heat treatment."

Thomas says, "This 3D printing process allows for exotic new shapes to be formed with complex hollow internal cooling sections, making a single, seamless component." He adds that aerospace demand for parts that can handle higher temperatures is driving the technology and creating a new market for advanced 3D printing.

The current x/y/z build envelope is 300 mm by 200 mm by 400 mm, with a layer resolution of 0.075-0.100 mm. There are no other geometry constraints, and hollow sections and overhangs are possible.

Although 3Dynamic Systems is still evaluating how its CMCs stack up to traditional carbon and silicon carbide composites (e.g., C/C, C/SiC, SiC/SiC, Ox/Ox, etc.), testing to date shows elongation to rupture is 1.1% and temperature resistance up to 1350°C — falling between reported figures for SiC/SiC and C/SiC. Visit 3Dynamic Systems Ltd. | www.bioprintingsystems.com

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Fig. 1 CFRP-enabled UAV

This unmanned rotorcraft contender for the US Army's Joint Tactical Aerial Resupply Vehicle features an unusual, low-profile four-prop configuration, the work of SURVICE Engineering (Belcamp, MD, US) and Malloy Aeronautics (Berkshire, UK).

Source (all photos) | CW / Photos | Bob Griffiths

2016 Farnborough International Airshow Report

Composites are not the novelty in aerospace that they once were, but there was still much to see at Farnborough this year.

By Bob Griffiths / Contributing Writer

» Held every other year (alternating with the Paris Air Show, in Le Bourget, France), the Farnborough International Airshow is a premier European aerospace showcase. Its 2016 edition took place July 11-15 at Farnborough Airport (Farnborough, Hampshire, UK). We noted in our report on the 2014 event that at the Farnborough Airshow and others like it, the display of composite aerostructures had become a common sight as they earned a place in many new aircraft programs, but it was acknowledged even at that time that composites were a bit less conspicuous than they had been at previous Farnborough shows.

First impressions

So it was with a bit of initial disappointment that, to this observer, there appeared to be even fewer composite parts about than in 2014, and The Boeing Co.'s (Chicago, IL, US) much anticipated press conference, based in part on its annually published *Current Market Outlook*, did not even mention composites!

Indeed, the single-aisle aircraft segment of the commercial aircraft market still poses a serious challenge to the composites industry; we have succeeded in getting 50% of the market for structures on the long-range aircraft, but on single-aisle planes, the two market leaders still have metallic wings and fuselages. Boeing reports that this sector represents 47% of the current backlog, and to this observer, the composites industry does not seem concerned at

these missed opportunities. Thanks does go out to Bombardier (Montreal, QC, Canada) and the Irkut Corp. (Irkutsk, Russia) for these companies' faith in new materials. Irkut's *MS-21* narrowbody single-aisle (130-210 passenger) commercial jet, for example, is 30% composites, featuring, notably, an *out of autoclave* (resin-infused, oven-cured) wing and wingbox — a first for large, primary aerostructures.

Second Impressions

On reflection, the absence of overt reference to composites at Boeing's press event is, possibly, a good thing: It indicates that composite materials have become an accepted industry norm and that any entirely new aircraft will likely have composite wings and, probably, a composite fuselage to match. Certainly, as the show progressed, there were encouraging signs. In the flying display, there was a *lot* of carbon fiber flying around: the first Royal Air Force F-35 refueling from an A400M; the first Swiss Air Bombardier *CSeries*; and also the first European display of the exception to one's composite expectations, Boeing's 737MAX.

And if the OEMs were a bit reticent on the subject of composites, the supply chain proved less so. The following is a selection of the more innovative composites applications on display in the exhibition halls.

GKN Aerospace (Redditch, Worcestershire, UK) had an interesting display of structures in its pavilion. Thermoplastic composite structure had a conspicuous presence, reflecting GKN's

Farnborough 2016 provided evidence that composite materials have become an accepted industry norm.

recent acquisition of Fokker Aerostructures (Hoogeveen, The Netherlands). A number of GKN team members were from The Netherlands, including Fokker's R&D director Arnt Offringa, who explained to visitors the options for applying stiffeners to panels using various joining techniques. GKN technical sales engineer Ali Ahmed described a new-generation de-icing technology that uses much thinner heating layers than those on existing systems, yielding benefits in reduced weight and less energy consumption.

The exhibition was full of UAVs built with varying amounts of carbon fiber. However, the biggest (Fig. 1, p. 34) was the result of an Anglo-American joint program. It is a leading contender for the US Army's Joint Tactical Aerial Resupply Vehicle. The companies involved are, from the US, Belcamp, MD-based SURVICE Engineering, and Malloy Aeronautics from Berkshire, UK.

In The Netherlands, Airborne Development BV (The Hague) is participating with Fokker and the Amsterdam-based NLR »

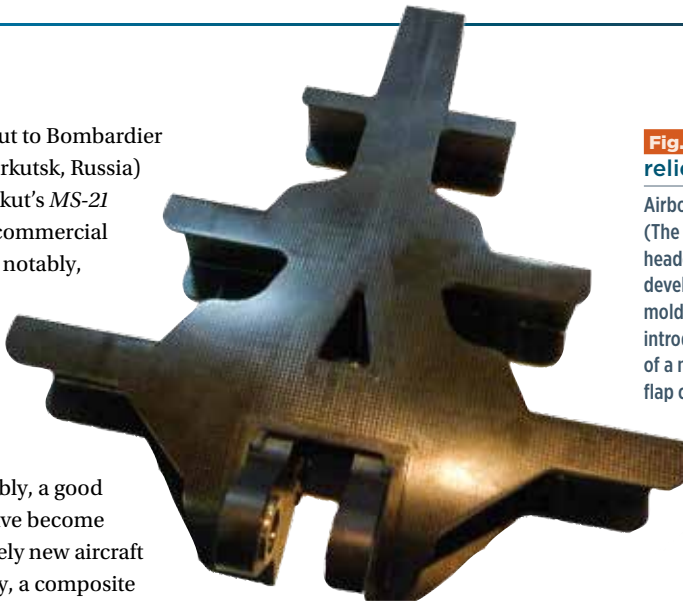


Fig. 2 Flap integrity relies on RTM'd rib

Airborne Development BV (The Hague, The Netherlands) headed a team that developed this resin transfer molded carbon fiber rib that introduces load into the spar of a new CleanSky program flap concept.



Fig. 3 ATL for volume tape deposition

Airborne's tape laying head for 150-mm-wide prepreg tape.



Fig. 4 CleanSky's reconceived unducted blades

Evidence of CleanSky program progress also included this model of Safran's (Paris, France) Open Rotor System, now ready for ground testing, a re-imagining of a previously abandoned turn-of-the-21st Century unducted fan blade concept.

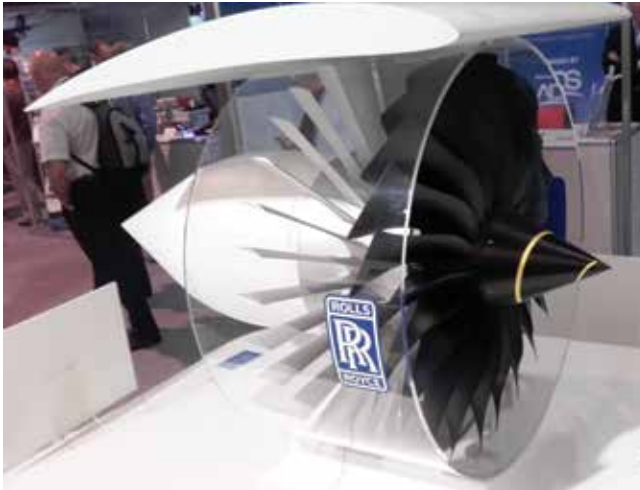


Fig. 5 Rolls-Royce/Airbus E-Thrust System

This futuristic jet engine fan system will alternately draw on system batteries and gas during takeoff/climb, recharge those batteries and power flight via gas turbines during cruise, shut down gas turbines and operate systems (electrical and electronic) off batteries while engine rotors act as wind turbines to recharge batteries during descent, and then restart gas-powered units to facilitate reverse thrust during landings.

(Nationaal Lucht- en Ruimtevaartlaboratorium or National Aerospace Center) in a CleanSky program to make an innovative flap for business jets. The flap's structural integrity depends on the load introduction rib on display at Airborne's stand, a very complex part made by RTM (Fig. 2, p. 35). Also on display was an automated tape laying head developed for use with 150-mm prepreg tape (Fig. 3, p. 35).

DTC (Dutch Thermoplastic Components BV, Almere, The Netherlands) is well known for its expertise in press-forming thermoplastic composites for aerospace applications. It had three recent innovations to report: The development of its own thermoplastic UD tape; a pick-and-place layup machine; and, on the marketing side, a start at supplying structures to the automotive market, with a contract to make 400 seatbacks for an unnamed customer.

CTRM (Melaka, Malaysia) demonstrated its expanding capability with the announced delivery of its first helicopter structure to Airbus (Toulouse, France), the *fenestron* (the duct that surrounds the tail rotor) of the new H130 rotorcraft, as well as an Airbus A350 XWB fan cowl, which is supplied to UTC (Chula Vista, CA, US).



Fig. 6 "Smart" composites concept demonstrated

TWI (Cambridge, UK), demonstrated its Surflow technology, which can transmit digital data in the form of electromagnetic waves through CFRP panels. A camera on the right transmitted video data through the beam mounted atop the upturned paper cups, to the monitor on the left. TWI says Surflow has potential utility in "smart" composite applications, including possible use in real-time nondestructive inspection.

Fig. 7
Diversification and expansion

Williams Advanced Engineering (Oxfordshire, UK) displayed its Formula-E racing car, powered by batteries located in a crashworthy composite structure, in hopes of attracting aerospace customers.



Back at the end of the past century, unducted fan blades were forecast to power the next generation of aircraft. Low-cost oil and problems with noise put an end to this program. Now the concept has been renamed an open Rotor and is very much a live project, again, under the CleanSky program. The effort, led by Safran (Paris, France), has reportedly reached the stage where ground testing is imminent. Models of the system were on display (Fig. 4, p. 35), together with an even more futuristic system, the Rolls-Royce (Derby, UK)/Airbus E-Thrust System. The latter comprises an embedded gas-turbine that drives a superconducting generator used to power distributed electrically driven fans (Fig. 5, p. 36) that will reduce fuel consumption, and reduce emissions and noise on future aircraft.

TWI (Cambridge, UK) showed a demonstrator of a new, patented application of a very old phenomenon, which it has named Surflow. Surflow employs a property of electromagnetic waves that enables them to be transmitted *through* linear mate-

The Farnborough exhibition hall was full of UAVs built with varying amounts of carbon fiber.

rials, such as a CFRP panel, that incorporate both dielectric and conductive materials. On the TWI stand, a composite panel was set up and used to transfer data (in this case, pictures from a video camera) through the panel's length to a small monitor, which displayed the pictures taken by the camera (Fig. 6, p. 36). This technology works even if the panel suffers ballistic damage, making it a more damage-tolerant data transfer system than those that require embedded copper wires or fiber-optics. One of the first applications being studied is in UAVs. The Surflow process also has potential application in nondestructive testing, in the form of real-time composite monitoring. Subtle changes in the transmitted electromagnetic waveform could, for example, enable damage to an aircraft component to be identified immediately, as a potential alternative to costly scheduled groundings for lengthy manual inspections.

Williams Advanced Engineering (Oxfordshire, UK), primarily known as a Formula One racing team, is diversifying its engineering services company by expanding into aerospace. Thus its presence at the airshow. The company designs and builds Formula E electric racing cars. In this formula, all the cars have the same structure and suspension but may have different electric drive systems. The difficult bit is to design the car's composite main structure so that it will contain the heavy batteries in the event of a crash (Fig. 7, at left, p. 36).

IHI (Tokyo, Japan) had two composite engine parts on display (Fig. 8, top right). These were the fan case and the structural guide vanes for Pratt & Whitney's (East Hartford, CT, US) PW 1100G-JM, the new geared turbofan being fitted to the Airbus A320neo. »



Fig. 8 Geared TurboFan for the Airbus 320neo

On display at the IHI (Tokyo, Japan) stand was the composite fan case and structural guide vanes for Pratt & Whitney's new PW 1100G-JM geared turbofan engine.



Fig. 9 Lightweighting for launch vehicle battery packs

EAS' (Nordhausen, Germany) weight-saving carbon fiber composite case, designed to contain one of the 200 lithium-ion cells destined to ride with the *Proton* rocket into space, was shown with an existing metallic case.

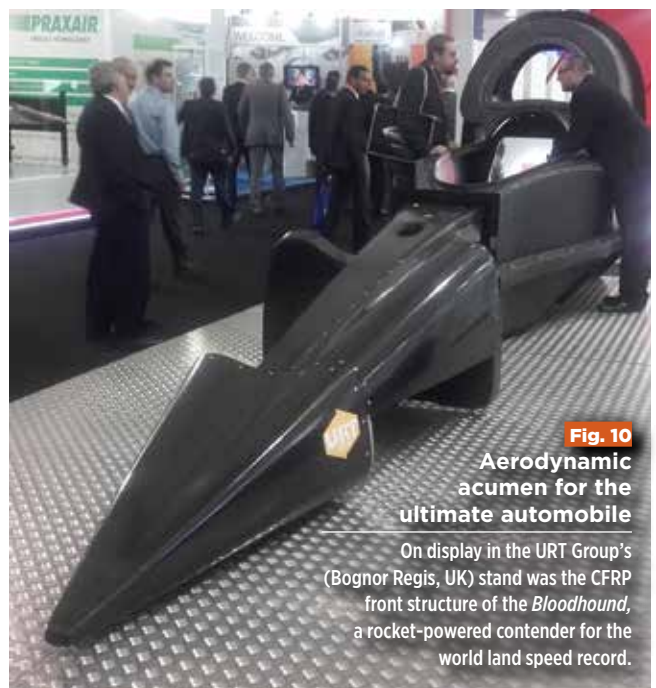


Fig. 10
Aerodynamic acumen for the ultimate automobile

On display in the URT Group's (Bognor Regis, UK) stand was the CFRP front structure of the *Bloodhound*, a rocket-powered contender for the world land speed record.

EAS (Nordhausen, Germany) demonstrated a new application for CFRP — cases for lithium-ion cells. Compared with the metallic cases currently in use, they save 50g each in weight, which seems like very little. However, the significance is obvious when one realizes that on a *Proton* rocket, there are 200 of these cells. This gives a total weight savings of 10 kg, a very important edge

when launching satellites into orbit (Fig. 9, p. 37).

The URT Group (Bognor Regis, UK) is building, for the *Bloodhound* hybrid car/rocket,

the main structure from CFRP, including the driver's cockpit. The *Bloodhound* project will attempt to push the World Land Speed Record past 1,000 mph (1,600 kph) in 2017. The *Bloodhound* structure was on display on the URT stand where it attracted a lot of interest from aerospace engineers (Fig. 10, p. 37).

Aviation Week and *SpeedNews* presented a briefing on Commercial Aerospace Manufacturing in two sessions. The first, related to "Automation in Aerospace Manufacturing," was of great interest to composites professionals: Craig Turnbull, from Electroimpact UK (Hawarden, UK), shared an interesting vision of future developments in automation, including Quadbots — robots that can work

alongside humans — and the need for more in-process inspection to eliminate time-consuming post-production NDT processes now used with composites.

It is encouraging, in an era when many civil aircraft look very similar, that 1 mm below the skins, they can be made from very different materials and these, in turn, can be processed in totally different ways. Fuselages can be made from conventional aluminum alloys, aluminum/lithium with or without the local use of Glare, or follow Boeing or Airbus twin-aisle practice and go for carbon/epoxy prepreg. Wings offer choices, but the industry seems to be focused on carbon/epoxy with some disagreement about the processes to be used. These can be conventional AFP plus autoclave cure or infusion, where the choice is oven or autoclave cure. When it comes to flight-control surfaces, the selection is broader: thermoplastics are earning a share, as are OOA prepreps, RTM and SQRTM on the thermoset side.

All this makes composites engineering a really interesting career at present. Long may it continue. **CW**

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ABOUT THE AUTHOR



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Taking the hand out of hand layup

Emerging research shows that it's possible to automate the hand layup process.

By Jeff Sloan / Editor-in-Chief

» Hand layup of prepregged fiber reinforcements has long been a standard of aerospace composites fabrication processes, and this has suited OEMs and molders well, particularly given what were historically the aerospace industry's relatively low build volumes. Further, the 100% inspection requirement imposed by aerospace OEMs ensures that any error introduced by humans during hand layup will more than likely be caught and corrected before delivery to the customer.

Marrying quality and quantity

For the mainstream automotive industry — the next great frontier for composites — the *modus operandi* has always rested at the polar opposite end of the fabrication spectrum. For the automaker, the hallmarks are high volume, high speed, repeatability, consistency, and quality control based on randomized part sampling, *none* of which favor hand layup of prepreps. All the same, the discrete placement of prepreg plies is a core advantage of composites design philosophy and not a process that the automotive

■ Giving hand layup a hand up to higher volume

Researchers at Bristol University (Bristol, UK) are working on robot-centered technology designed to automate traditional hand layup of composite prepreps. If successful, it might help “hand” layup move into higher-volume end-markets and applications. Source | ACCIS/Bristol University

industry wants to dismiss out of hand. Further, in the aerospace industry, the definition of “high-volume” is getting higher, which has put pressure on composites fabricators to be faster and more efficient in that industry as well.

Although automated fiber placement and automated tape laying (AFP and ATL, respectively) have obviously done much to automate prepreg tow, tape and fabric placement, these technologies are not cost-effective or efficient for all prepreg fiber placement operations. Each is most effective when parts are relatively simple: Large, flat or gently curved surfaces, such as wingskins come to mind. They are less so for parts with highly contoured, and/or deeply drawn surfaces, where bridging is a risk in tight radii and/or complex curvatures challenge the machinery's capability to successfully drape materials — situations in which human digits are still more capable.

So, the question is, can you replicate the process of hand layup without the potential for error inherent in touch labor? More to the point, can you mimic the dexterity and deftness of human thumbs, fingers and palms, and in the process provide higher speeds and greater consistency? In short, can you replicate hand layup *without* the human hand? The short answer appears to be a qualified “yes.”

Putting potential into practice

Proof of concept is being provided, as part of the CIMComp project, by the research team of lecturer in composites design, processing and manufacture Carwyn Ward and Kevin Potter, professor of composites manufacture, with research associate Michael Elkington, at the Advanced Centre for Composites Innovation and Science (ACCIS), Department of Aerospace Engineering, at Bristol University (Bristol, UK). They reported on their work in a paper presented at SAMPE Long Beach (May 23-26, Long Beach, CA, US).

The team focused its research efforts on developing layup automation for what it called a U-shaped panel, using a metallic mold that features a raised U-shaped section with tapered sides and a recess in the center of the U. They then closely studied how layup technicians place plies. “The key focus was on how the laminators actually create in-plane deformation in the plies,” they note. “Once an area had been appropriately sheared, it was adhered to the mold surface and then the shearing of the neighboring areas began.”

In addition, they said, “as small regions of the ply are sheared, the surrounding regions can begin to fold or wrinkle because of the discontinuity in in-plane strain across the ply.”

To cope with such wrinkling and folding, the team's paper notes, human laminators perform "a series of grasps and actions" to make sure each ply lays in the mold as it should, before the next ply is placed. This can be done, of course, because the laminator's hands are guided by well-trained eyes, which can see and identify the location of wrinkles and folds as they develop. Even with today's advanced visual technologies, that instant, symbiotic relationship would be difficult and expensive to simulate, at present, with automated robotic systems.

To address these challenges of in-plane deformation, then, the team decided to perform material shearing prior to layup, thereby minimizing the risk of wrinkling and folding. This "pre-shearing" step involves placing the ply in a press-type mechanism to form it into the approximate shape it will assume on the final part, generating at the same time the in-plane shear desired. Once plies are pre-sheared, they are ready for layup.

The researchers evaluated the possibility of using a press for this operation, but noted that control of order of ply layup is critical to ensure the quality of the contact between the epoxy in the prepreg and the mold surface. This was difficult to achieve with a press mechanism and instead they favored an automated approach that approximates the action of the human hand.

Because human laminators use their hands in so many different configurations to push prepreg into a mold, the researchers developed three end-effectors that would attach to the end of an ABB

IRB 140 6-axis robot.

All three end-effectors were mounted to the same robotic attachment. "To switch between them,

the head of the robot would simply re-orientate, allowing rapid changeovers," they note.

Each end effector, fabricated from silicone, uses a different design to target specific geometric features. The cylindrical roller end effector is designed for flat, convex and mildly contoured surfaces. The "profiled" roller end effector features a sphere with a sharp ridge at the outermost point for applying pressure into tight internal corners. The wedge end-effector is for concave double-curvature geometries and applies localized high pressure.

Tests and lessons learned

After a series of trials to assess the end-effectors' capabilities, the research team began layup of the U-shaped mold described above. The team learned during this process that some adjustments and modifications were required for effective layup:

- Prepreg tended to separate from the mold near corners, thus the robot was slowed at corner regions to promote adhesion.
- Material bridging was not uncommon and required repeated and extended laydown actions.
- Despite pre-shearing, some prepreg began to spring back on the mold. Therefore, it was decided that the highest



■ Robotic end-effectors for prepreg ply placement

The Bristol University research program developed three end-effectors for layup. This is the profiled end-effector, designed to exert pressure into tight internal corners. Two other end-effectors have been designed, respectively, for flat and double-curvature surfaces. Source | ACCIS/Bristol University

shear areas should be placed first (this led to pre-shearing strategy changes, which also solved many problems).

When these adjustments were made, the researchers conducted three layup trials with the automated end-effectors. For each trial, three plies were pre-sheared and laid up with no visible wrinkles or bridging. The layups were cured at 125°C under 7 bar pressure for 70 minutes, followed by 60 minutes of high-temperature dwell. The layup was successful, "but there were a few resin-rich areas around the internal recess corners." For comparison, another layup was done by hand by a laminator deemed of "intermediate" experience. This part showed similar regions of resin richness, which led the researchers to conclude that the automated method was approximately level with human performance at this early prototype stage.

Going forward, say the researchers, they would like to make improvements and progress this technology. This includes increasing layup speeds, improving mold surface tack, greater force applied by the robotic system, optimizing end effector geometry, and possibly multiple robots, although the latter, they note, will add a larger degree of complexity and cost. **CW**

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■ First styrene-free prepreg

Reichhold partnered with what is now the North American branch of Solvay (Brussels, Belgium) on the development of the composites industry's first fully commercial, VOC-free vinyl ester hybrid resin/woven-glass-reinforced prepreg, which is now used to manufacture the Chevrolet *Spark EV* battery enclosure, mounted over the back wheels in the *Spark* cutaway pictured here. The finished, compression-molded, two-component enclosure, consisting of a tray and cover, extends forward under what typically serves as the driveshaft tunnel in rear-wheel-drive, gas-engine-powered models. The complex structure (below) weighs 40% less than the part as originally conceived in magnesium.

Source (far left) | Reichhold

Source | SPE Automotive Div.



Styrene-free resins: More than emissions reduction

Since the first introductions of low- and no-styrene resins, the emphasis has shifted from mere compliance to comparable — or better — performance.

By Michael LeGault /Contributing Writer

» Long favored for their processing characteristics, mechanical properties and relatively low cost, styrene-based resins, such as unsaturated polyesters, have been the go-to, workhorse polymers for composites fabricators who make products for the marine, spa, sports board and a host of other industries. In anticipation of increasingly more stringent regulations, however (see “Styrene regulatory update,” p. 43), resin formulators have developed fully commercial lines of styrene-free resins. These products are designed, as much as is feasible, to be “drop-in” alternatives to currently sold styrenated products should regulations at some point mandate replacements. At present, however, they serve a variety of practical needs, from helping to meet emissions requirements to improving worker comfort and safety, within the composites industry.

Offerings options to open molders

Targeted primarily toward the marine and bathroom/spa market, styrene-free H164 polyester resin from AOC LLC (Collierville, TN,

US) is a medium-reactive, thixotropic resin designed for the applications most vulnerable in the current regulatory climate: hand lay-up or spray-up laminating processes. AOC's R&D director John McAlvin says that, from a performance standpoint, H164 compares favorably with unsaturated polyester resins that contain dicyclopentadiene (DCDP), a standby compound used in resins favored by the boat and tub-and-shower industry.

“The resin has comparable strength and modulus and *better* elongation than DCDP[-based] resins, and comparable heat-distortion temperature,” McAlvin reports, noting these particular properties are important to fabricators in the spa and boat markets to which the resin is targeted.

Luck does *not* play a role in achieving such improvements in properties. Taking a standard, off-the-shelf, unsaturated polyester and dissolving it in non-styrenic monomers — for example, acrylates — will most likely yield a resin with poor mechanical properties, McAlvin notes, because the functionalities of the two components are incompatible. The key is proper engineering of

the polyester resin. In the case of H164, the polyester's polymer backbone has been redesigned with chemical functionalities that are compatible with those of the monomers — a proprietary mixture of alternate molecules — which, in turn, promotes copolymerization.

H164 can be used with all types of open-molding equipment and, as such, can be considered a drop-in replacement for styrene-based resins, with one caveat: Like other styrene-free products, H164 can remain tackier longer and require more time to fully cure, a process carried out at room temperature. Within its limits, however, the resin can be tailored to specific gel and cure times as necessary to meet the requirements of the application.

AOC also manufactures several grades of styrene-free resins for composite cured-in-place pipe (CIPP) applications, including an isophthalic grade, EcoTek L704-FAHG-VT. The high-molecular-weight resin is thinned with vinyl toluene. It contains no hazardous air pollutants and its combined renewable bio-derived content and/or recycled content is 16%, yet it provides the corrosion resistance, durability and toughness that is required for cured-in-place sewer-pipe applications

“Our objective is not to replace styrene-based products, but to give fabricators options,” McAlvin says. In addition to being regulated under the Federal Clean Air Act as both a hazardous air pollutant (HAP) and a VOC, styrene emissions also might need to meet guidelines set by state and local laws, which in some cases can be more stringent than federal. Under the various permitting requirements, a fabricator might need to switch to a styrene-free product at a certain time of the year in order to remain in compliance, says Frank Sizemore, director of regulatory affairs at AOC, noting specifically that in reference to styrene, the US state of California's stringent local permitting requirements actually exceed the federal limits. Late in the year, therefore, when the molder nears its local emissions limit, it switches to the styrene-free resin. It's a more cost-effective strategy than running the styrene-free resin exclusively because there is a price premium for the styrene-free product.

Striking a balance between styrene-based and styrene-free resins, Ashland Performance Materials' (Dublin, OH) Aropol L 67214 is a *reduced*-styrene resin. Introduced to market in 2015, the resin is intended as a complement to the company's line of general marine laminating resins. Aropol L 67214 meets the desired appearance and processing times of standard styrenated resins, yet reduces styrene emissions by 30%, according to Charlie Fisher, North American marine industry manager. Additionally, the resin is more cost-competitive than the styrene-free systems, has faster barcol and reduced shrinkage.

“There is a noticeable reduction in styrene odor during spray and rollout, which leads to a healthier and happier workforce,” Fisher reports.

CF prepreg for volume applications

On the market for about three years, Reichhold's (Durham, NC, US) trademarked Advalite resins comprise two product groupings:

a liquid vinyl ester hybrid resin and a monomer-free vinyl ester hybrid hot-melt grade. The liquid vinyl ester hybrid version, which does not contain reactive diluents, is targeted mainly toward pultrusion processes, but also can be used in filament winding, RTM and other closed molding process. The Advalite hot-melt grade is used in the manufacture of prepregs and was initially developed for applications that require low residual styrene.

In the first such applications for the Advalite hot-melt, Reichhold partnered with then Cytec Industries (Woodland Park, NJ, US), now Solvay (Brussels, Belgium), in the development of the composites industry's first fully commercial, VOC-free thermoset, vinyl ester hybrid resin woven-glass reinforced prepreg, which is currently used to manufacture the Chevrolet *Spark EV* battery »

SIDE STORY

Styrene regulatory update

From resin suppliers' and fabricators' perspective, the “worst case” scenario has yet to transpire. The composites industry still consumes millions of kilograms of styrenated resin per year, a situation that is unlikely to change anytime soon. Yet, much as it has during the past 20 years, styrene continues to attract the attention of a variety of regulatory bodies. Sustained scrutiny, in turn, has intermittently reintroduced a troublesome variable — *uncertainty*.

“Styrene continues to be a hot topic for regulators,” says Frank Sizemore, director of regulatory affairs at AOC LLC (Collierville, TN, US). In 2011, the US National Toxicity Program (NTP), administered by the US Department of Health and Human Services, listed styrene as a “reasonably anticipated cause of cancer” in humans. Industry argued vigorously that the available evidence did not support such a stance. (Tom Hedger, president of Magnum Venus Plastech (Kent, WA, US), for example, took a very public stance on the subject in August 2011; see *Learn More*, p. 45). Notably, the ruling fell short of calling styrene a definitive “cause of cancer.” Nonetheless, the NTP ruling was sufficiently cautionary to provide the US state of California with cause, in April of this year, to place styrene on its Proposition 65 list of chemicals “known to cause cancer or birth defects or other reproductive harm.”

The Proposition 65 listing has specific implications for composites fabricators. They have one year from the day of the listing (April 22, 2016) to test their finished products to determine if they emit more than a “non-significant residual limit” of styrene. Currently, that limit is set at 27 micrograms per day. However, Sizemore says that could change.

“Realistically,” he points out, “there is no concern of styrene exposure in most cured composite products at levels above California's Prop 65 NSR [no significant risk level]. However, unless a company tests the individual product, or applies for a Safe Use Determination (SUD) from the state of California, they will have to provide a Prop 65 warning label on their product.”

Ultimately, some companies will choose to label because of the effort and cost required to obtain a SUD. A composite pipe manufacturer whose product will be buried 2m underground, for example, might go with a label. But other molders whose products are in human contact on a daily basis, he explains, will go through the steps of obtaining an SUD “because they are concerned with possible product deselection,” says Sizemore. “You can imagine, if you are a company making composite bathroom sinks and counters, you wouldn't want your product in a store with that kind of label on it.”



■ Reduced-styrene alternative

Boat manufacturer Malibu (Loudon, TN, US) uses Ashland's (Columbus, OH, US) reduced-styrene Aropol L 67214 resin to mold a variety of parts, including these gel-coated storage covers. The resin meets the desired appearance and processing times of standard styrene-based resins, while reducing styrene emissions by 30%, and is more cost-competitive than styrene-free systems as well.

Source | Malibu Boats

enclosure (see Learn More, p. 45). The enclosure, manufactured from composites by Continental Structural Plastics (Auburn Hills, MI, US), won a 2013 SPE Innovation Award in the Electrical Systems category.

Glade Gunther, Solvay North America's automotive program manager, says the part was originally conceived as a metallic solution, including the possibility of a magnesium casting, but was changed when engineers realized the enclosure dimensions — a lower tray and mated cover about 150-cm long by 110-cm wide by 34.4-cm high — exceeded then current casting/tooling capability. As a result of their involvement in a concurrent project to develop composite materials for automotive underbody components, Solvay was aware of Reichhold's styrene-free Advalite resin. Solvay subsequently

re-formulated its MTM23 resin using the Advalite resin. Additional materials testing and development work culminated in the successful production of a prepreg comprising its MTM23 hot-melt resin and 18-oz glass fabric, featuring fiber supplied by PPG Industries (Pittsburgh, PA, US) and woven by Chomarar (Anderson, SC, US). The finished, compression-molded tray and cover, together, have cut the enclosure weight, as originally conceived in metal, by more than 40%. Additionally, because the enclosure sits directly below the passenger compartment, required testing of the part for emissions of volatile compounds (part of the safety specifications regimen for head space) found no presence of either styrene or VOCs.

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Solvay and Reichhold are attempting to capitalize on this and other benefits of the vinyl-hybrid resins — in particular, snap cures of 1-2 minutes and room-temperature shelf life of up to a year.

Jim Bono, Reichhold's senior technical manager, says the company worked in concert with a number of prepreg manufacturers and compounders to evaluate various grades of carbon fiber and types of sizing. Testing of samples prepared from filament wound Naval Ordnance Laboratory (NOL) rings, typically used in physical tests conducted to simulate burst pressures in pressure vessels, is used to determine which systems provide good interlaminar shear strength in an Advallite hot-melt matrix. "The prepreg systems we are designing ensure a snap-cure performance similar to SMC, and mechanical properties compare favorably to carbon/epoxy systems," Bono claims.

The company is currently working with partners to qualify the material for high-volume commercial automotive structures, such as battery trays and body pillars, as well as aerospace applications, where the dielectric properties of the carbon prepreg make it suitable for radome applications.

Fewer emissions, comparable performance

Although the regulatory climate, as it pertains to styrenated resins, is difficult to predict with certainty, the foregoing establishes that, today, styrene-free alternatives are not only possible, but commercial. But the future likely depends on the degree to which composites manufacturers are compelled to conform to tighter regulatory strictures on the use of styrene or

the sale of products that contain it and, ultimately, the timing of federal and regional decisionmaking, over which this industry has little control. What is certain is this: The already demonstrated will and skills of resin formulators will be key if suppliers are to field styrene-free resins that bring more to the table than fewer emissions, and go on to match or exceed the performance of the styrenated polymers they're designed to replace. **CW**



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Clear Carbon & Components: Bristol, RI, US

Breaking barriers in process and complexity, this agile manufacturer is gaining renown as a composites problem solver and champion of Class-A cosmetic surfaces.

By Ginger Gardiner / Senior Editor

» Many CW readers are already familiar with the aesthetics achieved on parts produced by Clear Carbon & Components (C³, Bristol, RI, US), having seen them as showpieces in exhibitors' displays — A&P Technology (Cincinnati, OH, US), for one — at composites tradeshow. C³ also is the manufacturer behind the stunning carbon fiber-reinforced plastic (CFRP) bodies for the composite violins, violas, cellos and bass viols marketed by Luis & Clark Stringed Instruments (Milton, MA, US), highlighted in a 2012 CW feature article (Fig. 1, p. 47, and Learn More, p. 53). A leader in the composites-intensive US state of Rhode Island, C³ president Matt Dunham was one of the founding members of the Composites Alliance of Rhode Island and continues to serve on its steering committee (see Learn More).

Dunham was a metal worker, making America's Cup 12m racing sailboats out of aluminum, when that industry switched to CFRP in the late 1980s. Dunham followed, establishing C³ in the early 1990s, but then quickly focused on diversification.

Today? "There is no industry that we don't touch," Dunham remarks, listing an impressive range of other finished products to support his point:

- Unmanned aerial vehicles (UAVs) and parts for the aerospace industry
- Parts for motorcycles and other transportation industry applications
- Antennae, electronics enclosures and more, for military ground forces
- Sonar enclosures and communication buoys for naval operations
- CFRP vertical-axis wind turbine (VAWT) and other renewable energy projects
- CT scanner head support and other medical products
- Architectural components, including a 4m-tall spiral staircase with one-piece CFRP spar (see Learn More)

Further, C³ is active in numerous R&D programs. "We do a lot of R&D," says Dunham, "but it's all aimed at getting one more part into production." Schooled in America's Cup excellence, yet faced

■ C³: Living up to its name

This Bristol, RI-based company's name, Clear Carbon & Components, sums up its dual but complementary business emphases: "Clear carbon" describes its attention to the aesthetics of exposed carbon weave and R&D work that has produced superior part surface quality. "Components" acknowledges equal emphasis on part production that ensures the bills get paid.

Source | Clear Carbon & Components



Fig. 1 Attempting what others won't

C³ has built a reputation for tackling product development tasks others pass up. Examples include one-piece VARTM'd fins (lower left), and stringed musical instruments, such as this violin body built for Luis & Clark Stringed Instruments (Milton, MA, US), hollow one-piece CFRP railings with end terminations (top left) and new processes for molding curved composite tubes and springs (bottom middle).

Source | Clear Carbon & Components

with the realities of operating a small business, he explains a requisite balance: "I believe you have to have both serial production *and* R&D. The R&D is important to develop new technology and new business leads, but you can't sustain a company that way. You must have the everyday, bread-and-butter production." Dunham says the two are treated as separate business segments, adding, "If one-off projects like the spiral staircase were all that we targeted, we'd never get the production jobs we need to stay healthy and diversified."

C³ and its staff of 20 seeks both in its 1,400m² facility in Bristol, purchased in 2010 after a move there five years earlier. C³ makes its wide variety of composite components using wet and prepreg layup, vacuum infusion and compression molding. Dunham's recent invitation for *CW* to take a walk through the C³ operation revealed evidence of an organized yet out-of-the-box mentality that makes clear how this small company has reached so far into the markets that composites serve.

Development-refined production

CW's tour begins in the front office suite and CAD room, where engineers design not just parts, but the plugs/patterns and molds necessary to produce them, using SolidWorks (Dassault Systèmes SolidWorks Corp., Waltham, MA, US), Rhino 3D (Robert McNeel & Associates, Seattle, WA, US) and MasterCam (CNC Software Inc.,

Tolland, CT, US). "It's really important to do your homework in the digital modeling," says Dunham. "Walking through the potential construction issues can make the difference between profit and loss on the type of high-performance and high-aesthetics projects we do."

When asked about the company's reputation for "clear carbon" parts, where the high-gloss surface shows the fabric weave without skew, wrinkle or other imperfection,

Dunham explains that understanding the materials and various molding processes has been the key. "We get better surface finish with infused laminates vs. hand layup because of the lower void content," he asserts, adding, "the print issues must be addressed, however."

Print, or print-through — when the texture of the laminate can be seen through the part's paint or topcoat — is a key quality issue. "For example, we want to fill in the interstices between the fibers in a fabric weave, because, over time, these will show pock marks," says Dunham. He notes it is also important to avoid pinholes in the finished laminate.

Dunham opens the door into C³'s large production space (Fig. 2, p. 48) and turns right to walk through the serial production area, referred to as the production work cell, where racks of assembled parts await finishing and inspection. Across from the racks, workstations are organized for efficient assembly of products (Fig. 3, p. 49). "We've developed how to do cost-effective serial

C³'s organized yet out-of-the-box mentality balances R&D and production to reach multiple markets.



Fig. 2 Tracing roots to sailboat racing

C³ founder Matt Dunham's first composites formed hulls for formerly aluminum racing yachts. C³ recently produced the infused stringers for the 30.5m-long racing yacht *Comanche* (several are bagged on the layup table in the main photo) shown in the inset after installation in the *Comanche* hull.

Source | Clear Carbon & Components

manufacturing, with over a dozen products running through our production workcell at any given time," says Dunham.

One example of C³'s high-quality, serial production is ladders for docking yachts, produced for Bristol Yacht Components (Essex, CT, US). The yachts move up and down relative to the dock, so the stairs must articulate. Dunham explains, "After about nine

stairs, you have to turn the step sideways or the disembarking passenger would end up off the other side of the dock into the water." These ladders comprise CFRP treads, rails, a regulator (which keeps the stairs parallel and level) and a slewing platform. This 0.9m wide circular platform has a pivot mechanism that enables the ladder to rotate and cascade out in different directions. The CFRP components make the ladders lightweight and unique.

This highlights one of C³'s strengths: building relationships with customers. "We focus on more high-end applications," notes Dunham, "but then we drive cost down in serial production." The company also specializes in one-off applications that have hit obstacles in manufacturing. "We figure out how to make the parts," says Dunham. "A lot of what we do is developing new processes to make composites production possible." Not just possible, but high performing and high quality, cosmetically.

The company also has strong relationships with key suppliers, including advanced materials suppliers Core Composites and Gurit USA, both based in Bristol, and 3D textile weaver T.E.A.M. Inc., located less than an hour away in Woonsocket, RI. Dunham shows a large "brick" of 3D woven carbon fiber. "We've worked with T.E.A.M. to make carbon-reinforced carbon [carbon/carbon] composites using a compression infusion process," he relates. The materials are being used to mold complex-shaped military components.

Compression molding capability

The last stop in the production workcell area is a tour of two compression molding presses supplied by Wabash MPI (Wabash, IN, US). The larger, 150-ton vacuum press — i.e., maintains vacuum while pressing parts — is heated and cooled, and capable of processing at 430°C. "It helps to maintain low void content, pulling volatiles outgassing from the part if you need it," explains Dunham. The smaller, 75-ton press can go up to 315°C. Dunham describes how charges are prepared for press

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Fig. 3 Ultimate goal: Finished parts

C³'s production work cell features racks of assembled parts that await finishing and inspection, and well-organized stations for efficient assembly of products. As many as a dozen different products are running through C³'s production workcell at any given time. Source | Clear Carbon & Components

molding using techniques borrowed from the garment industry, such as die cutting, which produces multiple laminate plies quickly and cheaply.

"We developed compression molding for making 'widgets' to join parts," Dunham explains, "for example, a CFRP weldment used for transition to bond a stanchion onto a rail. Because this weldment has a Class-A surface on both sides, I can now very precisely control my bondline spacing, which is key for long-term bond performance." The CFRP rail Dunham shows is hollow with a formable core and bent, tapered ends (shown as part of Fig. 1, p. 47). C³ also compression molds the lightweight, watertight hollow CFRP body parts for the *SeaHex* marine-duty tri-copter UAV.

Dunham shows several other aerospace parts, in this case, compression molded from Quantum Composites (Bay City, MI, US) carbon fiber sheet molding compound (SMC). "It provides two Class-A surfaces," says Dunham of the material and process combination, "as well as very high tolerances, for example, molded-in

circular cutouts within 0.025 mm." The finished parts also can be drilled without having to reinforce the perimeters of the holes with metal. Combine this with compression molded CFRP's lightweight, strength and unique aesthetics, and it becomes an appealing alternative for applications such as motorcycles.

Indeed, C³ helped Walt Siegl Motorcycles (Harrisville, NH, US) adapt the process for a custom *MV Agusta Brutale 800*, a one-off signature bike to help artist/designer David Yurman celebrate his new line of carbon composite accessories (Fig. 4, below). The *David Yurman Forged Carbon Moto* features a front fender, a rear hugger, a triple tree and brackets made from a CF molding compound that Lamborghini (Sant'Agata Bolognese, Italy) and Callaway Golf (Carlsbad, CA, US) partnered to develop and market as Forged Composite. Dunham continues, "We also can make a part every 15 minutes and are playing with thermoplastic compounds for even lower cycle times." He notes that with thermoplastics, in particular, the process is more about how to handle cooling rather than heating.

"We have also developed a method for making CFRP coiled springs (Fig. 1), what we call contoured composite tubing," says Dunham. "We use a very low-cost mold for making these coiled springs, which come out of the mold with this high finish quality. None are post-finished."



Fig. 4 Compression molded motorcycle parts

C³ helped Walt Siegl Motorcycles adapt its compression molding process to produce carbon fiber parts on the *David Yurman Forged Carbon Moto*, a one-off signature bike to celebrate the artist/designer's new line of carbon composite accessories. Pictured here is the carbon fiber composite handlebar detail over the bike's front fork. Source | David Yurman



Fig. 5 More than a custom molder

C³'s in-house CNC equipment, machine shop and paint shop — the latter shown here with a custom-painted cello destined for Cirque du Soleil — offer the agility required to meet the unique demands of very challenging and diverse projects. Source | Clear Carbon & Components

Equipped for agile manufacturing


Adjacent to the production workcell is an enclosed trim room. The built-in dust collection system within includes down-draft evacuation and a HEPA filter. The trim room walls are soundproof to insulate the rest of the facility from the noise. Similar to the production workcell stations, trim-room tools are organized for easy access, a result of C³'s focus on lean manufacturing.

Past the trim room is an enclosed CNC machining room. "This has become a big part of our business," says Dunham. "We can take a CAD file from anywhere in the world and go directly to a mold. The days of making patterns are over."

C³'s CNC machining operation also has eliminated the need for C³'s carpentry shop operations, making that space available now for small-parts production.

On the way to the opposite side of the open production space, Dunham points out a dedicated resin mixing station. "We use all neat resins that we promote and mix ourselves,

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Fig. 6 CTE-matched infusion table

Infusion processing is a core competency, facilitated by this 2.7m by 6m CFRP table, heated from below to provide the same CTE as the high-quality carbon parts it produces. Source | Clear Carbon & Components

because we must know exactly what the resin gel times are for processing,” he explains.

Passing by a 4m by 8m paint booth, no less a point of potential C³ innovation (Fig. 5, p. 50), he arrives at a substantial machine shop, which, Dunham explains, “allows us to make our own jigs, fixtures and tooling, so we aren’t dependent on anyone else’s lead times to begin production.”

The result is agility that enables innovation, exemplified by the composite ISO military shelter C³ is assembling during CW’s visit. Typically, 2.4m wide by 6m long, these lightweight, rigid-walled enclosures are intended for quick deployment via transport aircraft or helicopters, for use as emergency housing, medical facilities and to protect electronics and other mission-critical equipment. Their cored-panel construction provides thermal insulation, resists weather, meets fire standards and can withstand significant handling abuse. The shelters C³ is helping to develop are basically composite containers that fold out into 7.3m by 7.3m field hospitals.

Although the current ISO shelter design is only certified to ship six shelters high, C³ designed a new, hollow CFRP corner post, machining the aluminum tool for it in-house. The hollow composite post is laid up in the aluminum tool with an expanding mandrel, which provides compaction during cure and contracts upon cooling for easier demolding. The new post can withstand 95,708 kg and, therefore, will allow shipping of shelters stacked *nine* high on new super-container ships.

Infusion as an enabler

The center of C³’s production space is occupied by a 2.7m by 6m carbon composite table (Fig. 6, this page) heated from below to provide the same coefficient of thermal expansion (CTE) as the parts it is used to infuse. Resin infusion has become a core competency for the company, highlighted in many projects. One of note



involved all-carbon fiber/epoxy, hollow (uncored) hat sections molded in segments more than 18m long for the 30.5m sea racer *Comanche*, owned by famed billionaire/sailing enthusiast Jim Clark (Fig. 2, p. 49). The all-carbon racing yacht smashed the transatlantic monohull record, completing the 2,880 nautical miles on July 28, 2016, at an average speed of 21.44 knots!

“The challenge was to infuse the carbon unidirectionals,” Dunham recalls. “We do a lot of infusion. I’ve got people who have been doing infusion for 20 years. We have developed a lot of tricks for how to get the resin to move where we want it, without dry spots and foaming, which is key both for low voids and long-term aesthetics.” »

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Fig. 7 Finished shelter panels, out of the mold

For a next-gen composite military shelter, C³ has developed a method to control the condensation reaction of phenolic resin for infused panels, using A&P Technologies' QISO reinforcements for damage resistance, and employing modular tooling to produce cored panels with a finish-quality surface on both sides *and* molded-in edge features so that no post-finishing or machining is required.

Source | CW / Photo | Ginger Gardiner

One of C³'s recent advances is infusing phenolic resin. "It's all about controlling the cure," Dunham explains. "You have to know what the temperature is at all times and how to ramp it to control the condensation reaction of the phenolic resin. Because it actually produces water as it cures, you have to control the cure to avoid this."

Also used for the ISO military shelters, the infused phenolic panels help meet fire resistance requirements (Fig. 7, at left). But Dunham's team has gone a step further, developing a method to infuse panels with two finished sides *and* molded-in edge treatments. "Edge treatment is typically the Achilles heel of a composite panel system like this," Dunham notes, "and also for architectural applications. We have figured out how to do very sophisticated edge treatments to meet customer needs." He describes a tooling system that delivers edge features when molding so that no post-finishing or machining is required.

For the military shelters, it's not just the edges where the panels are attached to form the enclosure, there are also "knock-outs" — that is, areas that are easily removed to install HVAC systems. Dunham says the edge closure for these areas used to require a 50-piece system of metal frames and fasteners. "We have eliminated that through our molded-in geometry and local reinforcements," he says.

The shelter floor also is a study in unitization, molded in one piece with integrated stringers. Where attachments are needed



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in the floors *and* walls, hard points have been molded-in using fiber-reinforced, high-density polyurethane foam (e.g., foam board from Coosa Composites, Pelham, AL, US). There is no secondary machining, just installation of fasteners for overall shelter assembly.

The shelter's infused panels also are improved by C³'s longtime partnership with A&P Technologies, using the latter's QISO material to optimize impact resistance. "QISO was originally developed for the braided containment ring used in GE90 engines for the 777 aircraft," says Dunham. "The fibers in the braid go up and over each unidirectional, encapsulating it and preventing delamination." Dunham says this is indeed the next generation of military shelters, and C³ is making both 6m and 3m long versions.

Skunkworks for composites companies

The final stop on the tour reveals a significant space currently devoted to an unusual program done under a nondisclosure agreement, one which has just entered production.

"This project was actually brought to us by *another* composites company," says Dunham. It was big, unprecedented, complicated and ... well, no one else wanted to do it. And it's not the first time. "We're kind of the 'skunkworks' for other companies in the composites industry," he quips. "They come to us to help them figure out how to make stuff."

Indeed, since CW's tour, C³'s full-scale parts for the proprietary effort have

passed field tests, and C³ has completed large-scale tooling, doing one of the things it does best, overcoming significant challenges in geometric complexity.

But doing the unusual isn't that unusual for this big little shop in Bristol: From violins to fold-out medical units, yachts to UAVs, if it's CFRP, C³ makes it quickly, delivering high performance and high quality, and if required, with C³'s renowned clear carbon finish, no matter the difficulty. **CW**



ABOUT THE AUTHOR

CW senior editor Ginger Gardiner has an engineering/materials background and has more than 20 years in the composites industry.
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FRP CHARGE AIR COOLER STANDS UP UNDERHOOD

Injection molded glass/PA streamlines turbocharger intake manifold build

► In the quest to make internal combustion engines smaller and more economical, yet maintain high performance, engine designers often turn to turbocharging. The challenge is to engineer a way to cool air that must pass through the turbocharger. In the past, that has meant feeding this “charge air” up to the front end of the car for direct ambient cooling, then feeding it back to the engine intake manifold. Engine parts manufacturer MAHLE (Stuttgart, Germany), however, has developed a method of *indirect* charge air cooling, using a liquid coolant design, which saves space and prevents pressure drop, a risk factor associated with the other method.

The BMW Group’s (Munich, Germany) B58, the 3-liter, straight-six gasoline engine used in its 740i, 440i and 340i models since late 2015, features MAHLE’s innovative indirect charge air cooling design incorporated into the engine intake system. The charged air is cooled by a liquid coolant that is, in turn, cooled by outdoor air in a separate, compact low-temperature circuit that uses a small radiator mounted close to the engine. This concept opens up front-end space for other design purposes (e.g., pedestrian protection), and the bulky charge air hoses that would be used in direct charge air cooling are replaced by shorter, smaller-diameter liquid coolant lines. The compact system and short lines reduce pressure loss by around 50%. The higher density of the cooled charge air and lower pressure loss mean there is more air available to the engine for combustion. The result: improved engine responsiveness.

The concept, jointly developed by a team from MAHLE, BMW and **DuPont Performance Materials** (Wilmington, DE, US), required a heat exchanger/intake manifold housing made from a polymer that, when cured, would exhibit good stiffness and resistance to engine heat and chemicals, *and* be able to resist a phenomenon called *hot-air aging*. The latter describes brittleness that results when exposure to high temperatures drives out volatiles, in this case, plasticizers. The team selected DuPont’s thermoplastic polyamide 95G35, a 35% (by weight) glass fiber-reinforced grade of trademarked Zytel PLUS, which can withstand temperatures up to 230°C, with good weldability and flow characteristics. It incorporates DuPont’s proprietary SHIELD technology that reportedly combines an innovative polymer backbone with specific polymer modifications and additives that address aging.

The part consists of an upper and lower housing that, together, enclose an aluminum heat exchanger through which the liquid coolant flows. The housings are injection molded in one shot in a tool with a 1+1 cavity, then are joined via friction welding. The heat exchanger is inserted into the housing onto molded-in guides.

Martin Valecka, development project manager at MAHLE, says, “We needed a good balance of rigidity and impact strength, and the material allowed us to mold in thin-walled but highly effective supporting ribs that minimize deformation of the intake system even at high charge air pressures and temperatures, and ensure durability over the entire service life.” Tests show that the intake’s mechanical properties hold up even after 3,000 hours at 230°C — well above conventional polyamides. **CW**



MAHLE’s heat exchanger/intake manifold housing for its indirect charge air cooling system consists of complex, ribbed upper and lower sections injection molded in a 1+1 tool cavity. The mated upper and lower enclose the aluminum heat exchanger (partially removed in bottom image) through which the system’s liquid coolant flows. Source | DuPont

Composite megatanks gain ground in Brazil

Oblate strategy ensures FRP tank transportability



Source | Techniplas

As is the case in many countries, liquid storage in Brazil is a critical infrastructure element. Although the need for storage tanks is great, composite tanks have had a hard time competing against those made of more conventional concrete and glass-lined steel, says Giocondo Rossi, director of large fiber-reinforced polymer (FRP) tank builder Techniplas (Cabreúva, Brazil). Rossi, who spoke in August at the National Exhibition on Sanitation and Environment (Fenasan), held in São Paulo, says the traditional tank materials have some severe limitations.

"Concrete is porous, and requires an internal rubber seal," he contends. "In addition to raising tank cost, the elastomeric coating has a limited lifetime. Then, after three or four years, the water begins to attack the steel reinforcement in the concrete, requiring heavy investments in maintenance or even the replacement of the tank." Large, glass-lined steel tanks require assembly of thousands of steel plates, each seam offering a potential leak point. But large FRP often lost out because finished FRP tanks were too big to transport on the roads to installation sites. To address this difficulty, Techniplas began several years ago to use "oblate" technology, in which the tank's filament-wound hoop sections, or "rings," are compressed after fabrication into an oval shape and then compressed further in the middle, forming a shape like a lazy number eight (8), with care taken not to overstress the laminate. Rossi says a 15m diameter tank can thus be reduced in one dimension to about 5m. Although it actually grows larger in the other dimension, the 5m width falls within the Brazilian standard for wide-load transport.

Ring sections are uncompressed at the installation site, then they and tank tops, also are made in sections, are wet-laminated together to form the finished tank structure.

Techniplas has manufactured dozens of tanks using this method. Advantages of oblate technology include reduced transportation time and costs and better logistics. These join composites advantages that include leak resistance, corrosion resistance, high mechanical strength and the ability to use resins compatible with drinking water. **CW**



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Waterjet system with four heads

Jet Edge Inc. (St. Michael, MN, US) has introduced its latest generation of Mid Rail Gantry waterjet systems, capable of operating up to four abrasive jet or water-only waterjet cutting heads to increase



productivity. The system features ± 0.001 -inch (± 0.0254 -mm) linear positional accuracy (over 12 inches/305 mm) per axis and ± 0.001 -inch (± 0.0254 -mm) repeatability (bi-directional). Moving elements are supported on THK linear ways. Precision ball screws are directly coupled to servomotors, and critical motion components are protected with metal covers, brushes, labyrinth passages, lip seals, and high-volume, low-pressure filtered air. Jet Edge notes that the Mid Rail Gantry separates the motion system from the waterjet cutting table, which reportedly eliminates vibration and maximizes part quality. Motion is controlled with Jet Edge's Aquavision Di industrial PC controller, which guides the user through the process from job setup to production. Available in a range of sizes, from 5 by 5 ft (1500 by 1500 mm) to 24 by 13 ft (7300 by 3900 mm), the system comes standard with one abrasive jet cutting head, with additional heads as options. Also optional is a mirroring package that enables waterjet operators to cut large parts twice as fast. A Jet Edge UHP waterjet pump offers pressures of 36,000 psi, 60,000 psi and 75,000 psi. www.jetedge.com

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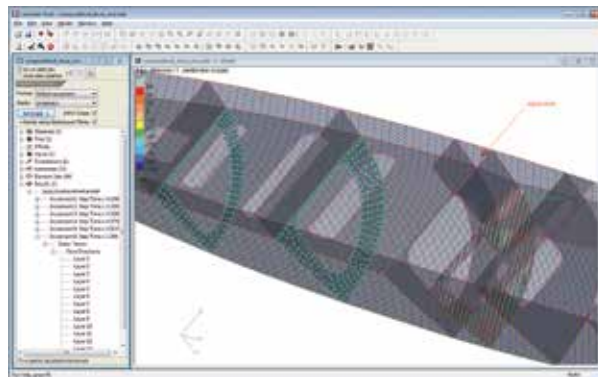
Epoxy-based fiber sizing

Michelman (Cincinnati, OH, US) has introduced Hydrosized EP876, a high-molecular-weight epoxy-based fiber sizing for PBT (polybutylene terephthalate) and thermoset composite manufacturing applications. The new grade of Hydrosized also can be used as a binder in nonwoven applications. As a water-based, formaldehyde-free dispersion, Hydrosized EP876 is said to be environmentally friendly and eliminates the use of flammable solvents. It can be used with glass, carbon and natural fibers, produces good strand integrity and offers good chopping behavior. Michelman says the sizing also exhibits a natural tendency to be sticky, which makes it particularly effective as a binder. www.michelman.com

» CAD/CAM/CAE/FEA SOFTWARE

Design software updated

Anaglyph Ltd. (London, UK) has launched version 4.6 of its established Laminate Tools design software program. This standalone Windows-based application is designed to address the entire



geometry import/design/analysis/check/manufacture process of composites structural design. It links the various disciplines and communicates original data between all parties involved in the process. Laminate Tools interfaces with most CAD and FEA applications. It is used by composite structures designers and stress analysts in the automotive, aerospace, marine, energy and leisure markets. New in this version is a feature for discontinuous projected plies and a dynamic ply point definition tool. It also has several user enhancements, as well as improved manufacturing output.

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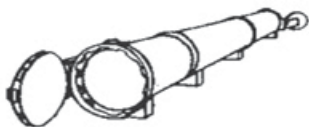
GMS Composites (Melbourne, Australia) has developed GMS EP-540, a new high-performance, flame retardant (FR) epoxy prepreg with good toughness and a short gel time. The nonhalogenated epoxy resin matrix prepreg passes the UL94 V0 flammability rating. It replaces EP-530, a previously developed FR grade that had an average 16-minute gel time at a 120°C mold temperature; the new EP-540 grade has a gel time of 6 minutes at 120°C for thinner laminates, with parts fully cured within 2 hours. According to the company, EP-540 has a tensile strength of 460 MPa, flexural strength of 578 MPa, and an Izod impact strength of 230 J/m. Fire performance data show that the UL94 V0 rating is comfortably achieved in the most demanding vertical flame test, recording an average burning time of only 3 seconds, 7 seconds less than the maximum allowable combustion time to meet the V0 rating, and 2 seconds less than the EP-530 grade it replaces. GMS EP-540's resin formulation reportedly provides molders a high degree of processing versatility, with a range of possible cure cycle, pressure and ramp-rate options, depending on the part being produced; the tack also can be varied. The cure cycle temperature can be as low as 80°C to a maximum of 150°C.

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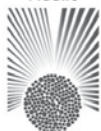
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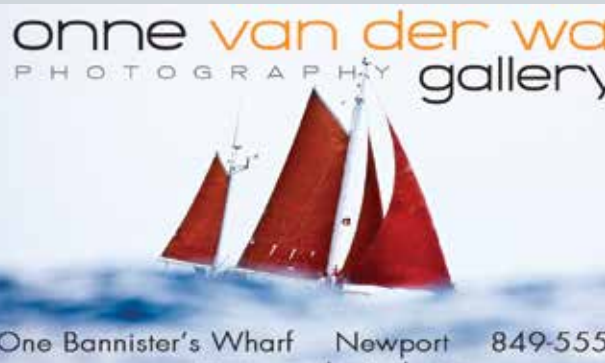
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Engineering large-diameter underground pipe

A combination of design and new materials enhances pipe performance without adding cost.

By Sara Black / Technical Editor

» In the underground pipe market, like most markets served by the composites industry, customers want high performance — in this case, corrosion resistance, great strength and long-term reliability to reduce or eliminate costly repairs — without a high upfront price tag.

That makes good design essential. And that begins with material selection. As is the case in most markets, the traditional materials here — iron, steel, concrete and more recent arrivals

thermoplastics — currently rule the large-diameter water and wastewater piping market. That's because "potential customers using traditional materials today fear that fiber-reinforced plastic [FRP] composite pipes may be damaged during transport and installation underground, possibly because the first cast FRP pipes on the market in the 1970s tended to be brittle," says Nick Crofts, managing director of pipe manufacturer Amiantit Europe (Mochau, Germany), which acquired Flowtite Technology and its composite pipe design engineers from Owens Corning (Toledo, OH, US) in 2000, after having been its principal licensee.

"We wanted to come up with a new product," Croft maintains, "tougher than even the best FRP pipes available today, at a comparable or lower price point to these traditional materials." The goal was a pipe product that, especially in large diameters, "could better withstand in-ground installation and handling — that's been the Achilles heel for composite pipe."

Continuously wound for a century underground

A new grade of fiber-reinforced polymer (FRP) large-diameter Flowtite pipe for underground installation, dubbed Flowtite Grey, has been designed for greater impact and abrasion resistance and is anticipated to have a 100-year service life.

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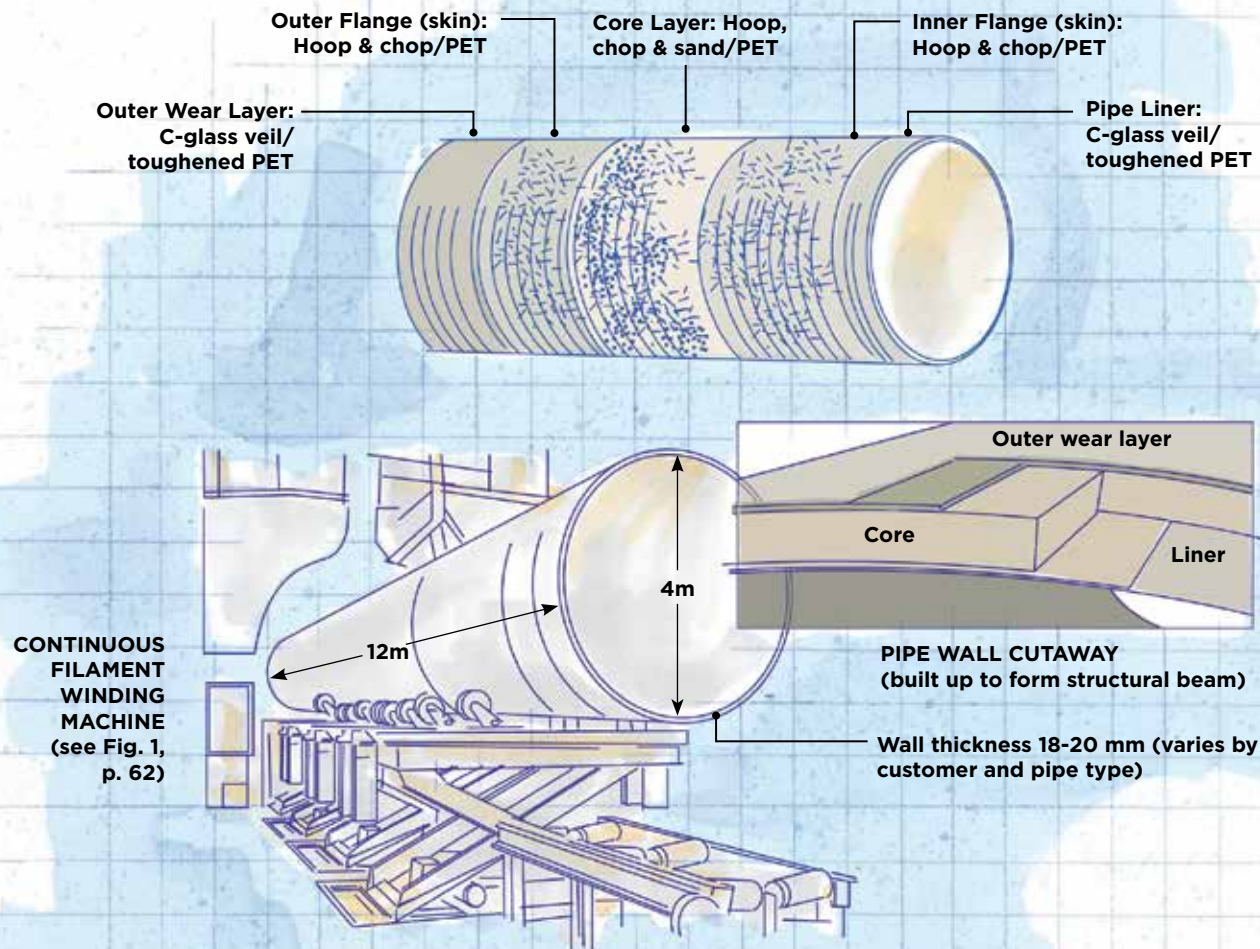
Toward that end, Amiantit recently introduced Flowtite Grey pipe for water, sewage, waste and raw material management. Envisioned as a way to expand the existing Flowtite product line, Grey would be much more resistant to rough installation and transport practices, better able to handle unexpected debris within the pipe and, especially, able to resist pressure-jet cleaning — a practice typical in concrete, steel and iron pipelines to control slime buildup.

And, it would be engineered to withstand a range of loads imposed by underground burial, which are typically much greater than the loads on a pipe in above-ground installations. "Customers want reliability, especially in remote installations. They're looking for pipeline lifetimes of 100 years. We were challenged to add safeguards against the unknown," adds Crofts.

Designing-in large-diameter durability

"Unreinforced plastic pipe is the benchmark for small-diameter, low-pressure applications, because of low cost, great performance and corrosion resistance. But," Crofts explains, "plastic pipes





DESIGN RESULTS

Amiantit's Flowtite Grey Large-diameter FRP Pipe

- Fiber architecture, using continuous and chopped glass, mimics an I-beam for axial strength, without the need for axial or helical fibers.
- Improved glass sizing and toughened resin result in greater impact and abrasion resistance for more durable pipes.
- A 100-year lifespan is possible, because pipes can better withstand rough handling and the weight of soil and traffic loads during and after burial.

Illustration / Karl Reque

don't work well for large diameters, because wall thickness has to increase proportionally to handle hoop stress, and they become very heavy." At diameters greater than 400 mm, FRP pipe can be less expensive than plastic or ductile iron, yet deliver better corrosion performance, good flow characteristics and lighter weight for easier shipping and onsite handling. To accomplish this, the properties of the produced FRP pipes often vary. Because each project's design is unique, based on installation-specific pressures, pipe stiffness class, burial depth, in-pipe vacuum, and handling, each is built to provide the necessary performance but also minimize cost.

Grey pipe designers, therefore, employ the American Water Works Assn.'s (AWWA, Denver CO, US) widely used guide, titled

Fiberglass Pipe Design (Manual M45). "Manual M45 gives the highest safety factors of all the FRP standards, and was our design basis," says Crofts. Its design equations take into account the velocity and pressure of the conveyed fluid, head loss due to turbulent flow, water hammer, buckling pressure and surge pressure. Flowtite's application engineering manager, Thomas Hoffmann, adds that additional calculations are required to cover site-specific design conditions, including loads from soil type and depth, traffic loads, backfill type, ambient temperatures and whether the pipe will be restrained by the backfill or require thrust blocking to prevent pipe movement after burial (see other CW coverage of underground pipe challenges in Learn More). »

Fig. 1 Continuous winding of large pipe

Flowtite Grey pipe is made in this continuous filament winding process, using a rotating mandrel that is supported on one end and open on the other (foreground). An endless-loop steel band wrapped around the mandrel's expandable superstructure forms a *moveable* cylindrical tool surface, which supports the windings as they are applied and continuously advances, pulling the pipe through the fabrication stages.



Fig. 2 Building a load-tolerant pipe wall

This closeup of the fabrication of a Flowtite Grey pipe section shows the buildup of the pipe wall layers — note the significant emphasis on hoop fibers — as the pipe moves forward on the mandrel. It will progress through a curing station (the bright light in Fig. 1) and exit the mandrel for subsequent cutting.



The customer's optimized design is produced on Flowtite's continuous filament winding machinery, a technology with a long history (see Learn More). Customizable to a range of pipe diameters, its cantilevered, horizontal rotating mandrel is made

up of longitudinal beams fitted with small, outward-facing roller bearings, a series of discs (sized to the pipe to be produced) that support the beams, and a steel "band," or endless loop (Fig. 1, above). As the mandrel rotates, the steel band, which is about 51 mm wide, is wound over the beams, hoop-wise, by a

placement head on the mandrel's supported end. As it is wound, the band also is pulled and, therefore, moves over the roller bearings in the axial direction, advancing toward the other (open) end of the mandrel. At that end, an exit head directs the band back through the mandrel's core to the supported end, where the placement head directs it onto the beams again. In this way, the wound band forms a continuously advancing, smooth tool surface onto which the pipe materials are applied, via filament winding heads on both sides. The wound pipe is pulled along by the advancing band through a heated zone near the mandrel's open end to cure. Then the cured pipe exits the mandrel system and is cut to the desired length. The technology can wind pipe to 4m in diameter.

Crofts explains that, in common with standard Flowtite pipe, the Grey wall structure is, in essence, a structural I-beam, built up in layers as the pipe mandrel continuously advances (Fig. 2, above). After a polyethylene terephthalate (PET) release tape is applied, the first layer placed onto the mandrel is a corrosion-resistant, boron-free fiberglass veil supplied by Owens Corning, wet out with

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a toughened PET. “This forms the essential resin-rich, corrosion-resistant pipe liner, and the toughened PET gives the performance to resist pressure jet forces,” adds Croft.

Over the liner are placed continuous glass rovings wet out with PET resin, in the hoop direction, together with chopped glass rovings that are sprayed simultaneously as the hoop fibers are applied, to form the beam’s inner “flange.” Crofts says the continuous hoop fibers provide hoop strength for pressure resistance, while the chop, although discontinuous, yields required axial strength. In some design cases, the chop can be oriented axially for greater resistance to axial contraction forces, as required.

The pipe wall’s “core” or center is a mixture of a fine-grained sand filler and chopped fiber, resin and more hoop fibers. Next, the outer “flange” is formed like the inner, with hoop and chop. Finally, another boron-free C-glass veil impregnated with the toughened PET forms the pipe’s outermost wear layer, providing a resin-rich protective seal.

“This fiber architecture gives maximum stiffness for the least amount of premium material,” asserts Hoffmann. “For projects where additional performance is needed, we can easily increase the thickness of any element for the desired property translation.”

Flowtite Grey can accommodate operating pressures as high as 32 bar and is offered in stiffness (SN) classes of 2,500 to 10,000 or greater (the larger the SN value, the greater the pipe’s resistance to deflection imposed by soil and traffic loads). Wall thickness, stiffness and diameter are tailored to the customer’s application. Large-diameter pipes are typically delivered in 12m lengths, while “rockers,” used to connect access points, such as manholes, are cut to shorter lengths (Fig. 3, this page).

Material improvements

Ultimately, Flowtite Grey’s greater durability also owes much to materials research. Owens Corning undertook an initiative in 2015 to improve its fiberglass products for piping manufacturers, and spent more than a year benchmarking changes to glass sizing (see Learn More). Bryan Minges, global product manager for Owens Corning’s composite solutions business, says that the silane-based sizing on its new PipeStrand M6000 roving plays an important role in Flowtite Grey’s superior mechanical properties: “Because the new sizing formulation allows a better bond between the glass and the resin than our previous pipe product, fabricators can use less resin to achieve the same part properties. That helps them get cost out.”

“The sizing and its compatibility with the resin is the key to the long-term performance of the Grey product,” adds Crofts. “While we have many fiberglass suppliers, Pipestrand gives us good performance for the cost.”

Flowtite Grey’s improved performance has been verified in tests conducted by Flowtite Technology’s R&D lab, in Sandefjord, Norway. Impact performance was measured via drop testing in accord with industry standards, and in some tests using heavier weights and longer fall heights than the standards. The tests showed no leaks after impact during sustained pressurization, at

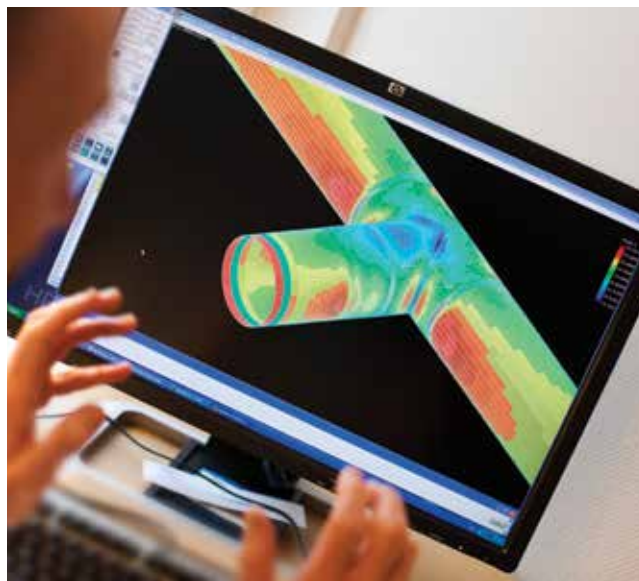


Fig. 3 Optimizing the cost/performance balance

A Flowtite engineer uses finite element analysis (FEA) to determine loads on a large-diameter pipe section at a “T” junction. Each Flowtite Grey project is engineered for maximum stiffness while minimizing use of premium material in the continuous filament winding process to keep costs under control.

1.5 times design pressure for 168 hours. Ultimate burst pressure was 75.6 bar. Says Crofts, “We’ve shown a 60% increase in abrasion resistance and a four- to 10-time improvement in impact resistance than original Flowtite FRP pipe, at a similar price point as competing materials, thanks to the design and materials used.”

The improved impact resistance means a customer can backfill with soils with heavier concentrations of gravel or mixed gravel/sand, without damaging the pipe, he adds. And, the company’s calculations of a 100-year pipe life are based on accelerated strain data consistent with industry standards, including buried pipe longevity data collected by Utah State University’s (Logan, UT, US) Buried Structures Laboratory.

Because Flowtite Grey was launched in April of this year, customer build specifications are still in progress. Amiantit Germany currently has 10 km of pipeline projects on the books, with installations scheduled for the end of 2016 or early 2017. “A credible pipe product has to address market demands,” concludes Crofts. “Flowtite Grey has been engineered to add security against the very rigorous conditions of large underground piping, for a long service life in a cost-effective way.” **CW**



ABOUT THE AUTHOR

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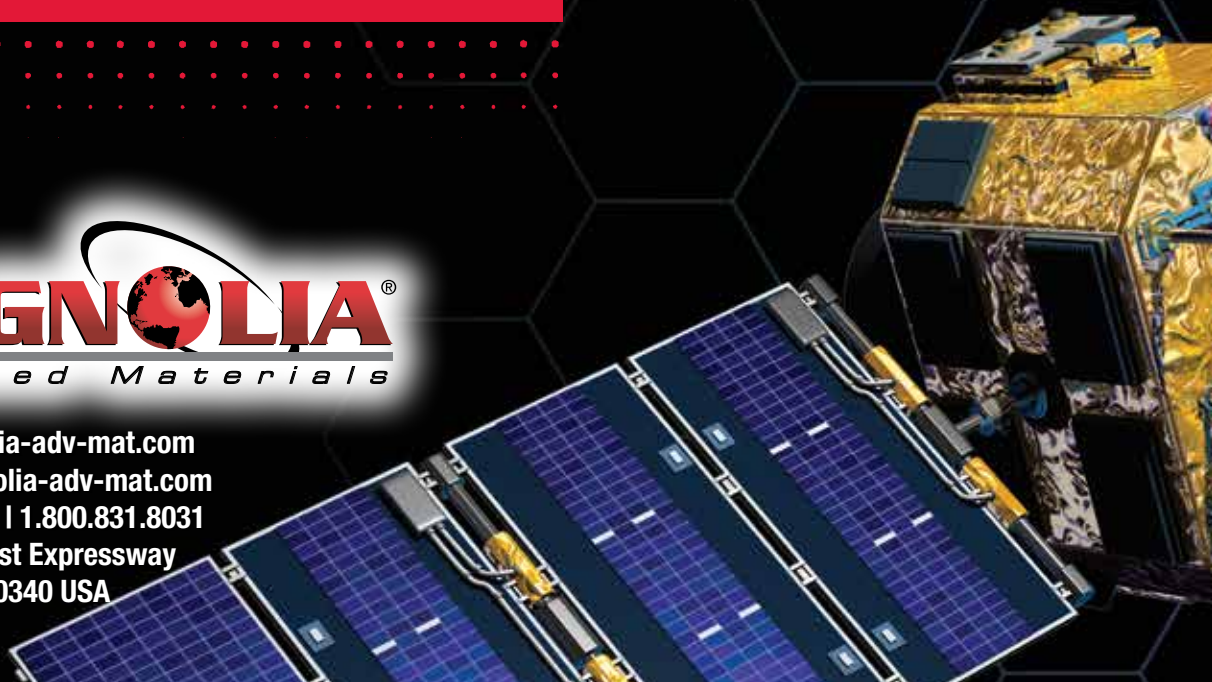
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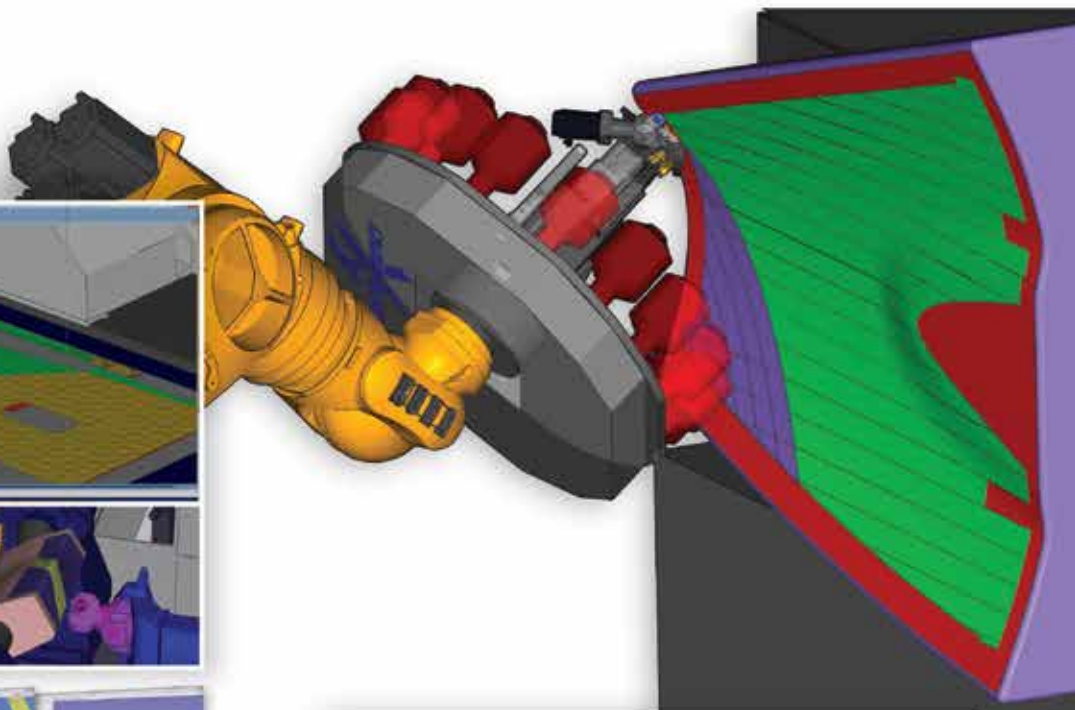
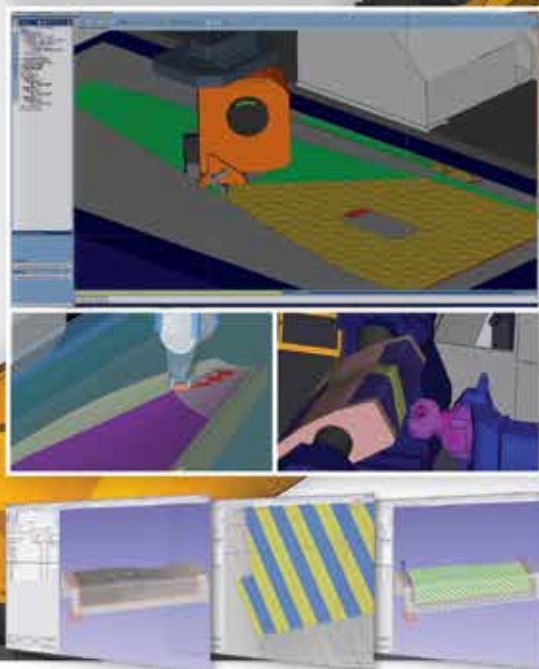
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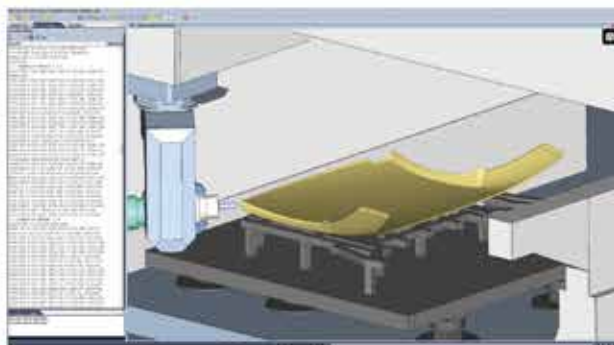
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