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COMPOSITES TECHNOLOGY

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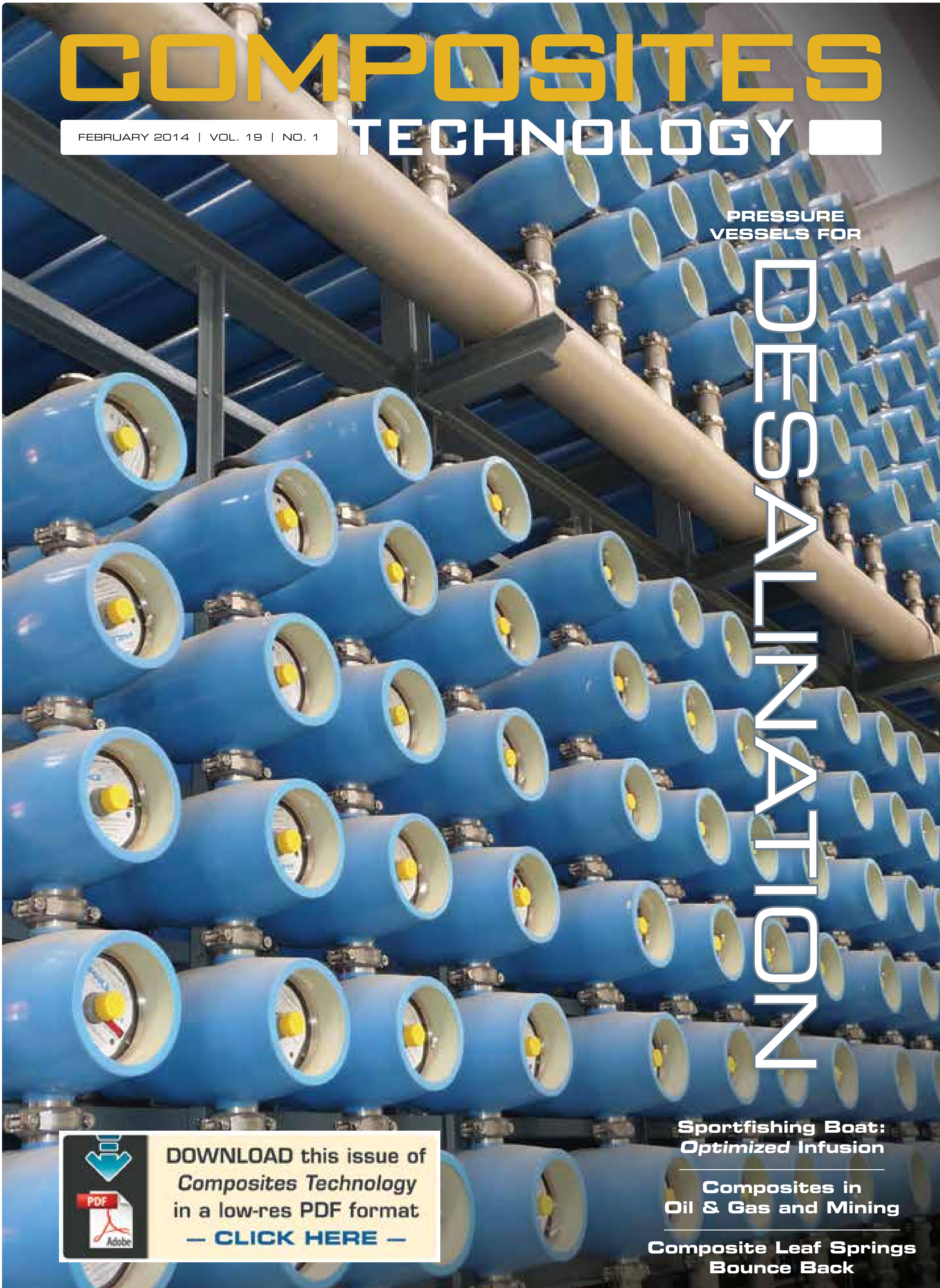

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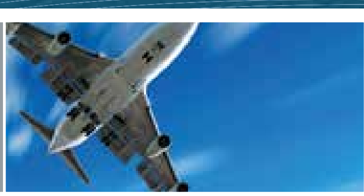


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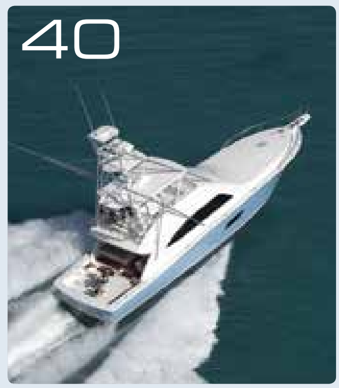

COMPOSITES TECHNOLOGY
February 2014 | Vol. 19 | No. 1

COMPOSITES WATCH

COLUMNS

DEPARTMENTS

FEATURES

COVER PHOTO

Protec-Arisawa (Tokyo, Japan) has filament wound composite pressure vessels for seawater reverse osmosis (SWRO) desalination plants all over the world. Pictured is a bank of vessels produced for a plant located in Barcelona, Spain. The company's newest project, in Southern California, is chronicled in our Engineering Insights design feature, beginning on p. 54.
Source | Protec-Arisawa

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MEMBERSHIPS:

Pipes vs. Vessels

American and European manufacturers are unduly burdened by regulation.

This lament often includes a reference to the fact that developing countries, such as China and India, have little or no regulation and, thus, enjoy a competitive advantage, unfettered by governmental overreach.

No matter how you feel about government regulation, it's true that there was a time in American and European history when manufacturers faced almost no regulation at all. Factory owners were free to employ whoever was willing to work for the wage offered, regardless of the employee's age, the factory's working conditions, the expected work hours, or the safety of the workplace. Labor history, as a result, is full of stories about employee injuries and deaths that resulted from equipment malfunction, lack of safety systems, fire, and fatigue-induced inattention. Government, inevitably, stepped in to establish standards for workplace safety and to prosecute offending employers.

> The fact is that whether they are over-, under- or well-regulated, not all SWRO housing manufacturers go to the effort and expense of meeting accepted standards.

Private industry, encouragingly, also responded, in part, by forming industry-managed organizations, like ASME (New York, N.Y.), which works with engineers to develop design, material and manufacturing standards. Among these is the *Boiler and Pressure Vessel Code* (*BPVC*), created in the early 1900s after boilers exploded at two shoe-manufacturing plants in Massachusetts, killing and injuring scores of people.

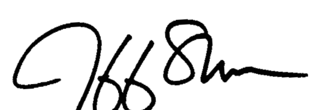
Fast-forward to the late 1970s, when then-new fiber-reinforced composite tubes used to house the membranes that enable saltwater reverse osmosis systems (SWRO; see story this issue, p. 54) were first designed and manufactured. SWRO systems desalt and otherwise purify ocean water, making it potable (safe for human consumption.) As our story indicates, these membrane housings were lighter, more corrosion-resistant (a boon for equipment constantly exposed to saltwater) and smoother internally than the legacy steel housings. Although these composite housings were capable of much longer service life, they lacked a design that could withstand the 600-psi pressure inside the housing. The result, at first, could be disastrous: Tubes would rupture, sending membranes, end caps and reinforcing collars, like cannon shot, through walls and windows, sometimes injuring workers.

Doug Eisberg, director of business development at Avista Technologies, recalls that composite housing manufacturers were applying the *wrong* standard: ASTM D2992, written for pipe. These these long, cylindrical SWRO housings resembled piping, but they were, in fact, *pressure vessels*, and they needed to be designed that way.

ASME stepped in, adding to its *BPVC* a Section 10: "Fiber-Reinforced Plastic Pressure Vessels." The new standard's test regime called for representative housings to be cycled 100,000 times from zero to design pressure at 150°F/66°C, followed by a hydrostatic test to *six times* the design pressure.

That's been good for customers because the ASME code stamp on a SWRO housing certifies that its supplier can and does meet a rigorous standard. But what of the suppliers — and there are a few — who wind such vessels *without* the certification? What of the customers who buy uncertified vessels under the impression that they do meet the standard?

The fact is that whether they are over-, under- or well-regulated, not all SWRO housing manufacturers go to the effort and expense of meeting the generally accepted standards — until and unless such negligence leads to a failure that causes injury or death. In the meantime, all of us in the composites industry pay the price via loss of confidence by customers who see the occasional failure as the norm.



Jeff Sloan

Legacy applications: Inspiration for future vehicles?

Bio | Dale Brosius

Dale Brosius is the head of his own consulting company and the president of Dayton, Ohio-based Quickstep Composites, the U.S. subsidiary of Australia-based Quickstep Technologies (Bankstown Airport, New South Wales), which develops out-of-autoclave curing processes for advanced composites. His career includes a number of positions at Dow Chemical, Fiberite and Cytec, and for three years he served as the general chair of SPE's annual Automotive Composites Conference and Exhibition (ACCE). Brosius has a BS in chemical engineering from Texas A&M University and an MBA. Since 2000, he has been a contributing writer for *Composites Technology* and sister magazine *High-Performance Composites.*

I attended the Society of Plastics Engineers Automotive Innovation Awards dinner on Nov. 6, 2013 (full disclosure: I am one of the event's blue-ribbon judges), where a number of excellent applications of plastics from around the globe took awards. Award categories included Powertrain, Body Exterior, Body Interior and others, and at the end of the evening, one of the category winners is selected for the Grand Award. The big winner in 2013 was an all-olefinic liftgate for the Nissan *Rogue*, consisting of a thermoplastic olefin (TPO) outer skin and a long glass fiber-reinforced polypropylene structural inner panel. The assembly is 30 percent lighter than the stamped-steel version it replaces — a considerable weight savings. It will be interesting to see if Nissan adopts this technology on the *Murano* and the *Juke*, two other crossover SUVs in its line — and if other OEMs will introduce similar technology.

The automotive industry is rife with good applications that failed to proliferate to other models built by the same OEM, let alone to other OEMs. This lack of proliferation has been a great source of frustration for Tier 1 suppliers *and* those who supply composite materials to them. Almost every composite materials supplier has looked at the automotive industry and, noting that the average vehicle weighs roughly 1,500 kg/3,300 lb, asked, "How hard could it be to get just 1 kg on every vehicle?" The answer — no surprise to industry veterans — is "very hard."

New materials *earn* their way onto vehicle platforms, one application and one model at a time. Although it seems logical that when a part offers weight or cost savings to one OEM, other OEMs would line up to gain the same advantage, it rarely works that way. OEMs differ in engineering philosophies and risk-taking perspectives; and then there's the "not invented here" syndrome. Given the new pressures to increase fuel economy and reduce CO_2 emissions, and the advances in composites manufacturing technologies, maybe it's time to revisit some composite solutions from the past and see if they can be reprised in vehicles now on the drawing board.

For inspiration, I looked back through the list of previous SPE Grand Award winners. Some applications, like polyamide radiator end caps (1981 winner), thermoplastic air-intake manifolds (1994) and integrated front-end systems (1995) have, indeed, managed to catch on across multiple platforms and OEMs. However, several structural composite winners saw brief periods of expansion, followed by contraction, but are by no means obsolete.

In 1980, for example, General Motors won the Grand Award for the transverse fiberglass/epoxy filament-wound leaf spring used on the *Corvette* front and rear suspensions. In addition to saving weight, the spring enabled the designers to lower the hood line, improving aerodynamics and styling. In the late 1980s, GM extended the concept to a line of minivans and to large-volume, midsize passenger cars, before moving back to coil and strut suspensions in subsequent models. The *Corvette* still uses composite springs, *but no other vehicle does*. Ford developed composite springs for the *Ranger* pickup that proved much more durable and 75 percent lighter than multileaf steel springs, but they never made it into full production. Given today's faster curing resins and improved winding machines, it seems a good time to take another look at composite suspensions. (For more on composite leaf springs, turn to p. 34.)

In 1984, I attended my first SPE Automotive Awards ceremony, where the filament wound carbon fiber/vinyl ester driveshaft used on the Ford *Econoline* van took the Grand Award. My employer at the time, Dow Chemical Co. (Midland, Mich.), supplied the vinyl ester resin for this application, which saved considerable weight and was less expensive (despite the high cost of carbon fiber in 1984) than the two-piece steel driveshaft design. General Motors followed a few years later with

Source | Honda Motor Co.

Source | Society of Plastice Engineers

The composite truck bed for the 2006 Honda *Ridgeline* pickup (top photo), and the 2013 SPE Automotive Innovation Grand Award-winning liftgate for the Nissan *Rogue*.

a version where carbon fiber/vinyl ester was pultruded over a thin aluminum sleeve, and installed on numerous pickup trucks over a period of about five years. Today, no North American vehicles have carbon fiber driveshafts, although a few models in Japan employ the technology. With today's carbon fiber prices and fast-curing epoxy resins, the economics, again, could be attractive.

In 2005, the Honda *Ridgeline* won the Grand Award for its sheet molding compound (SMC) pickup box with an innovative in-bed "trunk" storage system. In 2001, Ford had pioneered an SMC box in its *Explorer Sport Trac*, which remained in production until 2010. In 2002, General Motors introduced a *one-piece* composite box as a factory alternative to the standard steel box. Molded using directed-fiber preforms and the SRIM (structural resin injection molding) process, the 6.5-ft/2.0m long box shaved 50 lb/22.7 kg in weight vs. the steel box, and went on the vehicle in the same assembly line. Although it was a technical success, dealers were given little incentive to promote the composite box, so the option was discontinued after a couple of years. In 2006, a new Toyota *Tacoma* pickup model was introduced with an SMC box. Today, only the *Ridgeline* and the *Tacoma* have composite boxes. Compared to other options for saving weight in trucks, this definitely seems like an idea worth revisiting.

While it's easy to become infatuated with the "next big thing," like the carbon composite passenger cell in the BMW *i3*, there's good reason to take a look at what worked in the past and take advantage of new design software and manufacturing technologies that can breathe fresh life into those applications for future vehicles. Sometimes, a little nostalgia isn't such a bad thing. | CT |

Composites Business Index 51.3: Growing again

Bio | Steve Kline

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

After a month of growth in October, the November Composites Business Index of 49.1 showed that business activity had contracted at a modest rate. Although the CBI had indicated contraction in five of the previous six months, business conditions had improved compared to November 2012. In each of the three preceding months, the CBI had been higher — in November, 11.6 percent higher — than it was one year ago.

THE COMPOSITES BUSINESS INDEX						
Subindices	**December**	**November**	**Change**	**Direction**	**Rate**	**Trend**
New Orders	54.5	49.7	4.8	Growing	From Contracting	1
Production	49.6	49.4	0.2	Contracting	Slower	2
Backlog	49.6	45.7	3.9	Contracting	Slower	19
Employment	52.5	51.9	0.6	Growing	Faster	10
Exports	48.3	46.4	1.9	Contracting	Slower	20
Supplier Deliveries	53.7	51.9	1.8	Lengthening	More	25
Material Prices	61.2	60.7	0.5	Increasing	More	25
Prices Received	51.2	49.4	1.8	Increasing	From Decreasing	1
Future Business Expectations	74.0	70.5	3.5	Improving	More	25
Composites Business Index	51.3	49.1	2.2	Growing	From Contracting	1

New orders and production moved from strong growth in October to slight contraction in November. Backlogs continued to contract but did so at their slowest rate since March 2013. Employment had expanded at a relatively constant rate for five months. Exports remained in contraction due to the relatively strong dollar. Supplier deliveries continued to lengthen but more slowly than in early 2013.

A materials prices increase over four months moderated, and prices received by fabricators decreased for the first time in three months. This combination put pressure on profits. Future business expectations fell slightly from the October level, but were still at their second highest level since May 2012.

Facilities with 50+ employees expanded as they had for most of 2013, and those with 20 to 49 employees showed their first growth since March, but the smallest facilities had contracted every month.

Regionally, the Pacific grew for the second month in a row and at its fastest rate in November. The only other growth was in the South Atlantic. The Mountain, East North Central, and Middle Atlantic regions contracted after expanding in October. The West North Central contracted for the fourth consecutive month.

Future capital spending plans, however, were up significantly, and at their fastest rate in three months, in November. Future spending plans were up 54.1 percent compared to one year ago. The annual rate of change increased 11.0 percent in November.

The December CBI, 51.3, showed that composites business activity was improving again, for the second time in three months. In fact, conditions at composite fabricators had improved *generally* since July 2013 — December's CBI was 18.8 percent *higher* than in December 2012.

New orders grew at a significant rate for the second time in three months. However, production contracted at a modest rate for the second straight month. As a result, the backlog index had improved dramatically since August 2013, indicating that capacity utilization at composite fabricators will improve in 2014. Employment had grown at an increasing rate since June 2013. Exports continued to contract but the rate had slowed steadily since December 2012. Supplier deliveries continued to lengthen at a relatively constant rate.

Material prices were increasing, but the rate of increase in the previous four months was slower than in early 2013. Prices received increased four of the five previous months, but the rate of increase was much slower than the rate of increase in material prices. Future business expectations continued an upswing begun in November 2012, and reached their highest level since March 2012.

Facilities with 50+ employees expanded, as they had for most of 2013. In November, fabricators with 20 to 49 employees had grown for the first time since March 2013, but contracted again in December. Facilities 19 or fewer employees continued to contract, but the rate of contraction had slowed for three months.

The Pacific region grew the fastest in December and had done so at a faster rate each month for three months. The West South Central grew at the second fastest rate. The only other regional growth was in the East North Central, for the second time in three months. The Mountain region was flat. All other regions contracted.

Future capital spending plans were at their third highest level since February 2013. Spending plans were 32.2 percent higher than in December 2012. It was the fourth straight month of growth for the month-over-month rate of change, and the annual rate of change grew faster than it did in November. This indicated that capital spending should improve significantly in 2014. | CT |

Composites WATCH

An update on carbon fiber composites in production automobiles, and observations on the significance for the wind energy market of blade failures and the expiration of the PTC.

AUTOMOTIVE

Carbon Fiber 2013: The challenging outlook for AUTOMOTIVE composites

Source | CT / Photo | Jeff Sloan

One of the bigger topics of interest at CompositesWorld's Carbon Fiber conference, held Dec. 9-12, 2013, in Knoxville, Tenn., was automotive composites. Two conference presentations confronted this topic directly. The first was a three-hour preconference seminar led by Composites Forecasts and Consulting LLC (Mesa, Ariz.) principal Chris Red, titled "Emerging Opportunities and Challenges for Carbon Fiber in Passenger Automobiles: Is the CFRP industry ready for mass production?" Noting that the automotive industry, today, represents about 6 percent of total carbon fiber demand, Red identified 104 car models that now feature OEM-specified carbon fiber composites to some degree, despite the \$19.10/lb (\$42/kg) cost of raw fiber. By contrast, automotive steel is a mere \$0.66/lb (\$1.46/kg). In his view, "we can't get into mid- and high-volume model production scenarios within the next 10 years," due not only to the still high fiber price but also to processing issues. However, he observed that legislation that mandates reductions in greenhouse gas emissions will be a powerful driver for OEMs, who must dramatically improve fuel efficiency and reach end-of-life recycling goals during the next 10 years. Red believes that mid- to full-size luxury cars, luxury sports cars and some SUVs and CUVs hold the most promise for carbon composites adoption. He asserts there are good opportunities for composites beyond exterior body panels, notably in suspension components, such as chassis frames, powertrain elements, brakes and wheels. Of the OEMs examined in his research, BMW (Munich, Germany) and the Volkswagen Group (Wolfsburg, Germany) are the most prolific users of carbon fiber at present. A joint venture between Brembo SpA (Curno, Italy) and SGL Group (Wiesbaden, Germany) is one of the largest single users of carbon fiber materials, and occupies a dominant market share. Not surprisingly, 70 percent of carbon fiber composite part suppliers are located in Europe, the largest including ITCA Colonnella SpA (Colonnella, Italy), Sotira (Meslay du Maine, France) and Mubea Carbo Tech Composites GmbH (Salzburg, Austria). Some North American firms also made his "biggest" composites suppliers list, including Morrison Molded Fiberglass Co. (Ashtabula, Ohio), Multimatic Inc. (Markham, Ontario, Canada) and Plasan Carbon Composites (Bennington, Vt., and Walker, Mich.). Despite a recession-related drop in carbon fiber usage in automobiles of nearly 50 percent between 2005 and 2010, Red concluded that during the next 10 years — without a speculative demand add-on — the identified vehicle population is expected to consume more than 173 million lb/78.6 million kg of carbon fiber. "Outside of wind energy, the automobile represents the biggest opportunity for carbon fiber market growth and penetration," he maintained.

Many eyebrows were raised at the conference by the second automotive-composites-specific presentation, given by Patrick Blanchard, technical leader, Composites Group, at Ford Motor Co. Research & Advanced Engineering. Blanchard addressed emerging CAFE standards and the lightweighting efforts at Ford. He reminded the audience that CAFE targets progress annually and require 3.5 percent fuel-efficiency improvements year over year through 2025. He also noted that Ford research shows that consumers are not concerned about vehicle weight. They are most concerned, instead, with vehicle handling, braking and safety. Although vehicle weight affects these attributes, weight *by itself* is unimportant. Finally, he asserted that powertrain advances that involve hybrid-electric and plug-in electric technologies will enable an OEM, such as Ford, to meet CAFE targets. Reducing vehicle weight, he contended, will extend the driving range of high-efficiency cars, but weight elimination is not necessary to increase efficiency. That said, he admitted that weight is still an issue: New customer features in cars and trucks, adopted since 1998, have added 17 lb/year to each new car model and 43 lb/year to each new truck model. Ford, Blanchard noted, is looking at aluminum and lightweight steel to help trim mass. These "legacy" materials, he claimed, fit best with Ford's manufacturing systems, which, of course, favor metals. Carbon fiber composites, he noted, are lacking in several respects: Their production processes are not scalable to auto OEM volumes. Design and CAE tools need improvement. Robust repair technologies are not yet available. An adequate fiber supply is not yet in evidence. And carbon composites are not yet proven to be compatible with vehicle painting processes.

Surprisingly, Blanchard's objections did not include the high cost of raw fiber, but in the Q&A session that followed his presentation, he said that he left fiber price out of his presentation because Ford's infrastructure requirements present the bigger hurdles to the material. Blanchard noted that Ford has 39 assembly plants, globally, that produce 7 million vehicles per year. Reconfiguring those plants to accommodate carbon fiber manufacture, he claimed, would be prohibitively expensive. Nevertheless, Blanchard did say that he thinks composites usage in automotive has a future, particularly in multimaterial applications, but made clear that carbon fiber use at Ford is, at this point, anything but a forgone conclusion.

Notably, Ford representatives who have addressed composites industry audiences in the past have usually argued that carbon fiber's expense is the show-stopper, and have indicated that if the price came down, the material would see increased use. Blanchard, however, made it clear that carbon fiber cost, ultimately, may have little impact on the material's use at Ford. It also bears noting, however, that Ford is working closely with Dow Chemical Co. (Midland, Mich.) on development of a carbon fiber made with a precursor other than polyacrylonitrile (PAN). Ostensibly, this will lead to less-expensive carbon fiber and boost its use in the automotive industry. Given the noticeable disconnect between Blanchard's pronouncements and Ford practice, its clear that the dust is yet to settle in the unsettling conversation between the carmaking and composites-supply communities.

More revelations about recent U.S. WIND TURBINE blade breaks

Although they occur in a very small percentage of installed wind turbine rotor blades, blade failures do occur. *CT* took note, recently, when *North American Windpower* magazine (*NAW*, published by Zackin Publications Inc., Waterbury, Conn.) reported on its Web site that a fourth 48.7m/160-ft blade had broken off a GE (Fairfield, Conn.) 1.6-100 turbine, on Nov. 20, 2013. No one has been injured in the breaks, three of which occurred in November and one in March, 2013. Ironically, the GE 1.6-100 turbine was named 2012 Turbine of the Year by *Windpower Monthly,* and is notable for kick-starting the large-rotor trend, which, when combined with modest generator power, has reduced the cost of energy. The turbine also had has helped GE to surpass Vestas Wind Systems A/S (Aarhus, Denmark) as the number one turbine supplier in the world.

Source | Paxton Record

NAW reported on Dec. 19, 2013 that the Nov. 20 break, at Invenergy's (Chicago, Ill.) California Ridge wind farm in Illinois, was due to a lightning strike. However, GE has reportedly identified a "spar cap manufacturing anomaly" as the root cause of the three other 2013 breaks at other facilities, including Invenergy's Orangeville Wind Farm in New York, and the Echo Wind Park operated by Detroit-based DTE Energy in Michigan. The 2013 breaks followed two others that occurred in 2012, both in Illinois: In one, at the California Ridge Wind Farm, the broken carbon spar in the GE 48.7m blade could be clearly seen. Shown here is a broken blade at nearby Settler's Trail Wind Farm. In a 2012 statement, GE Renewable Energy spokesperson Lindsay Theile said an "isolated manufacturing issue was the cause of the two [2012] blade fault occurrences." Although the precise nature of the issue was not disclosed at the time, the March 11, 2013 break at DTE's Thumb Wind Park was attributed to a failure in the carbon fiber spar "at the 19m [62-ft] mark" reportedly caused by an accidental two-hour oven shutdown during cure.

GE recently released its report on the root-cause investigation into the more recent breaks. Although GE's Theile said she couldn't disclose much detail, she did say that a "suspect population" of 48.7m/159.8-ft blades had been identified, representing roughly 1.5 percent of the total blades in GE's installed fleet of more than 22,000 wind turbines. GE reportedly had a $1 billion supply contract with Tecsis (Sorocaba, Sao Paulo, Brazil) to supply blades to GE for U.S. wind power projects from 2006-2010. In a 2012 *Wind Turbine Overview* for the World Bank, GE presented its 1.6-100 turbine blade testing overview with a photo beside "Certification Requirements" titled "GE-Tecsis Collaboration," indicating a close relationship between GE and Tecsis, and it is possible, if not likely, that the five GE 1.6-100 blades that have failed in 2012-2013 were produced by Tecsis in Brazil.

It is believed that Tecsis uses Gurit (Isle of Wight, U.K.) carbon fiber Sparpreg material to manufacture the spars used in the 48.7m blades. When asked to confirm the relationship, however, GE responded, "The breakdown of our suppliers is confidential information." Neither GE nor Tecsis denied use of the material.

GE spokesperson Katelyn Buress told *CT* that investigative work continues. "Working with our customers," she reported, "we have assigned dedicated teams to perform thorough investigations of the recent breaks. GE's global fleet of wind turbines have recorded more than 500 million safe operating hours and achieved an availability rating of more than 98 percent. Our success in the industry is built on our high reliability and safety record. We are working closely with our customers to keep their turbines running reliably and safely." GE's Thiele indicated that GE has put additional controls and oversight in place to prevent this type of manufacturing issue in the future, including GE inspectors who are performing additional quality reviews and verification of data.

It is important to note that these carbon spar-related breaks are quite different, in terms of causation, from blade failures experienced by Siemens earlier in 2013 and by Gamesa in 2007. Siemens responded quickly to two B53 (53m/174 ft) blade failures in its SWT-2.3-108 turbines at the Eclipse wind farm in Iowa and the Ocotillo Wind project in California. The company immediately curtailed production of that turbine, performed a root-cause analysis and determined the culprit was adhesive-bond failure between pre-cast root segments and the main blade fiberglass laminate due to insufficient surface preparation. Since then, all of the B53 blades have been inspected and most are back in operation. Siemens will replace a number of blades due to delamination and will apply a minor modification in the field to all B53 blades that are not replaced, incurring $131 million in charges toward third quarter 2013 results. For Gamesa, a defect in a foot-long applicator produced an irregular line of adhesive, causing splintering and breakage in 13 of nearly 400 blades produced at its Ebensburg, Pa., plant that year. Seven blade failures were first observed at the Allegheny Ridge Wind Farm in Pennsylvania. The problem was corrected and the blades were replaced.

ENERGY

U.S. WIND ENERGY projects beat PTC expiration deadline

Although the expiration of the U.S. production tax credit (PTC) has, in the past, put the brakes on wind projects, the PTC's cliffhanger extension on Jan. 1, 2013, was different because it required only that a wind energy project be under construction before the expiration date of Dec. 31, 2013, to be eligible for the credit. A key reason was a follow-up Internal Revenue Service (IRS) advisory that declared a project "under construction" if its developer had incurred as little as 5 percent of the project's total capital costs.

Several wind projects benefited from the lenient definition: Vestas Wind Systems A/S (Aarhus, Denmark), for one, reported on Dec. 18 a 350-MW order from Enel Green Power North America Inc. (EGP-NA, Andover, Mass.). Vestas will supply 75 V100-2.0 MW turbines for the 150-MW Origin wind farm in Oklahoma. Vestas and EGP-NA also signed an agreement for additional 2-MW turbines. Under that agreement, 200 MW of capacity is confirmed, and the total could range as high as 836 MW. Deliveries for the Origin project are expected to occur in mid-2014, with commissioning by the end of the year. Vestas' factories in Colorado will be involved in manufacturing blades, nacelles and towers for Enel's order. Vestas has previously supplied wind turbines to Enel for three U.S. projects, most recently the 200-MW Caney River wind power plant in Kansas that was commissioned in 2011.


Source | USHispanics Web site - 11/08/13

Likewise, Siemens Energy (Orlando, Fla.) confirmed on Dec. 16, 2013, that the 1,050-MW wind-turbine order it recently received from MidAmerican Energy Co. (Des Moines, Iowa) is the world's largest onshore wind turbine order to date. It calls for 448 Siemens wind turbines at five project sites that, together, will deliver 1,050 MW of additional capacity in Iowa by the end of 2015. Construction activity is underway at each site. Siemens Energy's Fort Madison, Iowa, facility will manufacture all the blades, while nacelles and hubs are assembled at the Siemens plant in Hutchinson, Kan. Once complete, the new wind farms will generate electricity sufficient to power ~317,000 average Iowa households.

In 2012, more wind energy capacity was created in the U.S. than any other form of electric power generation: The PTC helped generate a yearly record of $25 billion in private investment, making wind the top source (42 percent) of newly installed capacity. Since 2005, the wind energy industry has attracted $105 billion of private investment to the U.S. economy.

JEC Europe 2014 | Preview

The composites show's appearance in Paris this spring promises to be bigger than ever before, reflecting the industry's post-recession resurgence.

In anticipation of its annual Paris composite industry event, the JEC Group says it is preparing it's biggest show floor yet for what the organization expects will be a record influx of exhibitors and attendees to its 2014 edition of the JEC Europe trade show. The largest event of its kind, JEC Europe hosted as many as 1,181 exhibitors in recent years, 26 percent from inside France and 74 percent from abroad.

Set for its traditional location in Porte de Versailles, in the southwestern part of Paris, the show will occupy an 8 percent larger space at the Paris Expo this year. The show floor will be housed, for the first time, in *two* exhibition halls, located in Pavilion 7. Thus, for 2014, the show will cover 54,400m^2 (585,556 ft^2).

Claiming 32,256 visitors in 2012 (this figure includes exhibitor personnel), JEC reports that attendance at the Paris event will continue to be international in scope: 20 percent of visitors come from inside France, but the balance reportedly hails from beyond its borders. Including those from France, 77 percent arrive from European locales. Asia is the point of origin for 10 percent. And 8 percent come across the Atlantic from the U.S. The remaining 5 percent represent the rest of the world.

An unusual visitor statistic is the breakdown between composites industry companies and those that are *end-users* of composites. JEC claims that 33.6 percent of its visitors are in the industry: 38.7 percent of those are composites processors, 22.3 percent produce raw materials for composites, and the remainder represent service providers, distributors and equipment/machine manufacturers. But the overwhelming larger group of visitors (65.7 percent) are said to attend on behalf of companies that incorporate composites in products sold into one or more end-markets. Notably, the largest percentage (24.3 percent) come from the automotive industry, followed by aerospace (20 percent), building and construction (16.9 percent), boatbuilding and marine (9.2 percent), with the rest divided between software and services, sporting goods, leisure and consumer goods, rail transport, medical and other.

Source | CT / Photo | Jeff Sloan

JEC expects more than 32,000 visitors in 2014, representing an 86 percent hike in attendance during the past 10 years.

WHAT: JEC Europe 2014

WHEN: March 11-13, 2014

WHERE: Paris Expo, Porte de Versailles, Paris, France

CONFERENCE EMPHASES

In 2014 the show's conference focus will be on two hot industry growth markets:

- ***Offshore Energies:*** Wind energy, oil and gas, and hydropower will be examined as promising new-growth drivers for composites.
- ***Hybrid Structures***: Weight reduction is now crucial in transportation. Hybrid structures enable end-market OEMs to take best advantage of each of a variety of materials in what some are now calling the "multimaterial" vehicle.

JEC'S COUNTRY OF HONOR

In 2014, the JEC Europe Show and Conference also will focus on the development of the composites industries in The Netherlands. Dutch companies and knowledge institutes in the high-tech sector of JEC's featured neighbor are renowned for their technological excellence. The JEC Country of Honor spotlight will be especially bright on the Dutch aerospace industry and its strategically located cluster of more than 100 companies. JEC will celebrate The Netherland's high-tech systems and materials sector, which bolsters innovations in the areas of high-tech equipment, components and materials. | CT |

Prospective attendees can register for JEC Europe 2014 online at www.mybadgeonline.com/JEC-Europe/home.aspx. For additional information, interested parties may also contact the JEC Hotline (available February 3, 2014), via E-mail: jec@badgeonline.net or Tel.: +33 (0)1 43 84 86 83.

Semipermeables

NEXT TREND IN INFUSION?

Source (both photos) | AMF-Miss Geico Racing

These liquid-blocking membranes promise molders better properties, less waste and reduced risk.

Semipermeable membrane technology is already having a practical impact: The *Miss Geico* world champion offshore racing team began testing Membrane Tube Infusion (MTI) hose (see photo and diagram, p. 16) from Ibbenbüren, Germany-based DD-Compound in 2012. The team raced infused carbon fiber/epoxy parts on the 2013 boat, including engine-mount structures, dashboard and canopy, with *zero* failures even after experiencing up to 12G impact loads.

In conventional infusion processes, the vacuum system ideally draws resin in and draws air out to reduce the incidence of surface porosity and laminate voids. But despite the use of bleeders and breathers, evacuated air is inevitably accompanied by resin. This wastes resin, clogs vacuum lines and must be kept from damaging the vacuum pump through the use of catch pots. Vacuum lines must either be flushed with solvent or thrown away. In either case, processing cost is magnified. One promising solution is the semipermeable membrane (SPM), a thin, flexible film or fabric typically made from polytetrafluoroethylene (PTFE) or thermoplastic polyurethane (TPU). SPMs are permeable to gas but not to liquids.

The use of an SPM is common in processes like reverse osmosis in water filtration (see, for example, our Engineering Insights article on composites in seawater desalination, in this issue on p. 54) and in the medical industry. A familiar example is Gore-Tex, a porous PTFE-based fabric produced by W.L Gore & Associates (Newark, Del.), which is best known as the breathable but waterproof component of performance outerwear.

In the composites industry, SPMs are touted by proponents as potential pathways to easy, repeatable, high-quality infusion. Proponents variously suggest that SPMs be used as an additional layer in all or part of the materials stack or simply as a filtering cloth wrapped around the evacuation hose.

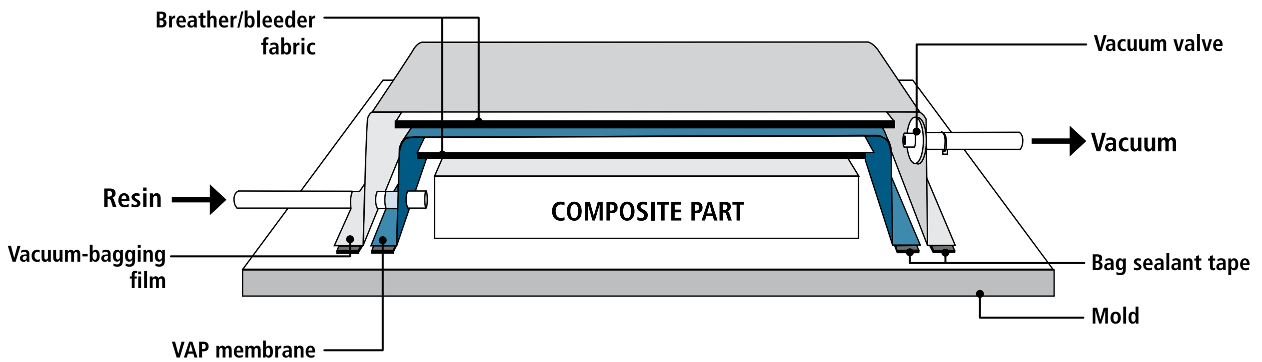
MEMBRANES ACROSS THE PART

The Vacuum Assisted Process (VAP), patented by European Aeronautic Defence & Space Co. (EADS, Amsterdam, The Netherlands), is credited with significant improvement of infusion processes by using an SPM across the entire surface of the layup. Andrew George described it in his 2011 Doctor of Engineering Sciences (Dr.-Ing.) thesis for the Institute of Aircraft Design (or IFB), University of Stuttgart:

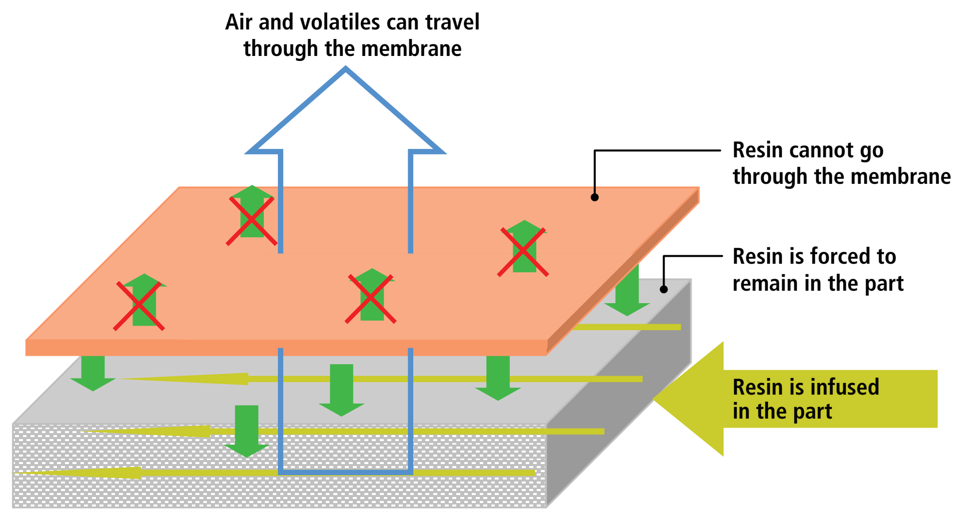
> *"VAP is a patented variation of resin infusion, where a semipermeable membrane separates the vacuum outlet from the surface of the part. This creates a full vacuum gradient and continued degassing across the part surface, as opposed to only at the end-edge of the part in traditional resin infusion. The full vacuum gradient theoretically results in fewer voids and reduced thickness gradients … thus higher mechanical properties and repeatability."*

George evaluated Gore-Tex and a variety of similar semipermeables from Saertex (Saerbeck, Germany), Pil Membranes (King's Lynn, Norfolk, U.K.) and Airtech (Huntington Beach, Calif.). Other sources include Trans-Textil GmbH (Freilassing, Germany), now the licensed supplier of SPM products for EADS' VAP method.

VAP proponents credit the use of an SPM with improving consistency in the flow front and removing dry spots without having to reduce vacuum. George noted that dry-spot removal during VAP is achieved without optimized vent placement. Citing University of Delaware research published in the 2004 *Journal of Composite*



Source | Andrew George, Institute of Aircraft Design (IFB), University of Stuttgart



The Vacuum Assisted Process (VAP), patented by European Aeronautic Defence & Space Co. (EADS, Amsterdam, The Netherlands), uses a semipermeable membrane to separate the vacuum outlet from the surface of the part, creating a vacuum gradient and in-situ degassing across the entire part surface rather than at the part edges only.

Source | "VARTM Variability and Substantiation," *Joint Advanced Materials & Structures (JAMS) Center of Excellence Technical Review*, D. Heider, C. Newton, J.W. Gillespie, University of Delaware, 2006.

Materials article, "Process and Performance Evaluation of the Vacuum-Assisted Process," George also observed that without any pre-infusion degassing, void content was reduced from 1.64 percent to a mere 0.37 percent, and thickness gradient was reduced 77 percent. However, he enumerated several disadvantages:

1. Additional cost for the membrane — ~€15/m² ($1.90/ft²). for PTFE and ~€5/m² ($0.63/ft²) for polyurethane (TPU).
2. Additional manufacturing steps (layup of the SPM and inspection to ensure that the SPM is wrinkle-free and situated appropriately within the stack).
3. The risk of stretching the membrane during layup, which increases the pore size and, therefore, could reduce its ability to block liquids.
4. Slower tool side flow vs. standard infusion (due to higher compaction from uniform vacuum across the entire part).

George also cautioned, "For a membrane to function correctly, it must not be saturated by the resin for the duration of the infusion to full cure. Certain membranes work with a particular set of process parameters, and do not work with others." He concluded that wettability of the membrane is a critical parameter.

These concerns underscore the importance of modeling the process and performing actual tests — as infusion experts often recommend — to ensure desired resin flow when any new variables are introduced to an infusion setup (see "Learn More," p. 17). George's testing showed the lowest void content when an SPM was used in conjunction with a distribution medium (DM). With a DM, PTFE gave a lower void content than TPU. PTFE, however, is much more expensive, so George maintained that TPU was worth considering but first should be tested in the particular infusion application.

By contrast, Jay Carpenter, a technical instructor at Abaris Training Resources (Reno, Nev.), has used semipermeables and found that they work well to address problematic flow areas. "We put the material on top of that area followed by a breather," says Carpenter, "and it resolved the dry spot."

"It makes sense," he adds, "because now air can move out vertically, vs. having to be drawn out across the laminate from the vacuum inlet. It is an added step and expense, but it's a relatively easy fix," he notes. "A downside is that you can no longer see the flow because the semipermeable membrane isn't transparent."

MEMBRANE-WRAPPED EVACUATION LINE

Significantly, George reports that VAP had its genesis in the use of PTFE merely to protect the vacuum port from resin intrusion. Introduced in 2011, Membrane Tube Infusion (MTI) hose is designed for that purpose. Described as an evacuation hose surrounded by a nonwoven layer and an air-permeable membrane, MTI, according to its proponents, also optimizes the air evacuation process during infusion. Developed and patented by DD-Compound (Ibbenbüren, Germany), and available in the U.S. via German Advanced Composites (Miami, Fla.), MTI eliminates the need for a catch pot and reduces resin consumption but reportedly also reduces dry spots and porosity.

"MTI hose can be used wherever spiral tubes or evacuation media have been used," says developer Dominik Dierkes. When the hose is placed around the mold lip, resin reportedly stops when it reaches the membrane but continues to flow through the rest of the dry fabric, eliminating the need for complex calculations of resin injection points and ensuring complete wetout of the dry fabric.

When the *Miss Geico* offshore boat-racing team met Dierkes in October 2013 and agreed to give the MTI hose a try, team partner and crew chief Gary Stray admits, "I was very skeptical at first because, with composites, I have seen so many instances of 'This is the next greatest thing.'" Because the team had been building its 50-ft/15.2m carbon fiber/epoxy catamarans using a standard vacuum-bagged wet layup process with postcure, Stray also had misgivings about a wholesale changeover to infusion.

"We had various material suppliers come in and tell us infusion was the way to go, but I was not 100 percent confident in it. You had to turn valves off and watch and control the resin flow the whole time in order to completely wet out the part with no dry spots," he recalls. "It was not inherently easy nor repeatable." Further, the boats are powered by twin 3,500-hp engines that weigh 1,500 lb/680.4 kg each. Capable of 200 mph/322 kmh in flat seas, they frequently face 4-ft/1.2m waves, enduring continuous 4G to 12G impact loads. There was, therefore, a lot of risk riding on the decision. "So we tested the MTI hose and infusion thoroughly," says Stray, "making a ton of test panels and analyzing pure material specimens for properties."

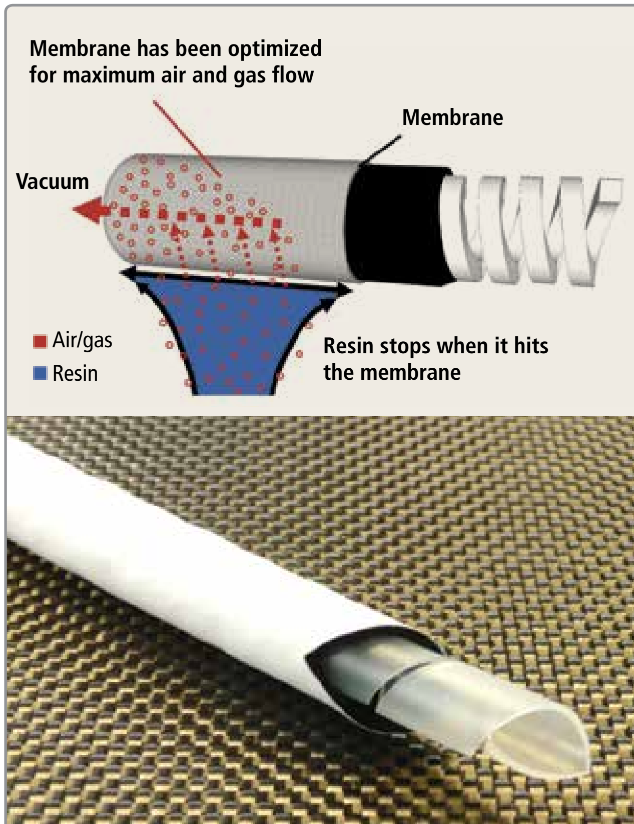
In the end, Stray and team were impressed: "With the MTI hose, the resin flow during infusion looks after itself," he claims, explaining that "it moves until it hits the MTI line and then stops. If you have a dry patch, there is only one way for the resin to go, and the vacuum keeps pulling until the resin has permeated everything."

That said, the team did not switch to infusion across the board but, instead, chose particular parts on the boat, including the structures where the engines are bolted in, the dashboards and the canopy. "All of these are critical parts," says Stray, "but also benefit from superior properties and compacted laminates."

For example, even though previous dashboards were built into the boat, they would vibrate and move when hitting a wave. "Now, using these infused structures, we haven't seen or felt any movement," says Stray, adding that analysis of cross-sectioned, finished laminates showed that "the parts we are pulling out have no air in them and no pinholes, where in the past we had to do a lot of postcure finishing." As a result, the team's 2013 boats, after four months of racing, experienced no failures, and the team made plans to infuse an entire boat in early 2014.

ENDORSED, WITH A CAVEAT

Longtime infusion expert André Cocquyt (ACSM, Harpswell, Maine) agrees that MTI hose, in particular, "will pretty much eliminate resin-filled vacuum lines and the need for catch pots in many applications" and adds that "membranes are definitely going to become a major asset in our infusion toolbox." However, he advises caution, lest molders duplicate processes that are covered, for example, by the EADS patent. "Users need to review existing patents to avoid violations," he asserts, suggesting instead that they "use these materials as building blocks for [their own] process innovations." ■



Source | DD-Compound

MTI features a nonwoven layer and an air-permeable membrane, which reportedly optimizes the air evacuation process during infusion, eliminates the need for a catch pot and prevents dry spots. ■

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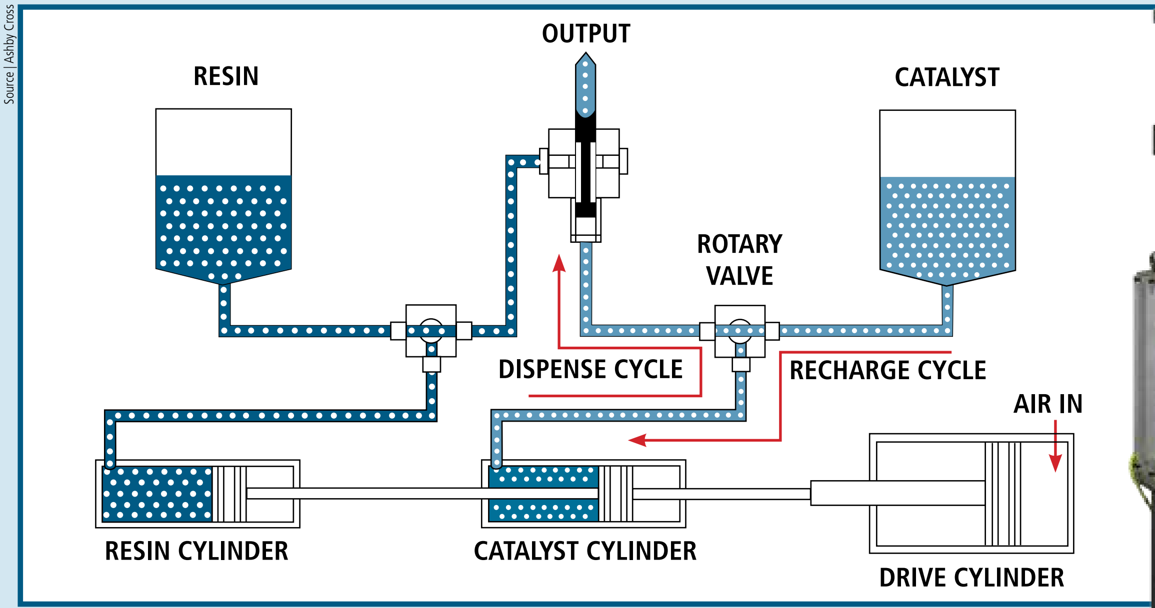
Read more about testing infusion strategies in "Aiming infusion at the application" | *CT* April 2013 (p. 26) | short.compositesworld.com/Qhht1BGP.

Source | Ashby Cross



Source | Nordson/Sealant Equipment & Engineering

Meter/Mix/Dispense Machines

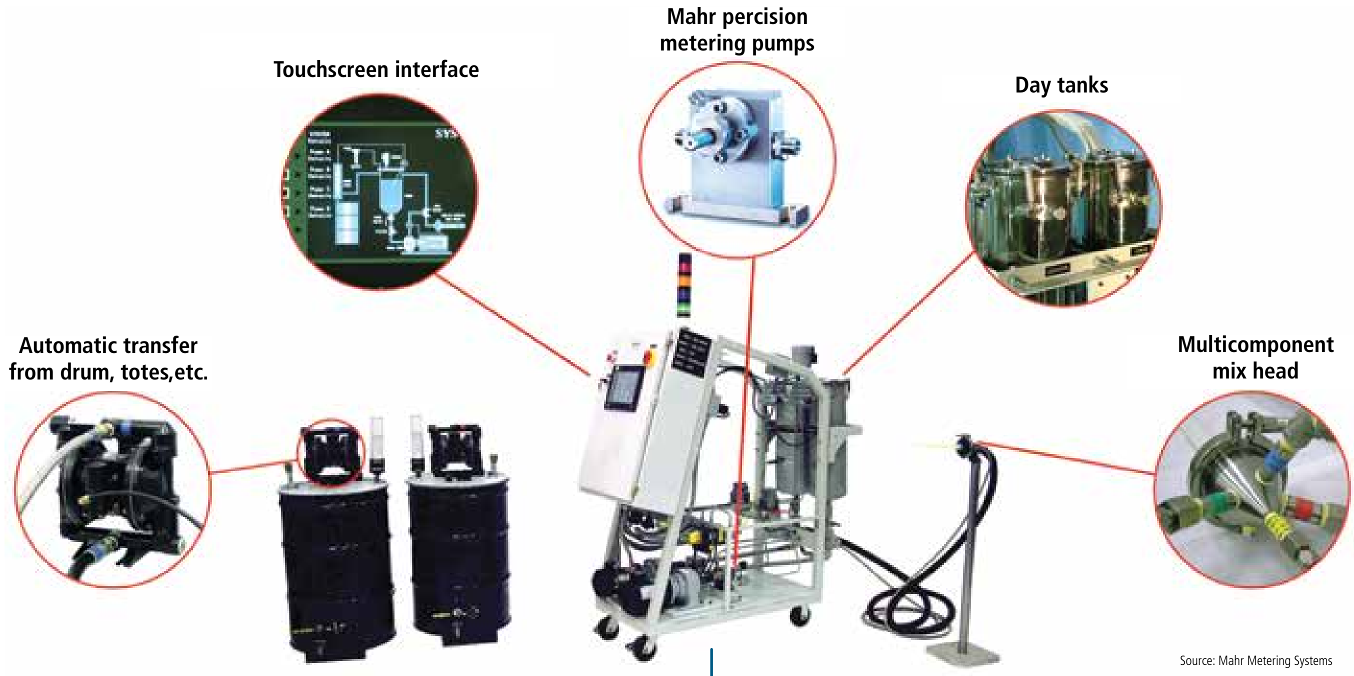
DOUBLING DOWN ON CONTROL

Source | GS Manufacturing

Meter/mix/dispense (MMD) basics are illustrated at top, in a setup for two-component mixing of polyester bonding putty. Although MMD machines can be relatively simple (pictured here is an XDS-1000 from GS Manufacturing, Costa Mesa, Calif.), they also can be quite complex for some applications: Pictured at top right is a See-Flo 488 from Nordson/Sealant Equipment & Engineering (Plymouth, Mich.). They also can incorporate a number of tangential functions (see, for example, the illustration on p. 19).

The latest equipment solutions deliver lower costs, faster cycle times and better part properties.

The need to meter, mix and then dispense lubricants, foams, paints, coatings and other fluid products has spawned a huge industry. In fact, equipment aimed at the composites industry is a very small part of the total meter/mix/dispense (MMD) market. That said, MMD has become a necessity throughout the business of composites fabrication. Molders use MMD equipment to supply resin systems to gel-coating and sprayup equipment, to inject them into pultrusion dies, to impregnate dry fiber in the filament winding process and to wet out layups and preforms in closed molding processes. MMD also plays a key part in the production of many raw fibers and base resins used in composites. Polymers must be metered and mixed before they can be spun into a fiber, and resin manufacturers must meter and mix resins with additives. This highlights a recent trend in materials suppliers using MMD machines to avoid the cost and inflexibility of batch processing, both in mixing powdered additives (e.g., pigments, fire retardants and glass microspheres) and in prepregging. One of the biggest trends, however, is the use of MMD and robotics in adhesive application, in search of the perfect bondline, as OEMs move away from mechanical fasteners in search of greater speed and reduced cost.



Most MMD equipment suppliers emphasize that every machine is unique and must be customized for each application. The features above can make custom machines more complex and expensive, but also much more precise, reliable and able to perform their functions much more efficiently. In addition to the pictured features, MMD equipment can incorporate heating and vacuum degassing of material plus fully digital control, based on electronic sensors as well as the capability to automatically solvent flush the mixhead.

MMD BASICS

Meter/mix/dispense MMD systems are used with *multicomponent* resin systems. Two-component thermosets predominate: Part A (the resin) and part B (hardener for epoxies or catalyst for styrenated resins). That said, systems that require up to six components — pigments, fire retardants and other additives — are not uncommon. But all MMD systems perform essentially the same function: They meter out precise amounts of each component, mix them, and then dispense them via *positive displacement*, meaning material is dispensed either by moving a piston or rod or by rotating an auger or gear, onto a surface or into a mold (see diagram, p. 18).

MMD equipment can be relatively simple. For example, in a *fixed* mix ratio system, the metered volume may be determined by the displacement of the cylinder used for each component. The cylinders are mechanically linked and actuated by a pneumatic drive, with discrete volumes dispensed one at a time

More complex systems, however, can mix *three or four* components, and do so at *variable* mix ratios that can range as widely as 1:1 to 100:1. They may also draw components from 55-gal (208-liter) tanks or *intermediate bulk containers (IBCs)*, also called "totes," which commonly hold 275 or 330 gallons (1,041 or 1,249 liters). Material also can be drawn into pressure vessels. For example, 2KM (Worcestershire, U.K.) lists 45-liter to 10,000-liter (12-gal to 2,642-gal) capacity pressure vessels as material feed options for its Process GearMix 520 and 720 machines. Onboard tanks are also an option, ranging in size from 1 liter (0.3 gal) for small R&D units to 60 liters (16 gal) and larger. These containers can be independently temperature controlled and vacuum degassed, and also can incorporate agitation to ensure homogenization.

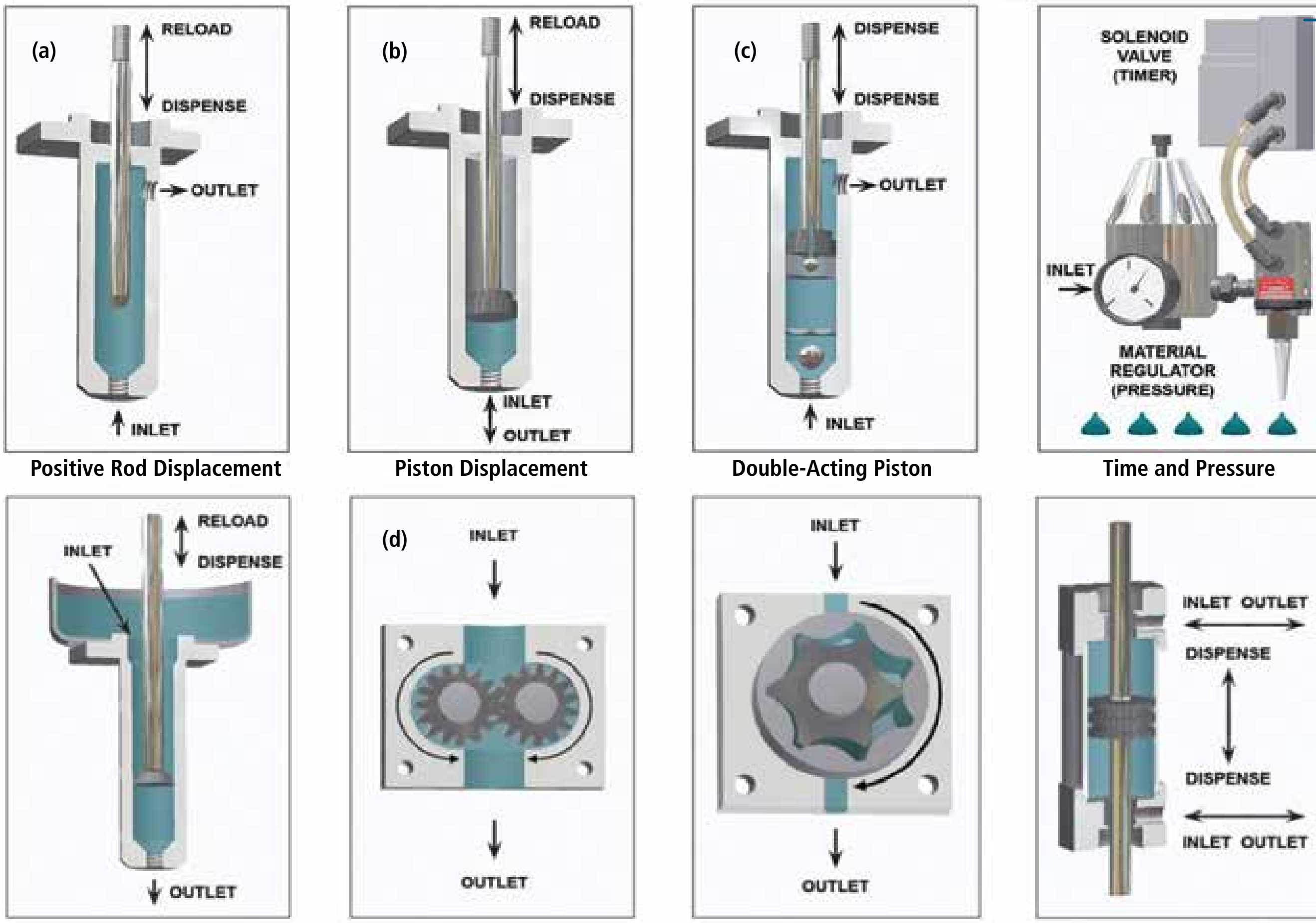
More complex systems feature precision gear pumps or piston pumps that use electronic linear encoders (piston pumps only) and/or mass flowmeters as part of a closed feedback loop with a programmable logic controller (PLC) to ensure mix accuracy of ±1 to ±2 percent. They maintain precise flow rate and pressure as they dispense material. Typically, their pumps are digitally slaved, rather than mechanically linked, to increase mix-ratio accuracy and can provide either metered *shots* or a continuous flow of material.

Most MMD control software not only stores hundreds of process recipes, but might also provide historical data tracking and communicate with the manufacturer's computer network as well as other equipment, such as a heated press. Accordingly, the cost of MMD systems can range from less than $10,000 to $600,000.

Once the components are metered, they can be combined with one of three mixers. *Dynamic* mixers have a rotating blade inside a chamber and reportedly give the most complete mixing, but may require purging with solvent after process completion to expel residual mixed material. *Static* mixing feature nozzles that have no moving parts. Instead, their convoluted interior shapes divide and blend resin components thoroughly as they pass through. There are also removable types, inserted into pipes and hoses (see "Inline static mixers" on p. 21). *Static-dynamic* mixers are similar to static mixers but have a rotating element for hard-to-mix materials (see bottom photo. p. 20), combining the higher mix energy of dynamic mixers with the disposability of static mixheads.

Which mixhead technology is most appropriate? That depends on the user's operations. According to Mahr Metering Systems (Charlotte, N.C.) president Mark Cauthen, "Customers typically buy one MMD machine for each type of chemistry they process," noting that otherwise, much time and expense is consumed in cleaning machinery: "If they want to use the same machine and change from a two-part to a three-part system or use different colors or addi-

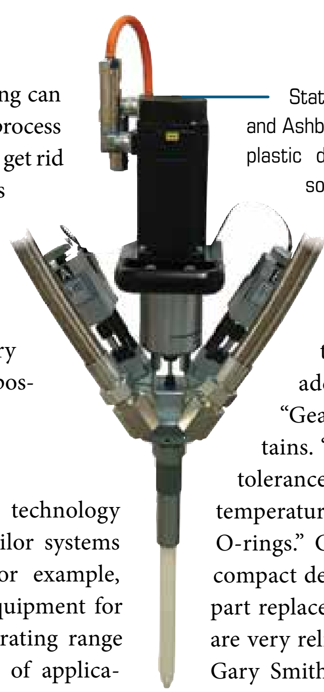
Source | Sealant Equipment & Engineering



Positive Rod Displacement | Piston Displacement | Double-Acting Piston | Time and Pressure

Piston Cup | Precision Gear Metering | Progressive Cavity | Reciprocating Piston

tives, they must purge in between." Although purging can be an automated function, added into the stored process recipes, Cauthen cautions, "You have to have a way to get rid of the purged material, so this has issues with solvents and EPA [U.S. Environmental Protection Agency] compliance." *Disposable* static mixers have become very popular, according to Kirkco (Monroe, N.C.) president Scott Kirkpatrick. "You take the tube off and throw it away." In general, he notes, industry prefers solvent-free equipment, and adds that disposables are an inexpensive ($5 to $6) alternative.



Static-dynamic mixers — like this one supplied by both Kirkco and Ashby Cross — use a motor to rotate the mixing element in the plastic disposable mixhead, achieving high-shear efficiency and solventless mixing.

Source | Kirkco and Source | Ashby Cross

WHICH PUMP IS BEST?

MMD suppliers differ on the subject of what technology performs best. Many offer multiple types and tailor systems to customer's needs. Graco (Canton, Ohio), for example, uses piston pumps (see *b*, above) on its MMD equipment for composites. "A gear pump [*d*] has a limited operating range for providing a good flow rate," claims director of application development, Mac Larsen. "The flow rate usually varies with infusion and RTM, but if too slow, then pumping is inefficient. Here is where piston pumps are better, more suited to a wider range of injection rates and to maintaining constant pressure." Larsen claims piston pumps fare better with fillers or particulates, "Gear pumps become too challenging to maintain when using abrasive additives." But Mahr's Cauthen takes a different view: "Gear pumps have been around for 100 years," he maintains. "They offer very steady flow, are made to very tight tolerances using high tool steel and can typically handle temperatures up to 700°F/371°C. Piston pumps have seals and O-rings." Cauthen claims gear pumps offer a simpler, more compact design, with no O-rings or seals that wear, and thus, part replacement and maintenance are reduced. "Gear pumps are very reliable, with no pulsation versus piston pumps,"adds Gary Smith, Jr., vice president at GS Manufacturing (Costa Mesa, Calif.). Cauthen also points out that for filled resins, gear pumps can use different gear profiles and designs — for example, helical gears. "If you know that the customer will be processing filled material, you can design that into the system," he says, but

Eight Principles of Metering as defined by Sealant Equipment & Engineering. Most MMD equipment used in composites achieves metering via positive rod displacement (a), piston pumps (b and c), or gear pumps (d). Double acting piston pumps (c) are commonly referred two as "two-ball" piston pumps.

adds a caveat: "You're limited to 40 percent filler by volume most of the time." Smith adds, "We work with our gear pump suppliers to determine the correct specifications to accommodate fillers. More often than not, piston pumps have a hard time with heavily filled materials, too. The packings, a type of seal, will go out very quickly, which becomes a maintenance problem."

Piston pump proponents counter that for abrasion and wear from fillers, the answer could be a "ceramic pump," so called because it features ceramic-coated steel in place of bare metal for the piston and sleeve. The ceramic coating has a Mohs scale hardness of 9 — higher than silica, the raw material for most fillers. Accordingly, the pump surfaces exhibit significantly better abrasion resistance, but are also more expensive. Graco's Larsen notes, "There are other metal surface treatments that offer similar performance."

Nordson/Sealant Equipment & Engineering (Westlake, Ohio) prefers positive rod displacement (see diagram *a* on p. 20) for metering filled resins, claiming that it exhibits the least amount of friction and wear and the most accuracy in dispensed volume and mix ratio. Nordson marketing manager, David Mandeville says that in gear pump and piston pump systems "as soon as even a small amount of wear occurs, the mix ratio accuracy can suffer."

CLOSED MOLDING: FLOW VS. PRESSURE

When MMD is used in composites molding processes that involve resin injection or infusion, John Moore, president of JHM Technologies (Fenton, Mich.), points out that the MMD supplier must focus not only on the MMD componentry but also on the details of controlling the whole infusion/injection molding process: "Whether you use a gear or piston pump is not as important as maintaining the resin flow front through the volume of the mold." Moore and other suppliers say the accuracy with which the MMD equipment dispenses material depends on the ability to balance the *flow rate* and the *pressure* in the mold.

One way to achieve this balance is by using flowmeters. In the same way that a car's cruise control speeds up or slows down its motor to maintain overall vehicle speed, flowmeters are used to control the flow coming out of metering pumps. According to Hap Phillips, director of technical sales for Advanced Process Technology (APT, Middlesex, N.J.), "Even very accurate rotary gear metering pumps will slip when encountering back pressure as the mold fills with resin. Mass flowmeters sense the flow exiting each pump and, via the PLC, servo drive and rotary servo motor, increase the speed to overcome mold back pressure and push resin into the mold, or decrease the speed to prevent overpressuring of the mold. It does this for each of the components being mixed, continuously adjusting to keep the mix ratio intact."

Similarly, linear encoders measure the distance pistons or rods move — there can be up to 1,200 scale divisions per inch, providing very accurate output. The devices feed data back to the machine controller, which calculates how much material has been dispensed.

"With RTM," illustrates Graco's Larsen, "you want controlled flow, but also the ability to limit pressure. If you continue at a constant pressure toward the end of filling a mold, you can build up too much [pressure] and separate the tool." Larsen says that Graco HFR (hydraulic, fixed-ratio) systems are programmable for constant flow rate or constant pressure. Larsen explains that with HFR equipment, either flow or pressure can be the *primary control*, while the other is monitored and *kept below a critical limit*. For closed molding equipment supplier Magnum Venus Plastech (MVP, Clearwater, Fla.), however, the solution is its mold pressure guard, a feature incorporated into its INNOVATOR MMD machine. Designed for light resin transfer molding (LRTM) and vacuum-assisted RTM (VARTM), it features entirely pneumatic operation, with a control box and stroke counter. MVP's Jeff Austad, VP of sales and distribution, describes the guard's function: "At about 75 percent of the way to filling the mold, the injection pressure and the pressure at the resin flow front are very different. INNOVATOR uses a pneumatic sensor in the LRTM mold and/or vacuum bag to sense the inmold pressure and communicate back to the machine control to slow the pump, shutting the flow valve and stopping the pump, if required."

Most MMD suppliers, in fact, can design-in this type of emergency shut-off as well as alarms that indicate when pressure is too high or too low. All of this can be set as needed and settings can be stored in each process recipe.

Moore at JHM Technologies explains that the injection process also can be defined in discrete steps. For example, an initially high flow rate can be followed by three to four reductions. APTs Phil-

Aplicator System's MMD offerings include Ri2 equipment for infusion (left) and VIM5 for RTM (right), as well as IPP-8000 / T200 for wind blade adhesive application and P4 systems for automated preforming.

Company	Composite Applications	Model	Pump Type	Pump Driver	Comp. #	Resins	Fixed Ratio	Ratios	Ratio Control	Flow Volume	Flow Control	PSI Control	Cost
2KM	▸ Adhesives ▸ Resin infusion ▸ Tooling pastes ▸ Gel coat ▸ Degassing	**ResinMix**	Gear	Motor	2 to 3	Epoxy, PUR	Variable	1:1 to 100:1	Volume counters	1–60 L/min	Flowmeter	Inline and/or inmold sensors	$50,000 to $200,000
		Process GearMix	Gear		2 to 4	Epoxy, PUR			Volume counters	1 cc/min to 100 l/min			$20,000 to $100,000
		PolyMix	Gear & Screw		2	Epoxy, PUR			Volume counters	4-20 L/min standard			$100,000 to $300,000
Advanced Process Technology	▸ RTM/VARTM	**ECS Series**	Piston	Digital servo	2 to 4	Epoxy PUR Polyester Vinyl ester	Variable	1:1 to 100:1	Servo/PLC	up to 50 lb/min	—	Inline sensor	$50,000 to $600,000
		SRD Series	Gear	Indepen-dent servo				1:1 to 200:1			Flowmeter		
Aplicator AB	▸ Gel coat ▸ Robotic spray/ preforming ▸ Rollers ▸ RTM ▸ Spray up ▸ Vacuum molding	**RI-2**	Piston	Pneumatic	2 to 3	Polyester Vinyl ester	Variable	0.8:4	Mechanical linkage	up to 6 L/min	optional flowmeters	optional	—
		RI-15	Piston	Pneumatic	2			0.8:4		up to 6 L/min			
		IPR2-8000	Piston	Pneumatic	2			0.8:4		up to 12 L/min			
		VIM-5	—	Pneumatic	2	Epoxy, PUR Polyester Vinyl ester		0.8:4		up to 60 L/min			
		VRI-515	—	Pneumatic	2	Polyester Vinyl ester		0.8:4					
Ashby Cross	▸ RTM ▸ Vacuum molding	**2500 Series**	(DUAL ACTING) Piston	Pneumatic	2	Epoxy PUR	Fixed	1:1 to 20:1	Manual	1cc/min to 2000 cc/min	Linear encoder	Pneumatic/ electronic sensors	—
Graco	▸ Gel coat ▸ RTM and LRTM/infusion ▸ Spraychop ▸ Prepreg ▸ Robotic spray ▸ Precision flow	**Hydraulic Fixed Ratio (HFR)**	Piston	Servo Hydraulic	2	Epoxy PUR	Fixed	1:1 to 30:1	Mechanical linkage	3 cc/s up to 30 lb/min	Servo/flow meter	Electronic or manual	$8,000 to $100,000+
		VRM		Servo hydraulic			Variable	1:1 to 5:1	Flow meters	up to 66 lb/min	Flowmeter	Electronic or manual	
		PR70		Electric or Air			Variable	1:1 to 24:1	Mechanical linkage	up to 5 lb/min	Electric or air	Electronic or manual	
Graco/ Glascraft	▸ Gelcoat ▸ Chop ▸ Spray ▸ RTM	**FRP proportioners Spartan**	Piston	Air	2	Polyester Vinyl ester	Variable	0.5 to 3%	Mechanical linkage	Up to 2.5 g/min	Manual air	Manual air	
GS Manufacturing	▸ Adhesives ▸ Gel coat ▸ Polyester putty ▸ Robotic spray ▸ RTM/infusion ▸ Spray foam ▸ Spray/chop	**Gemini-ADH XDS-1000**	Gear/ piston	Pneumatic	2 to 4	Epoxy Polyester	Fixed or Variable	1:1 to 30:1	Gear	Up to 3 gpm	Flowmeters available	Manual	Priced for application, generally up to $40,000
JHM Technologies	▸ RTM/HP-RTM ▸ VARTM/LRTM/ infusion	**Infuser PRG**	(DUAL ACTING) Piston	Electro / Pneumatic	2 to 3	PUR, Epoxy Polyester Vinyl ester	Fixed or Variable	1:1 to 200:1	Slave Linkage/ Programmable	0.5 L/m to 12 L/m	Flowmeter or Linear encoder	In-line absolute sensor	$30,000 to $46,000
		Infuser SRV EPX	(SINGLE ACTING)	Digital Servo	1 to 2	Epoxy, PUR	Variable	1:1 to 200:1	Servo PID	5cc/m to 20 L/m	Encoder (PID)		$40,000 to $65,000
Kirkco (also Dopag and HUK distributor)	▸ Adhesives ▸ Gel coat ▸ RTM ▸ Robotic spray ▸ Tooling pastes ▸ Vacuum degassing ▸ VARTM/infusion	**COMPOMIX**	Gear	Indepen-dent servo	2 to 6	Epoxy PUR Polyesters	Variable	1:1 to 20:1	Volume counter	5 ml/min to 3 l/min	Flowmeter (Coriolis), mass flow-meter or linear en-coder, electric, pneumatic or manual, regu-lator, electronic closed-loop	Inline sensors, pneumatic electronic sensors, manual air	—
		ELDO-MIX	Gear or Piston	Indepen-dent servo	2 to 6	Epoxy, PUR Filled/Unfilled Polyesters	Variable	1:1 to 100:1	Volume counter or Mass flow-meter	5l / min to 60 l/min			
		VISCO-MIX	Piston	Hydraulic Pneumatic	2	Epoxy, PUR Filled/Unfilled Polyesters Polysulfide	Variable or Fixed	1:1 to 22:1	Mechanical linkage	2.5 l/min			
Magnum Venus Plastech (MVP)	▸ Gel coat ▸ Non-atomized spray systems ▸ Robotic spray ▸ RTM/infusion ▸ Spray/chop	**PATRIOT**	Piston	Pneumatic	2 or 3	Polyesters	Variable	1:1 to 100:1	Mechanical linkage	up to 60 lb/min	Pneumatic powerheads & hose dia.	Pneumatic sensors	—
		INNOVATOR				Polyesters Vinyl ester Epoxy							
		Universal Portioner			2	Epoxy Urethanes		1:1 to 20:1					
Mahr	▸ Adhesives ▸ RTM ▸ VARTM/ infusion ▸ Foam vacuum molding	**MAHRMAX**	Gear	Electric AC Motor	2	Epoxy, PUR Polyester Vinyl ester	Variable	1:1 to 300:1	FlowmeterPLC	2 ml/min to 36 l/min	Flowmeters	Adjustable Pressure Control	$10,000 +
		H.V. Drum											
		L.V. Drum											
		Multi-component Meter Mix											
Nordson/ Sealant Equipment	▸ Adhesives ▸ Robotic dispense ▸ RTM/infusion	**See-Flo 7**	Piston	Pneumatic	2	Epoxy PUR 1:1 Polyesters	Variable	1:1 to 20:1	Fulcrum	Continuous	Pneumatic	Manual air	$25,000 to $250,000
		Servo-Flo 704	Gear	Servo			Variable		Electronic	Continuous	Electronic	No	
		Servo-Flo 105	Rod	Servo			Variable		Electronic	up to 1400 cc	Electronic	No	
		Servo-Flo 505	Rod	Servo			Fixed		Linked Dual Rods	up to 154 cc	Electronic	No	
		See-Flo 690	Rod	Pneumatic			Fixed			up to 154 cc	Pneumatic/ hydraulic	Manual air	

CT polled MMD suppliers about the systems they offer. The data in the chart were provided by the suppliers. For more information, contact the individual supplier. For easy access to additional information about the companies in this chart and the ability to contact the suppler via e-mail, see their Showrooms at the online *SOURCEBOOK*, www.compositesworld.com/suppliers.

lips describes a similar capability with his company's SRD-series equipment. "You can begin at a continuous flow rate," he notes, "but then switch over to resin being drawn in with vacuum while maintaining the mold at a certain pressure, utilizing pressure transducers in the material lines. The machine will sense when the mold hits the operator-set threshold pressure and will automatically change pump speeds to control flow to maintain that pressure." He adds that the operator may want to vary that pressure if, for example, a mold features large, open sections and more closed, complex geometries. "The flow would be fast at first, but then slow as the mold cavity gets tighter," Phillips explains. He adds that on programmable MMD systems the operator can vary the pressure and also add that variation into the process recipe.

Moore cautions, however, that a thorough understanding of the process is required, recalling by way of illustration a mass-transit part made using LRTM and JHM's Infuser PRG equipment: Mold temperature was controlled through circulating heated water, and although resin temperature, flow rate, mix ratio and pressure were maintained by the MMD equipment, the pressure during processing began to rise 0.2 bar (2.2 psi) as mold fill neared completion. In this case, the final pressure increase was due to the resin cure kinetics, with the resin just starting to cure as the mold was about to vent. Adjustments were made to the programmed catalyst levels via the MMD equipment and later runs programmed for constant pressure increase in the same final stage of mold fill produced void-free parts with excellent finish on both A and B sides. "The project engineer was amazed at how the entire laminate was influenced by subtle changes in the flow," Moore recalls, noting that he also "would not have known what was causing the defects without the precise flow controls and feedback."

JHM goes one step further: A simple, low-cost RFID tag can be affixed to each mold. A scanner linked to the injection system reads the tags, enabling the system's program software to automatically call up the injection recipe. "The problem with having an operator set a stroke counter is that there are so many variables that can cause that setting to be incorrect, resulting in overfilled or underfilled molds and defective parts."

AUTOMATION IN PREPREGGING

Mark Cauthen at Mahr says that meter/mix *on demand* is new to prepregging, but growing quickly. When prepreggers apply a thin film of resin to a 54-inch to 60-inch (1.4m to 1.5m) wide web of continuous fabric, he points out, "the resin must be mixed and applied very accurately." Graco's Larsen cites increased automation in the aircraft industry as one driver for using MMD in prepregging lines. "Suppliers are also making prepreg for wind turbines, sporting goods and automotive, and want to eliminate batch processing," he adds. Mixing batches of resin requires using slow-reacting resins to allow for laying a film. With inline MMD, says Larsen, "prepreggers can go to faster-reacting resins." MMD equipment reportedly also cuts waste, ensures accuracy, reduces equipment size and boosts efficiency. "Traditionally, large equipment would have been required to melt solid resins and apply them," Larsen explains, "but now *we* can do it with a much smaller footprint. A draw pump with heated platens melts the material right out of the barrel, eliminating preheating and the need for a second machine and traditional two-stage process." Kirkpatrick points out that this technology is proven. "Kirkco has supplied MMD equipment into many applications which require precision-mixed material, dispensed in thin films — for example, manufacturing of Mylar balloons, airbags and food protection wraps. All of these have used metering and mixing inline for years."

FASTER AND CHEAPER ADHESIVES

As manufacturers move to adhesive bonding to reduce the labor and cost of fasteners, Smith at GS Manufacturing says MMD of methyl methacrylate (MMA) adhesives is a trend. MMAs are preferred because they reduce or eliminate the need for prebond surface preparation, which saves time and labor. Smith explains, "Sanding and grinding can be eliminated because the chemistry actually etches into composites ... to provide a mechanical bond."

To handle that aggressive chemistry, however, some MMD systems must feature stainless steel construction. Don Leone, marketing director for Ashby Cross (Newburyport, Mass.), says MMA adhesives can be dispensed in all Ashby Cross equipment, but they work better in piston machines and tend to dry out in MMD systems with gear pumps. Applications can range from gluing jets into fiberglass hot tubs to attaching a 40-ft/12m boat hull to its deck. "We actually sold two machines for this to one customer," he notes, explaining that because the material hardens quickly, it required *two* machines to lay ►

COMPONENTS AND CUSTOMIZATION

Although almost all MMD equipment suppliers offer standard models or a selection of proven components or modules, they also emphasize that every application is unique and, therefore, an MMD machine must be customized to meet the need. Suppliers begin with the following battery of questions. A system is then built to meet each unique combination of needs.

What is the **chemistry**: polyurethane, epoxy or polyester/vinyl ester?
What is the **process** (e.g., infusion/RTM, pultrusion, adhesive application)?
Will small or large **volumes** need to be dispensed and how quickly?
What is the mold volume and **cycle time**?
What **mix ratio** does the equipment demand: fixed or must the ratio be continuously adjusted for processing conditions?
Is the material **viscosity** high (e.g., 1 million cps) or low (<20,000 cps)?
Will it be **filled** (e.g., with chopped glass fibers or microspheres)?
How much **accuracy**, **control** and **automation** will be required?

Source | Ashby Cross

Mounted on a portable cart, this Ashby Cross 2500 Double Acting piston machine pumps MMA adhesive out of 5-gal supply pails. Its handheld dispense gun's 50-ft/15.2m hose allows operators flexibility in bonding sixteen 2-inch by 4-inch (51 mm by 102 mm) PVC channels (seen in background) to form each assembly. Then 896 assembly layers will be bonded to build the 15.6m by 15.6m by 60m long (51.2 ft by 51.2 ft by 197 ft) NOvA far detector. The MMD control console has alarms for low level in each supply pail as well as shot-volume control via linear encoder.

a 1-inch [25-mm] bead all the way around the hull and deck perimeter in time to mate the surfaces before the adhesive began to gel.

GS Manufacturing's Smith adds that this is why machines dispensing MMA adhesives must have a high output. "We design machines that allow an operator to lay in widths of 1.5 inches [38 mm] and higher very quickly; for example, 2 lb/min [0.9 kg/min] for Plexus [supplied by ITW Plexus, Danvers, Mass.] at a 10:1 mix ratio."

One of the biggest MMD applications is the bonding of wind blade halves. Windsys Solutions (Acworth, Ga.), a distributor for DEKUMED (Bernau, Germany), has developed expertise in MMD equipment for bonding blades, delivering viscous pastes loaded with chopped glass fiber at extremely high output rates. Meanwhile, 2KM has responded to the larger blades for offshore turbines with its PolyMix 2000, a machine that is 2m/7 ft taller with a 5m/16-ft extension that can provide flow of 18 to 20 kg/min (44 lb/min) while maintaining precision in the mix ratio.

Another "big" factor is that adhesives are expensive, prompting companies to seek cost savings by buying in bulk. MMD machines offer the ability to move away from pre-mixed cartridges, accurately mixing and dispensing bulk materials. An illustrative case history is Airbus' Stade (Germany) facility's use of DOPAG's VOLU-MIX equipment to apply polysulphide-based materials for sealing joints in the internal structure of the A380 composite vertical stabilizer, to prevent moisture ingress that might compromise the lightning protection system. VOLU-MIX equipment helped to achieve a 70 percent cost reduction by accommodating 30-liter/8-gal drums, which allowed Airbus to discontinue the use of expensive pre-packaged cartridges. The system's on-demand operation also eliminated waste in mixed material. "We see this fairly often," says GS Manufacturing's Smith. "Our customers call us when they get to where they are using enough adhesive to make buying one of our machines cost-effective."

"We also have machines that are used to refill the adhesive cartridges," Smith adds, noting that even in a volume-production environment, there are applications where cartridges work better, such as in small, hard-to-access areas. Indeed, similar systems from a variety of manufacturers are used in-house by most MMA suppliers, including Lord Corp. (Cary, N.C.), SCIGRIP Smarter Adhesive Solutions (Durham, N.C.) and Henkel Corp. (Rocky Hill, Conn.).

Cauthen says another recent trend in adhesives application is to mix powders with liquids on demand. He details, "Normally, you would do this in a bulk mix because the chemistries are very expensive and you want the cheapest price possible. But now they want to add fillers like glass beads inline vs. batch bulk processing, so we have developed equipment to do this."

HEATING AND VACUUM DEGASSING

MMD suppliers assert that the increased use of carbon fiber in closed molding has increased the use of high-performance resins. Graco's Larsen says this means that MMD systems must also be capable of "appropriate resin conditioning, such as heat and degassing." Windsys Solutions LLC president Dieter Wingel says that heating is a key MMD parameter because, for epoxy and polyurethane, viscosities are temperature-dependent. He also points out that, as the viscosity changes, it changes the internal pressure throughout the setup. "So you want to keep the material at a constant temperature," he says. "This becomes especially critical if you don't use flowmeters and rely on what you theoretically put through the pumps."

Austad at MVP explains, "If we can control the environment and maintain temperature from the start" — in the tote or drum, for example — "then the parts are more consistent."

Cauthen says that heated systems help to stabilize the processing environment, especially in unheated plants where cold winter temperatures can increase resin viscosity and alter its reactivity. To achieve this, Mahr offers electrically heated vessels, valves, fittings, lines and hoses.

Mandeveille says Sealant Equipment & Engineering offers thermal-electric *and* water-based heating technologies, both of which can heat and cool. Water heating systems, he says, show better wear resistance than electrical heating for automated systems where robotic operation causes a lot of hose movement. Cost is also a factor.

APT's Phillips comments, "Every inch of fluid in the system has to be controlled if you are doing it right." APT, therefore, uses independently controlled ceramic-enclosed infrared (IR) heaters for each resin component's compartment so that a separate temperature can be maintained for each.

Leone at Ashby Cross adds that multiple, independently controlled zones allow the user to keep temperatures relatively low in the bulk tanks, and then ramp them up as the resin moves toward the mold so that only the injected resin reaches the target temperature. "If you heat a 50-gal drum to the full temperature, but only use half of that material, then you are not only wasting energy," he says, "but also degrading the bulk resin and hardener over time, with repeated heating to the higher temperature."

Degassing is often necessary, especially in polymer casting and RTM, to prevent air bubbles and moisture uptake. "A resin with air in it is like a sponge for water," says Graco's Larsen. "If you don't *pre*-degas, you will degas *as the resin enters and flows through the dry laminate stack*. Vacuum degassing eliminates porosity, especially with fast cycle times." He admits that this function adds complexity to MMD equipment *and* isn't always necessary: "There is a lot of infusion being done without degassing," he allows, but insists that "where parts are thinner and more lightweight, the elimination of air voids becomes more critical, and parts manufacturers are looking to the MMD equipment to help." Gary Bauer at 2KM North America (2KMNA, Parry Sound, Ontario, Canada) sees demand growing for degassing "as companies refine resin infusion processing and work on more of the details."

As wind blades get larger, especially for offshore wind turbines, Bauer believes that larger equipment will be needed to handle the increased mold volumes. Wingel at Windsys Solutions LLC argues that it is not really possible to degas inline with wind blades or boat hulls and other big parts, because the very high resin throughput required by those processes does not allow the time needed to achieve full degassing. However, for applications with slower flow rates — such as medical devices and electronics — degassing is easily achieved in onboard tanks. Wingel concedes that very large tanks can offer hours of continuous flow, but warns that the rate of degassing is affected by many factors, including viscosity. "For some applications, degassing could be achieved with a flow rate of 20 liters/hr [5 gal/hr], where in others it might need to be 5 liters/hr [1 gal/hr]."

That said, 2KM worked successfully with a customer to replace a traditional "infusion vessel," which heated and batch-degassed the resin, to inline vacuum degassing and heating at flow rates from 1 to 60 liters/min (0.3 to 16 gal/min). Its ResinMix equipment feeds resin directly from a drum to a flow-through heater to reduce viscosity, then breaks the stream into small droplets in an evacuated chamber to remove the air and, finally, supplies degassed resin to the metering system. Most companies that do infusion only degas the resin component, but some in Europe now degas the hardener as well.

NO GOING BACK

MMD suppliers say the need for control can only increase in the future. "As the industry has matured, molders are beginning to realize that it takes far more precision than earlier thought to gain the needed control over quality and material cost," says JHM Technologies' Moore.

"Our goal has always been to emulate the 'rhythm' and minimal operator requirements of thermoplastic injection molding," Moore contends. But Clas-Åke Johansson, VP marketing for Aplicator Systems AB (Mölnlycke, Sweden), points out that although electronics and PLC control *have* increased MMD efficiency, "composites production is still too slow to compete with … injection molding." Aplicator System's MMD offerings include Ri2 equipment for infusion (left) and VIM5 for RTM (right), as well as IPP-8000 / T200 for wind blade adhesive application and P4 systems for automated preforming.

Most suppliers, however, anticipate additional challenges and opportunities as new composite materials and end uses come into view. On the material front, Mahr's Cauthen sees a trend toward nanoparticle and nanofiber additives. As these materials are added to production resins, molders will demand new types of MMD equipment to prevent, for example, the entanglement of nanofibers during mixing. Leone of Ashby Cross believes that, among new markets, civil engineering will be huge for composites. "Just the sheer size of the surfaces will place new demands on MMD equipment," he contends, noting that Ashby Cross supplied such an MMD system (see photo, p. 24) for use in the assembly of the massive "far detector module," a massive 15.6m tall, 15.6m wide and 60m deep (51-ft by 51-ft by 197 ft) structure in Ash River, Minn., designed to help scientists detect neutrinos in the NOvA neutrino detector project (www-nova.fnal.gov/nova_experiment_print.html).

"The trend I see is that many companies are getting very sophisticated and specific in what they need," APT's Phillips sums up, "and it is up to us to come as close as possible to giving them everything on their wish list." | CT |

IN-LINE STATIC MIXERS

Source | Charles Ross & Son Co.

Interfacial Surface Generator (ISG) static mixers from Charles Ross & Son Co. (Hauppauge, N.Y.) can be quickly installed in existing meter/mix/dispense (MMD) equipment piping at low cost. Four holes bored through each element split the resin into layers, recombine it, then split it again. The ends of the elements are shaped so that adjacent elements form a tetrahedral chamber. Two input streams entering an ISG static mixer are split into more than two million layers in just 10 elements. Available in stainless steel, polypropylene and Teflon, ISG elements reportedly are well-proven for thorough mixing of high viscosity ratios (up to 250,000:1) in a very short length of pipe, and the elements can be removed for individual cleaning.

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Fossil & Mineral Resources

COMPOSITES EXPAND

Source | Airborne Oil & Gas BV

Saipem SA (Milan, Italy) recently completed a four-month precommissioning process for a pipeline in the Guara & Lula NE gas line project in Brazil, using this 3-inch/72.6-mm (internal diameter) spoolable thermoplastic composite downline from Airborne Oil & Gas BV (Ijmuiden, The Netherlands). The downline reached a water depth of 2,130m/6,988 ft — a record for a fully composite pipe.

Attention-grabbing applications in these challenging, corrosive environments are positioning fiber-reinforced polymers for continued growth.

The easy stuff is already found.

In the world of fossil and mineral resources, that's been a truism for a generation. Year by year, new oil and gas fields and mineral deposits are increasingly scarce and, therefore, more difficult to locate. Sometimes, these new resources are entirely inaccessible with conventional equipment and techniques.

In the face of that reality, composites are earning respect. Increasingly recognized for their suitability in, and tailorability to, specific and demanding requirements in tough oil and gas industry and mineral mining operations, composites continue to displace metals.

The result? Currently, the oil and gas industry is experiencing one of its longer sustained booms. It's largely due to new extraction technologies and expansion into unconventional spaces: drilling for oil and gas in ultradeep seawater, hydraulic fracturing, or *fracking* (for definitions of this and other fossil/mineral-industry terminology, see the glossary on p. 28) to recover hydrocarbons and methane, and horizontal drilling technology. These methods aid more efficient well development and aid subsequent extraction of gas in oil deposits.

Unconventional extraction methods require a variety of technologies that include high-performance fiber-reinforced polymers (FRPs). "In addition, the traditional North Sea, shallow coast Africa and Gulf of Mexico oil and gas sectors have an especially heightened focus on safety, redundancy and system qualifications," says Michael Ruby, global composites business manager, engineered materials, Celanese Corp. (Florence, Ky.). "This is also driving a need for lighter weight, higher strength, corrosion-resistant and chemical-resistant materials like composites." So far, the most significant advances have been in piping infrastructure and fluid-handling systems, but there also is notable progress in structural applications.

Much like oil and gas, the mining industry also demands much from its materials. And composites are most advantageous in a very specific subsegment of the industry. "We're looking primarily at *mineral processing*," explains Thom Johnson, corrosion industry manager at Ashland Performance Materials (Dublin, Ohio). "We're not interested in coal, gravel and iron ore, but rather elements like nickel, cobalt, zinc and uranium that are extracted using corrosive leaching agents like sulfuric acid." A highlight for composites is the mining of rare-earth materials. "These operations are unusual because they employ aggressive media to separate the materials from the ore, as well as additional operations to separate the recovered elements from one another," explains Johnson. "The process demands a more complex system design that can benefit from composites."

Unlike the booming oil-and-gas segment, the mining industry's mineral-processing sector looks less attractive for composites than it has in the past decade. "To forecast the mining industry, we have to look at the end-market," explains Johnson. "Nickel mining, for instance, is primarily driven by the stainless steel market and, currently, there is an overabundance of stainless steel flooding the market and driving down prices." Copper mining is in a little better position but is tied, he says, to the global gross domestic product and infrastructure development in underdeveloped nations.

"There will likely be a lull for two or three years, and then capacities will increase again," Johnson predicts, "although, probably not near the boom time it has been over the past five years." That said, the long-term prospects hold much promise.

OFFSHORE OIL: DEEPER THAN EVER

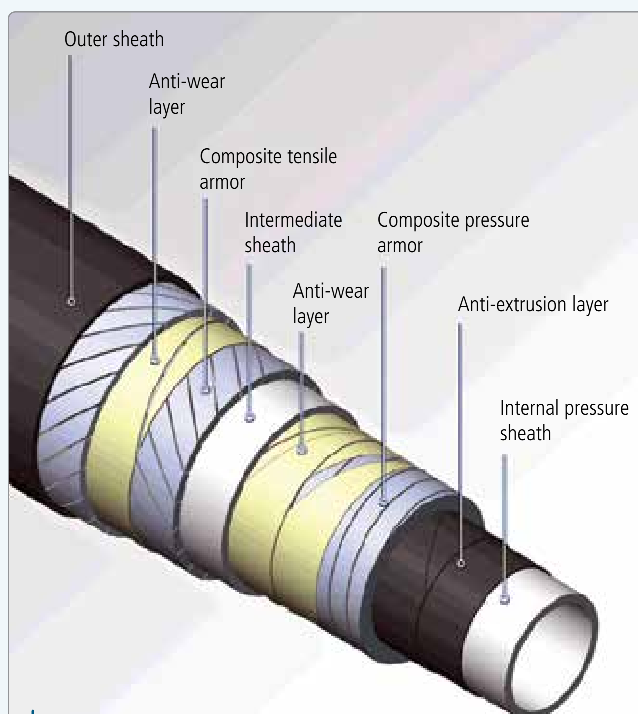
One area where composite solutions are enabling applications is in *ultra*deep oil and gas extraction. "Established, conventional technology that works well for traditional extraction becomes technically complex and capitally intensive in the ultradeep sector," says Ruby, in reference to depths greater than 1,500m/5,000 ft. "Top tensioning and flotation systems, installation expenses and deployment time, and longevity of asset life are all areas where high-performance composites can outperform traditional technologies in riser, jumper, intervention line, cabling and umbilical applications. Substantial progress in each of these areas is being made in terms of solution development and qualification."

"High-performance, high-strength reinforced systems deliver better longevity, better resistance to tough environments, better fatigue resistance, and reduce complexity and capital intensity of the aggregate system," he adds.

Source | Airborne Oil & Gas BV

In contrast to conventional flexible pipe, Airborne Oil & Gas BV's (Ijmuiden, The Netherlands) thermoplastic composite pipe has a solid-wall construction that features a single polymer material reinforced with embedded (melt-fused) fiber reinforcements. Shown here is the liner-laminate interface.

Airborne Oil & Gas BV (Ijmuiden, The Netherlands) manufactures flexible (spoolable), fully bonded thermoplastic composite pipe (TCP). The company started building customer confidence by providing piping for less complicated applications, such as composite coiled tubing as an alternative to steel coiled tubing. Then, Airborne attacked applications with increasingly greater complexity, to "gradually gain trust and confidence in the technology through



Source | DeepFlex

DeepFlex (Houston, Texas) has developed a lighter-weight, fully composite, flexible fiber-reinforced pipe (shown here) and a hybrid steel/composite version. Both are designed for deepwater (currently, as deep as 1,500m/4,921 ft).

operational experience in the field," explains Bart Steuten, Airborne's business development manager.

The ultimate prize is the composite riser system. "In the application of ultradeep water risers, all of the advantages of TCP come together," explains Steuten. "Yet, at the same time, out of all the pipeline applications, deepwater risers are the most demanding in terms of complexity and durability, he adds. "A thorough understanding and appreciation of the technology is required by not only the manufacturer but also the end-user."

Moving beyond composite coiled tubing, Airborne targeted the downline. "In deep water, the light weight and high-tension capability of TCP result in a fast deployment — without the need for buoyancy elements to reduce weight — and low top tensions," explains Steuten. Saipem SA (Milan, Italy), for example, recently completed the precommissioning process for two pipelines in the Guara & Lula NE gas line project in Brazil, using a flexible 3-inch/72.6-mm inside-diameter (ID) TCP downline from Airborne. Deployed more than 30 times, the downline reached a depth of 2,130m/6,988 ft — a record for a fully composite pipe — and reportedly reduced top tension by 90 percent compared to a steel-reinforced flexible tubular. The lighter TCP construction enabled downline operations from a smaller construction-support vessel than otherwise would have been possible. In addition, the TCP downline was deployed to the seabed in less than 2.5 hours. Conventional flexibles, which require the deployment of additional buoyancy support, would typically require 12 hours or more for a similar deployment, reports Steuten.

Airborne is currently qualifying TCP for well-access and well-intervention services, such as methanol and chemical injection, choke and kill, and plug and abandonment. These temporary services, executed on all drilling rigs and service vessels, benefit from the rapid deployment enabled by spoolable pipe. Moreover, the TCP spools require less shipboard deck space than spooled conventional, steel-reinforced flexible pipe.

Also, the company is conducting a two-year qualification program for the use of TCP in an offshore production flowline for Kuala Lumpur, Malaysia-based mineral producer Petronas. "The project was commissioned by Petronas to mitigate corrosion during operation," explains Steuten. Anaerobic sulfate-reducing bacteria (SRBs), which produce hydrogen and cause sulfide stress cracking, thrive in the waters and seabed soils of the South China Sea. The composite solution, designed to replace carbon steel, consists of Vestamid NRG, a glass-reinforced polyamide (PA) 12, supplied by Evonik (Marl, Germany). The 6-inch/152.4-mm ID TCP flowline has a working pressure that ranges from 100 to 375 bar (10 to 37.5 MPa/1,450 to 5,440 psi). Petronas is studying the TCP's long-term integrity, in terms of aging and creep, and is testing an integrated, optical-fiber-based structural health-monitoring system. The program will be completed in mid-2014.

Steuten discussed the company's composite pipe at the Rio Pipeline Conference and Exposition (Sept. 24-26, 2013, in Rio de Janeiro, Brazil), explaining that unlike conventional flexible pipe design, TCP has a solid wall construction. The pipe wall consists of a neat resin inner liner and outer jacket that encase fiber-reinforced thermoplastic layers, all of which are constructed of the same thermoplastic polymer and then fused together to form a solid, fully bonded laminate. Reportedly, this design eliminates risks associated with unbonded pipes, such as rapid gas decompression or cover blow-off. Currently, Airborne's TCP is produced from polyethylene, polypropylene or polyamide resin. "Using thermoplastic matrix material rather than a thermoset — epoxy-based — material results in a more ductile structure, yielding superior toughness and impact resistance," explains Steuten.

Polyvinylidene difluoride (PVDF) pipe systems are currently under development for applications at higher temperature. The reinforcement is based on the demands of the application. At relatively low pressures, E-glass fiber offers the best commercial value, Steuten explains, but structural high-strength-glass (S-glass) is best for ►

FOSSIL AND MINERAL INDUSTRIES: A SHORT GLOSSARY

For those who encounter unfamiliar terms in this article, HPC *compiled the following definitions:*

Carcass profile: The carcass prevents collapse of the pipe liner as a result of gas expansion or hydrostatic pressure.

Choke and kill: Pipelines used to reduce or stop pressure from the well as part of a deepwater blowout-preventer system.

Counter-current decantation vessels: A series of settling vessels in which solids can be treated continuously and diluted.

Downlines: Used to convey nonhazardous fluids (i.e., water, air, nitrogen) to the seabed for temporary applications, such as pipeline commissioning/precommissioning and/or servicing or seabed excavation.

Electrowinning: The electrodeposition of metals from their ores.

Flowlines: Pipelines.

Fracking: Slang for hydraulic fracturing, in which fluid is injected into cracks to create fractures in rocks and rock formations that allow greater access to gas in shale formations.

Hydrometallurgy: Any method for obtaining metals from a solution (liquid).

Intervention or work-over: any operation carried out on an oil or gas well during or at the end of its production life.

Jumpers: Pipes that carry fluids from each subsea *tree* (well) to the manifold; also can connect manifolds and riser bases to flowlines.

Launder: A trough for holding or conveying water used to wash ore.

Plug and abandonment: Interrupting the pressure from the well and then plugging the wellhead.

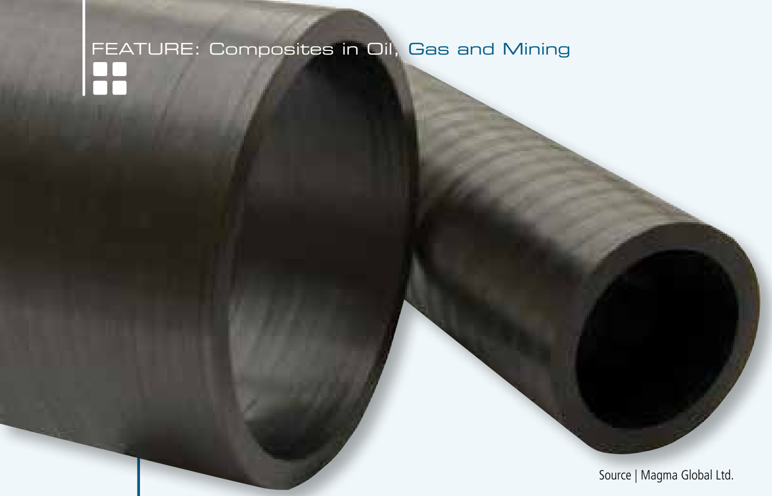
Rare-earth element: Any group of chemically similar metallic elements. Although not especially rare, they tend to occur together in nature and are difficult to separate from one another.

Riser: Rigid or flexible conduit used to transfer materials (i.e., hydrocarbons, injection fluids, control fluids, etc.) from the seafloor to surface production and drilling facilities.

Subsea tree: A tree-shaped device (hence, the name) attached to a subsea wellhead. It monitors/controls the operation of a subsea well.

Sour service: Describes the function of pipelines that handle fluids or gases that contain hydrogen sulfide.

Top tension: The tension required to stabilize a riser system. On offshore drilling vessels or platforms, riser tensioners are complex hydro-pneumatic systems that, simply put, pull up on the riser string. The heavier the riser string, the greater is the top tension required to support it.



Source | Magma Global Ltd.

Trademarked m-pipe from Magma Global Ltd. (Portsmouth, U.K.) is a flexible, bonded composite pipe manufactured from Toray Industries' (Tokyo, Japan) T700 carbon fiber and polyetheretherketone (PEEK) resin supplied by Victrex Polymer Solutions (Cleveleys, Lancashire, U.K.). It is designed for ultradeep risers, jumpers and flowlines.

high-pressure applications where spoolability is key. For applications that require maximum strength-to-weight ratio and stiffness, carbon fiber is used. Fiber angles can be varied for each layer to optimize design. Flowlines, for example, demand optimized flexibility, internal pressure containment and external pressure capabilities, but a relatively low tensile strength. By contrast, composite risers, downlines and coiled tubing require optimized tension and pressure containment, both internal and external. The pipes are manufactured in a continuous length, limited only by the size of the carousels that can be handled in the factory and during transport.

Magma Global Ltd. (Portsmouth, U.K.) also offers flexible monolithic composite pipe. Constructed of carbon fiber-reinforced polymer (CFRP), Magma's trademarked m-pipe was developed for use in ultradeep risers, jumpers and flowlines. Magma uses a proprietary process to produce m-pipe from T700 carbon fiber (Toray Industries, Tokyo, Japan) and polyetheretherketone (PEEK) resin from Victrex Polymer Solutions (Cleveleys, Lancashire, U.K.). The pipe is available with IDs that range from 2 inches to 24 inches (51 mm to 610 mm). Recently, Magma introduced s-pipe, which offers the fundamental qualities of m-pipe in smaller diameters (up to 3 inches/76.2 mm) in versions rated up to 20,000 psi (about 138 MPa). Designed for intervention and work-over applications that require ultrahigh pressure, high temperatures, sour service and fatigue resistance, s-pipe features Victrex PEEK reinforced with a combination of high-strain fibers.

Houston, Texas-based DeepFlex has had flexible composite pipe in service for several years in applications that include downlines for pipeline commissioning in water depths to 1,500m/4,921 ft. However, it has taken a different approach, replacing the steel armor layers in *unbonded* flexible pipe with layers of FRP. DeepFlex has developed a fully composite, flexible, fiber-reinforced pipe (trademarked FFRP) and a hybrid version (trademarked FHRP). Both are intended for ultradeep seawater applications. In the FFRP design, an internal liner of extruded polymer is chemically resistant to hydrocarbon fluids. Pultruded fiber-reinforced tapes are bonded together to form reinforcement stacks that provide hoop and tensile reinforcement in various layers within the pipe. The hoop layer provides resistance to internal and external pressures, while layers of unidirectional fibrous tapes (with fiber orientation in at least two directions) surround the polymer membrane in the middle of the pipe wall to provide tensile strength. An outer jacket provides abrasion resistance. Notably, the layers are discrete, allowing them to move independently from one another to maximize pipe flexibility. FFRP reportedly offers a 50 percent reduction in weight compared to unbonded steel-reinforced flexible pipe.

DeepFlex is developing, qualifying and will deploy an FHRP riser solution for service in the Gulf of Mexico, with sponsorship from lead operator TOTAL (Paris, France), Shell (Houston), Statoil (Stavanger, Norway), BG Group (Reading, Berkshire, U.K.) and the Research Partnership to Secure Energy for America (RPSEA, Sugar Land, Texas). The FHRP combines composite armor layers with a stainless steel carcass profile and steel-interlocked primary pressure reinforcement layers (see illustration, p. 27). The riser solution designed for qualification has a 7-inch/178-mm ID, a 10,000-psi design pressure, and is rated for 120°C/248°F and a water depth of 3,000m/9,843 ft. A prototype pipe will be put through qualification testing, after which a riser system will be fielded for six months of performance monitoring. Reportedly, the FHRP design provides a 30 percent reduction in top tension, which enables use in water as deep as 3,000m, from lighter-weight installation vessels with smaller footprints and production platforms, which were previously limited to depths of 1,500m/4,921 ft.

ONSHORE: FLUID MANAGEMENT

Although the environments are different, the material requirements are surprisingly similar in onshore efforts to find oil and gas. Distribution and transmission systems for natural gas are reportedly moving toward reinforced thermoplastics because they can be installed with greater speed and offer the ability to more easily install longer pipe networks, enabling suppliers to move the gas from the point of extraction to the point of use.

There are also downhole applications that can benefit from composites. Ruby points, by way of example, to well-bore casing pipe, bearings, couplings and fittings, downhole tooling cables and sucker rods.

Hydraulic fracturing, which requires the management of millions of gallons of water per frack and the outflow and treatment of that water, is also creating opportunities for hub-and-spoke water management and filtration systems, says Celanese Corp.'s Ruby. "Composites are well suited to deal both with influent/feed water, as well as flowback — what's coming back up out of the ground," he adds.

FRP significantly reduces pipe weight. A 30-ft/9.1m length of commonly used 12-inch/304.8-mm high-density polyethylene (HDPE) SDR 9 pipe, for example, weighs 655 lb/297 kg. But trademarked Fiberflex-11 glass fiber-reinforced HDPE pipe of the same length, from Composite Fluid Transfer LLC (Kilgore, Texas), weighs only 128 lb/58 kg. At 4.26 lb/ft, Fiberflex-11 is reportedly lighter than all other composite and plastic pipes with comparable diameters and pressure ratings. Designed for general water-transport infrastructure applications, the pipe can be used in distribution systems, oil and gas operations and hydraulic fracturing feed-water and produced-water transportation. The 10.5-inch/267-mm ID, 11.1-inch/282-mm outer diameter (OD), pipe has a 250-psi/1.72-MPa operating pressure (500-psi/3.45-MPa burst pressure).

Source | Celanese Corp.

Trademarked Fiberflex-11 composite pipe from Composite Fluid Transfer LLC (Kilgore, Texas) is designed for general water-transport infrastructure applications, including distribution systems, oil and gas operations, and hydraulic fracturing feedwater and produced-water transportation.

Glass fiber-reinforced HDPE tape (Celstran CFR-TP from Celanese) is wound around a specially designed, extruded HDPE liner and then heat-fused, using a proprietary process developed by Composite Fluid Transfer. An outside layer of HDPE film, manufactured by Valèron Strength Films (Chicago, Ill.), is added to protect the system from ultraviolet damage and abrasion. The pipe is flexible enough to allow for a 90° bend over a 60-ft/18.9m span of pipe.

In Jacksboro, Texas, FiberFlex-11 pipe was installed to connect a rig site to a water source 1.8 miles/2.9 km away. Specially designed quick-connect fittings reportedly enabled 30-ft/9.1m joint installation in less than 20 seconds. The connections are reportedly leak-free and need no structural support. The piping supplies 73 barrels per minute with one standard 8- by 10-inch (203- by 254-mm) Cornell water-transfer pump, despite an elevation increase of more than 95 ft/29m.

FiberFlex-11 was a finalist in three regions during the 2013 Oil & Gas Awards, and Composite Fluid Transfer was Manufacturer of the Year in the Western U.S. region. The company also picked up a JEC Innovation Award Oct. 2, at JEC Americas 2013 in Boston, Mass, in the Pipes & Water Management category.

Source | Vale

Vale's Long Harbour (Newfoundland, Canada) processing plant is expected to process 50,000 metric tonnes/yr (more than 110.2 million lb/yr) of nickel ore, using more than 4,536 metric tonnes (10 million lb) of FRP equipment and infrastructure.

MINING: SHINING A LIGHT ON COMPOSITES

Although the growth of composites in mineral processing has declined after reaching a peak over more than 10 years, Ashland's Johnson insists it's a positive time. "I would consider composites to be a relatively *new* technology in mining," he explains. "Even though we've had a large number of successes and have been in the market for more than 40 years, if you look at the market *share*, composite material is still a very small player — maybe 1 percent or less of the overall market. In the mineral and rare-earth metal markets, FRP accounts for less than 10 percent, probably closer to 5 percent."

There is, therefore, plenty of room for growth. "FRP is emerging as a standout," Johnson contends. "Composites fit very well in corrosive mining operations, and mine owners and engineering firms are becoming more knowledgeable about FRP, especially in light of recent success stories."

For one, FRP has infiltrated recent hydrometallurgy installations in North America. In the past five years, three large hydrometallurgy plants have been built in North America — Vale's Long Harbour (Newfoundland, Canada) complex, which is processing nickel, cobalt and copper ores from the Voisey's Bay mine; Vancouver, B.C.-based Baja Mining Corp.'s El Boleo copper, cobalt, zinc and manganese mineral processing plant in Baja California Sur, Mexico; and Greenwood Village, Colo.-based Molycorp's Mountain Pass Rare Earth processing plant in California. All three plants feature FRP-based mineral processing equipment and infrastructure. Hundreds of storage tanks, extraction vessels and electrowinning cells, and miles of acid- and abrasion-resistant piping were fabricated, primarily from epoxy vinyl ester resin and corrosion-resistant glass fiber, such as E-CR glass. "The operating conditions associated with mineral processing often require materials that can withstand process acids and acid chlorides at temperatures up to 90°C/194°F," says Johnson, who discussed the projects at the Materials Science & Technology 2013 conference in Montreal, Quebec, Canada in October 2013.

When it starts up in 2014, Vale's Long Harbour plant is expected to process 50,000 metric tonnes/yr (110.2 million lb/yr) of nickel ore, extracting the nickel via a proprietary process that relies on hydrochloric acid at elevated temperatures. The plant will house more than 4,536 metric tonnes (10 million lb) of FRP infrastructure, such as acid- and abrasion-resistant piping, ducting and exhaust fans.

Plasticon Canada (Les Cèdres, Quèbec, Canada), one of several fabricators selected to support the project, delivered a wide array of FRP equipment, including 64 cylindrical and six rectangular tanks. The company also supplied scrubbers, demisters, stacks and clarifier circular covers, all fabricated from glass fiber/epoxy vinyl ester. An additional 64 filament-wound FRP storage vessels were sourced from members Ershigs (Bellingham, Wash.), Fabricated Plastics (Maple, Ontario, Canada) and Belco (Belton, Texas). A number of vessels had diameters up to 13.4m/44 ft and heights of 15.7m/51 ft.

"Initially, Vale was unconvinced that such large vessels could be made from FRP," Johnson recalls. In the end, however, Ershigs was able to point to larger FRP structures currently in service at flue gas desulfurization projects in the power industry to prove their feasibility.

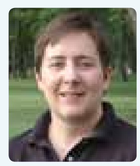
In Mexico, when the Boleo plant comes online, it's expected to produce as much as 349,000 metric tonnes (769.4 million lb) of copper, cobalt, zinc and manganese carbonate annually. The six 60m/200-ft-diameter counter-current decantation (CCD) vessels have a concrete base and a thick glass fiber/epoxy vinyl ester liner fabricated by Fiber-Tech Industries (Spokane Valley, Wash.) to protect against acid and abrasion. Nearly 200 FRP launders, manufactured by Structural Composite Technologies (Transcona, Manitoba, Canada), complete the CCD system.

RPS Composites supplied the facility's acid-/abrasion-resistant piping. Plàsticos Industriales de Tampico (PITSA, Tamaulipas, Mexico) is fabricating more than 500 metric tonnes (1.1 million lb) of FRP piping (conductive and nonconductive) and accessories for organic flow service. The conductive piping features a carbon fiber veil and brominated epoxy novalac vinyl ester matrix, with 5 percent antimony added to meet fire retardant requirements.

FRP GROWTH: SLOW BUT STEADY

As in other industries, replacement of traditional materials (in this case, metal alloys and unreinforced plastics) is following a historically gradual pattern. "In the oil and gas industry, it is through years of qualification and infield testing that a material becomes widely characterized and trusted," Ruby sums up. "In many cases, composite materials are being built using matrix resins that have been proven in the industry in unreinforced forms," he points out. "Currently, the areas where composite materials are commercial or near-commercial are those areas where the environmental conditions demand a high-performance composite, or where regulatory circumstances or technological advances help drive the application requirements and, therefore, adoption." But Ruby believes that as the promise of composites comes to fruition in on- and offshore installations, field personnel will force engineers to consider FRP. "That will feed on itself, eventually reaching a natural tipping point."

Even more tradition-bound, the mining industry has yet to embrace composites, but mineral processors in search of corrosion-resistant equipment, especially in the acidic environments of the rare-earth segment, now have lightweight composite alternatives with long service lives, installed in prominent processing plants. For proponents of composites, the rest is just a matter of time. | CT |



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Chevrolet's *Corvette* has included transverse composite leaf springs, manufactured by Liteflex (Englewood, Colo.), since 1981. In the 2014 *Corvette Coupe*, the leaf spring is always loaded against the subframe, and shock loads are directed into the side of the frame. In 2014 models with standard suspension packages, the leaf spring has eliminated the need for a standalone rear antiroll bar.

Composite leaf springs:

SAVING WEIGHT IN PRODUCTION SUSPENSION SYSTEMS

Source | General Motors

Fast-reacting resins and speedier processes are making economical volume manufacturing possible.

Composite leaf springs are not new to the automotive industry. In fact, the leaf spring itself dates back to the horse-drawn carriage. By design, leaf springs absorb vertical vibrations caused by irregularities in the road. Variations in the spring deflection allow potential energy to be stored as strain energy and then released more gradually over time. Composites are well suited for leaf-spring applications due to their high strength-to-weight ratio, fatigue resistance and natural frequency. Internal damping in the composite material leads to better vibration energy absorption within the material, resulting in reduced transmission of vibration noise to neighboring structures.

The biggest benefit, however, is mass reduction: Composite leaf springs are up to *five times* more durable than a steel spring, so when General Motors (GM, Detroit, Mich.) switched to a glass-reinforced epoxy composite transverse leaf spring (supplied by Liteflex LLC, Englewood, Colo.) on the 1981 *Chevrolet Corvette C4*, a mono-leaf composite spring, weighing 8 lb/3.7 kg, replaced a ten-leaf steel system that weighed 41 lb/18.6 kg. This reportedly enabled GM to shave 15 kg/33 lb of unsprung weight from the *Corvette*, yet maintain the same spring rates. The leaf spring was transverse-mounted; that is, it ran across the car's width at each axle. This eliminated the coil springs that sit up high in a spring pocket on the frame. Thus, the car can sit lower to the ground, which improves car handling.

Today, GM continues to employ transverse GFRP composite leaf springs on the front and back of its *Corvette* models. The 2014 Chevrolet *Corvette Coupe* includes a double-wishbone suspension, which, at GM, goes by the name short/long arm (SLA). SLA refers to the fact that the upper control arm is shorter than the lower one. A transverse composite leaf spring presses against the lower arm and spans the width of the car. In fact, the spring is always loaded against the subframe. This design directs shock loads into the frame side, eliminating the standalone rear antiroll bar that must be incorporated into models with standard suspension packages. The spring's camber curve also is said to improve tire contact with the road during cornering.

Composites also have the potential to replace steel and save weight in longitudinal leaf springs (see "Building a stronger longitudinal leaf spring," p. 36). These run parallel to the length of the vehicle, providing suspension as an integrated part of the wheel guidance system. "Longitudinal leaf springs have a higher safety factor," claims Frank Fetscher, head of business development, Benteler-SGL (Ried, Austria), a joint venture of Benteler Automotive and the SGL Group – The Carbon Company (Wiesbaden, Germany, see "Learn More," p. 39). "They can have a linear spring rate or a progressive spring rate — multistage springs — and must perform better with respect to torsion and side stiffness than transversal springs."

HIGHER SPEED, GREATER VOLUME

To date, commercial glass- and carbon-reinforced composite leaf springs have been limited to low-volume production models. "When resins were first being used in the automotive industry, epoxy systems already proven in the aerospace industry were the first to be selected," explains Scott Simmons, business development specialist for chassis, Henkel Corp. (Madison Heights, Mich.). "While these epoxy systems provide a very high-performing part, the prepreg manufacturing process primarily employed with these resin systems is better suited for the low-volume production associated with aerospace."

Epoxy prepreg systems weren't fast reacting because they didn't need to be for autoclave processing, which, for purposes of quality assurance to high aerospace standards, necessarily involved slow and carefully controlled applications of temperature and pressure. However, much research has gone into expediting the production process through the use of faster molding processes and the development and use of suitably fast-reacting resin systems. These emerging systems show promise for economical mass production of composite leaf springs.

POLYURETHANE & HP-RTM

"In automotive, RTM [resin transfer molding] is the go-to process," asserts Simmons, "and maximizing the speed of processing is critical for high-volume manufacturing to become a reality." To that end, Henkel has developed a polyurethane matrix resin system designed for fast automotive high-pressure RTM (HP-RTM) processes. "Our goal was to mimic the performance characteristics of epoxy, while increasing processing speed and flexibility," explains Simmons, noting that, ultimately, "Automotive OEMs want a composite system that will allow 100,000 to 250,000 parts per year at a relatively low capital investment cost."

Henkel's Loctite Max 2 matrix resin reportedly provides an answer: A high modulus (2,800 MPa) in combination with an elongation-to-break of 5 to 10 percent, with tensile strength of 80 MPa. Due to its specific polymer backbone structure, which combines "soft" polymer segments with strong H-bridging of the urethane moieties, the neat polyurethane resin is said to exhibit intrinsic toughness. According to Henkel, this eliminates the need for additional toughening agents that increase cost and viscosity. The toughness properties of the resin translate, practically, to fatigue resistance. This is critical because automotive leaf springs are subjected to dynamic loading under driving conditions, and are required to pass tests that require 700,000 recurring load cycles. The use of flexible materials with high fatigue tolerance prolongs the life of the leaf spring considerably.

Henkel has collaborated with Benteler-SGL to commercialize mass production of a lightweight, fiber-reinforced leaf spring using a polyurethane-based HP-RTM process. The process combines unidirectional (UD) glass fiber preform technology with Henkel's Max 2 resin system. The result is a leaf spring that, Henkel says, weighs 65 percent less than the conventional steel option — 6 kg vs. 15 kg (13 lb vs. 33 lb).

When Henkel approached Benteler-SGL with its polyurethane process, the latter was developing a front-axle composite leaf spring for the Mercedes-Benz *Sprinter,* a lightweight cargo van manufactured by Daimler AG (Stuttgart, Germany). The *Sprinter* has

Source | Daimler AG

Source | IFC Composites

IFC Composites (Haldensleben, Germany) has been mass-producing glass-reinforced epoxy-based leaf springs since 2005. The company uses a prepreg manufacturing system, and has supplied more than 1.3 million composite leaf springs for light duty trucks, including Daimler's Mercedes-Benz *Sprinter* cargo van (top photo).

Henkel Corp. (Madison Heights, Mich.) worked with Benteler-SGL (Reid, Austria) to commercialize leaf spring mass production, using its polyurethane matrix resin system, Loctite Max 2, via RTM. Shown here is the glass fiber-reinforced composite transverse leaf spring manufactured for the front axle of the Mercedes-Benz *Sprinter* cargo van.

sported a composite leaf spring for a number of years. As with previous iterations, the part was designed with glass-reinforced epoxy. "Benteler-SGL had already designed the orientation and density of the fabric," says Simmons, "and we presented an alternative resin that could work with the design already in place."

"Replacing the existing epoxy system with Max 2 polyurethane was appealing to Daimler because polyurethane is tougher and can withstand bending and flexing better than epoxy," he maintains. "It also offers improved resistance to crack propagation, meaning that if a rock pops up and strikes the leaf spring, any chip or crack that might occur is less likely to propagate."

"Benteler's interest was in regard to speed," says Simmons. "The existing epoxy resin required a mold time of approximately 30 to 35 minutes. With a program requiring 100,000 to 150,000 parts annually, a 30-minute cycle time would require a large number of molds to meet demand, which then impacts capital investment costs significantly," he says, noting that "the Max 2 resin system offers a faster injection time — from minutes with the epoxy to seconds with the urethane — and a faster mold time — from 30 to 35 minutes with epoxy down to eight minutes with urethane."

"With HP-RTM, we have an economic[al] process that offers geometric design possibilities," explains Fetscher. "In the end, the final product has the same properties as it would with an epoxy system." According to Fetscher, the rheological behavior of the polyurethane matrix resin as a function of temperature and isothermic cure kinetics were evaluated to determine a process window for injection at minimum resin viscosity. The optimum processing window proved to be 70°C to 110°C (158°F to 230°F). "Under optimized processing parameters, it is possible to inject the mixed polyurethane matrix resin at viscosities as low as 30 mPas, [30 cps]" claims Fetscher. "Using high-pressure RTM equipment, low matrix resin viscosities enable an ultrafast injection rate of 100g to 300g of resin per second. At the same time, the unique flow behavior of polyurethane matrix resins doesn't lead to undesirable fiber displacement effects that can be seen with matrix resins of higher viscosities."

Henkel recently introduced its Max 3 polyurethane-based system, which it developed with input from Benteler-SGL. Notably, the new system also includes an *internal* mold release to enable easier processing. "Typically, some type of mold release is required in RTM or compression molding, so we have integrated the internal mold release into the product to eliminate the need for that step," explains Simmons. Further, optional accelerators can be added to the base isocyanate and polyol to enhance processing speed.

Max 3 also offers an increased glass transition temperature, which improves finished-part temperature resistance. "Increasing the temperature resistance continues to be a target for our future polyurethane systems," Simmons emphasizes, noting that the continued research amounts to an insurance policy of sorts. "In automotive, a temperature resistance between 150°C to 180°C [302°F to 356°F] would allow the parts to go through the e-coat process," he explains. "Not that the composite parts necessarily need the e-coat process," he observes, "but our goal is to allow for composite parts that can withstand the same processing temperatures as the other components on the car, to streamline production."

BUILDING A STRONGER LONGITUDINAL LEAF SPRING

Benteler-SGL (Ried, Austria) has identified a carbon fiber hybrid system for production of longitudinal springs. "The longitudinal spring is wheel-guiding, so it is a security-related part, and a breakdown will lead to severe problems," says Frank Fetscher, Benteler-SGL's head of business development. "In order to have a much more robust part, we are developing an enhanced manufacturing process within composites in order to combine the advantages of filament winding, prepreg and RTM."

The proprietary process is still in development. "We have achieved first milestones — first positive results — and we have a projected target," says Fetscher. "We have achieved longitudinal leaf springs with the RTM process as well, but we are seeing physical demands increasing and, therefore, would like to have a second process on hand in order to be more flexible while maintaining the cost benefit of the RTM process."

The longitudinal leaf springs are more exposed to impact from the outside than transverse springs. Because of this, glass fiber-reinforced polymer longitudinal leaf springs are not commonly employed. "There is a level of stiffness that is required in longitudinal leaf springs that is always independent of the width of the spring," says Fetscher. "You need a flexible width and thickness variation in order to meet the demands of the level of stiffness combined with the main function — the hub stiffness," he adds. "This is something we hope to achieve with the new process — more flexibility than even with RTM. Filament winding allows flexibility in the width of the spring, and RTM and prepreg allow for alternating thickness change." Combining these processes and using carbon fiber, he says, could lead to a longitudinal leaf spring design applicable for light commercial trucks and pickup trucks.

EPOXY FORMULATORS RESPOND

Over the past several years, substantial progress also has been made in epoxy resin technology and the processes used to mold epoxy composites. Momentive Specialty Chemicals (Columbus, Ohio) has developed so-called "snap-cure" epoxy resin systems, designed to allow medium- to high-volume production of structural composites, including leaf springs. The new systems retain the properties of traditional epoxy-based composites, according to Momentive, yet process in a matter of minutes when used, like the polyurethanes, in HP-RTM.

"The advanced formulations are unique in that they provide a long-enough injection window for a robust impregnation of the reinforcing fibers while still enabling an extremely short cure cycle," claims Dr. Roman Hillermeier, who, with Momentive research partners Dr. Tareq Hasson, Lars Friedrich and Cedric Ball, presented findings at the Society of Plastics Engineers' 2012 Automotive Composite Conference and Exhibition (see "Learn More"). "The entire process requires a short cycle time to be viable for automotive mass production volumes," said Hillermeier. In practical terms, he said, that means less than five minutes.

One key to enabling these faster production speeds is the preform binder. "In the case of rapid RTM processing, it is particularly important that there is good compatibility with the resin matrix, the reinforcement's permeability is not negatively affected, and the binder provides enough strength to prevent distortion of the fibers during injection," explained Hillermeier. "The higher level of performance was achieved by means of a 'reactive' or 'crosslink-able' binder."

At production speeds of five minutes or less, the time required to fill the mold and complete fiber wetout is a challenge with epoxies. Structural composite parts require relatively high fiber volumes of 50 percent or more, Hillermeier noted. "Very low viscosity and having sufficient time for impregnation are the two key characteristics that are needed to achieve quality finished parts. The ideal injection viscosity of an RTM resin should be below 100 mPas [100 cps] for at least 60 seconds at processing temperature."

In answer, Momentive has developed two fast-reacting epoxy systems with ►

enough designed-in thermal latency to allow time for thorough fiber wetout of large or geometrically complex parts. Both systems are designed for HP-RTM processing. The first, EPIKOTE 05475 resin with EPIKURE 05443 curing agent, reportedly cures within five minutes at 120°C/248°F. The second, EPIKOTE 05475 resin with EPIKURE 05500 curing agent and Heloxy 112 internal mold release agent, reportedly cures within *two* minutes at 115°C/239°F. Most recently, Momentive introduced its EPIKURE 05500 fast-cure epoxy and EPIKOTE 04695-1 binder/EPIKURE 05490A curing agent for production of Class A composite auto parts using a *gap-impregnation* RTM process (see "Learn More").

Momentive also has worked with molders during the development of its new epoxy systems. A noteworthy example is IFC Composites (Haldensleben, Germany), which has been mass-producing glass-reinforced epoxy-based leaf springs since 2005. The company uses a semi-automated prepreg manufacturing system, during which continuous fiber is impregnated with resin. IFC has reportedly supplied more than 1.3 million composite leaf springs for light-duty trucks, including Daimler's *Sprinter* cargo van. The *Sprinter* front axle leaf spring manufactured by IFC measures 1400 mm/55 inches long, 75 mm/3 inches wide, 30 mm/1.18 inches thick and weighs 5.5 kg/12.1 lb compared to the 25-kg/55-lb steel front leaf spring it replaces.

NEXT STEP: MULTILINK SYSTEMS

New developments also include changes in the manufacturing approaches to auto suspension systems. "The next step for transverse leaf springs," predicts Benteler-SGL's Fetscher, "will be a move away from single component suppliers in the direction of systems suppliers."

"A multilink axle system with a composite leaf spring covering jounce and roll function is the most effective weight optimization for a complete rear-axle module and the next step in weight reduction," he adds. Development goals for Benteler's leaf-spring rear module include weight reduction through replacement of the coil spring *and* antiroll bar by a transverse composite leaf spring, with no reduction in the vehicle's handling behavior and an improvement in the suspension system's acoustic damping. Bump and roll stiffness would be supported by the leaf spring. Benteler believes vehicle dynamics would be improved. Reportedly, weight savings would be 4 kg to 8 kg (8.8 lb to 17.6 lb) per system and costs are within an acceptable range in relation to the weight reduction. Currently, Benteler has developed system integration within the axle suspension concept to include the function of the antiroll bar into the leaf spring. The system is fully developed and ready for program integration.

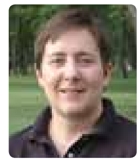
ZF Friedrichshafen AG (Schweinfurt, Germany), a global supplier of driveline and chassis technology, is taking it one step further with the development of a *wheel-guiding* transverse leaf spring. The system is designed to perform spring, antiroll *and* wheel-control functions. This leaf spring, however, is manufactured via heated compression molding, with an epoxy-based resin system and continuous glass fiber reinforcement.

According to ZF, the loading on the spring is complex, making process control, in terms of fiber content and orientation, a key to success. The spring's design eliminates a number of conventional steel components — an antiroll bar with mounts, two antiroll bar links, two control arms and two conventional coil springs. ZF reports that the composite leaf spring suspension system is approximately 12 percent lighter than a conventional MacPherson strut suspension, approximately 10 percent lighter than a conventional twist-beam suspension, and can be as much as 60 percent lighter than a steel multileaf spring. Key to precise wheel control and desired spring rates is the design of the leaf spring cross-section and the placement of the mounts. ZF's design is targeted to the compact car class, and the company is expecting first production applications in 2014.

MOVING FORWARD WITH COMPOSITES

Because transverse composite leaf springs are already in use in lightweight trucks and cargo vans, as well as high-end sports cars, "the main focus for the future of transverse leaf springs," says Fetscher, "will be the system integration of body-suspension (coil springs) and antiroll bar functions into a multilink leaf spring suspension concept." These will be a key factor in widespread adoption. "This system will target mainly passenger cars in the C- and D-class segments," he says, referring to mass-production compact cars and large cars, respectively.

On the longitudinal leaf spring side, composites are used primarily on higher clearance pickup trucks, large cargo vans and heavy-duty trucks. Here, prospects are a bit less promising. "For longitudinal leaf springs, we expect to see more of a component substitution of steel by FRP rather than system integration," explains Fetscher. That said, the likelihood that composite leaf springs that debuted in the rarified reaches of high-dollar 1950s-era sports cars will reach commercial production in everyday automobiles has, after 50 years of composites research, never been higher. **| CT |**



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The SGL Group has taken a leading role in the application of carbon fiber composites to automotive structures. Visit, for example, short.compositesworld.com/abBBuTEN.

Dr. Hillermeier and his co-authors published their finding in "Advanced Thermosetting Resin Matrix Technology for Next Generation High Volume Manufacture of Automotive Composite Structures," Momentive Specialty Chemicals Inc., 2012.

Gap-impregnation RTM is described online | short.compositesworld.com/lottahoods.

sportfishing yacht

INFUSION OPTIMIZED

This well-loved deepsea fishing brand has moved from Miami to a new facility, and to a state-of-the-art resin-infused laminate for its *Bertram 64*.

The venerable Bertram Yachts brand was born when founder Dick Bertram decided to build on his well-earned reputation as an ocean sailor and as the victor in the 1960 Miami-to-Nassau powerboat race. Bertram handily outdistanced all in the demanding, eight-hour open water speed contest, with a 31-ft/9.4m "deep-V"-hulled wooden boat called *Moppie*, after his wife's nickname. By 1961, he was molding a *fiberglass* version of *Moppie*, dubbed the *Bertram 31,* in the style of a sportfishing boat, with a wrap-around cabin and flybridge, Some marine insiders still call it "the top sportfishing boat on the planet," and a fleet of nearly 13,000 Bertram sportfishers exist, worldwide.

For Bertram and the rest of the marine industry, the Great Recession brought great change. Although annual retail powerboat sales are still far below the prerecession high-water mark of 300,000 units, they are rising — a resurgence reflected in increased activity at many boatyards. After building boats for more than 50 years in Miami, Bertram Yachts is riding this wave of change at a new facility in Merritt Island, Fla. "We're celebrating one year at our new site," says Alton Herndon, president of Bertram and a marine industry leader, "and are moving forward with optimized composite designs and improved fabrication to make our well-known sportfishing boats even better."

Source | Bertram Yachts

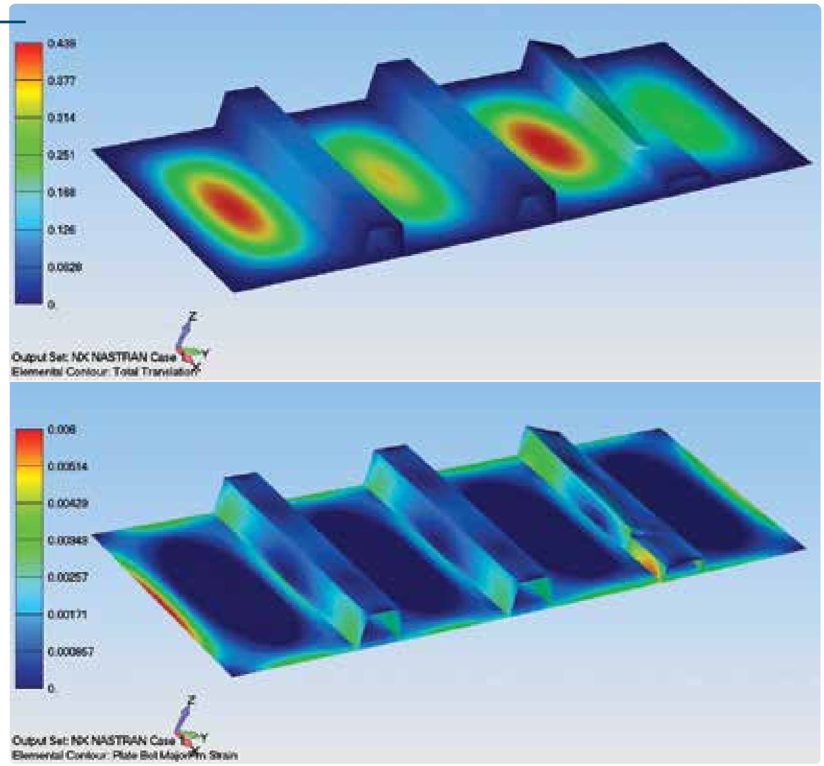
Bertram-brand sportfishing yachts are now built in Merritt Island, Fla., after a move from the company's original Miami location. Also new is an updated design for infusion undertaken for the *Bertram 64* (shown here) by the Bertram design team and Vectorworks Naval Engineering (Titusville, Fla.). ■

Part of the Ferretti Group since 1998, Bertram builds large, sturdy and seaworthy performance powerboats and sportfishing vessels that are often seen in use at deepsea fishing tournaments. The move from the company's Miami airport site to Merritt Island came about because the former was simply too small: "Any vessel larger than 60 ft in length had to be launched at high tide, since our slip was very tight," Herndon explains, "and when we began offering the *80*, the only option was to hire a 500-ton crane and literally lift the boat over the building into the water." Further, the heights of larger models exceeded the building's inside clearance, so final construction was done outside, in the weather. With access to both the Intercoastal Waterway and the Atlantic, the Merritt Island site boasts two larger buildings, 37 acres for expansion *and*, Herndon points out, a local workforce with deep composites-fabrication experience.

OPEN MOLDING TO INFUSION

A new location, however, was just the beginning. Bertram also left behind open molding and moved to vacuum-assisted resin infusion, which it had previously used only for smaller parts, for all of its manufacturing: "We were looking to improve repeatability and increase strength with a re-engineered composite laminate design," says Robert Ullberg, Bertram's VP of product development and engineering. To that end, and to

Vectorworks optimized the vessel's composite laminate, using classification society rules as well as finite element (FE) modeling. These FE screen shots show the longitudinal stringers in the forward section of the hull structure, where the outboard longitudinal stiffener (far right) is reduced in height due to the required elevation of the lower deck *sole* (floor). The analyses (top is deflection, bottom is strain) showed that the outboard stiffener, despite its irregular shape, provides adequate end-fixity for the hull bottom panel, and that it is not subject to excessive stress and strain.



Source | Vectorworks

improve their "comfort level" with an all-infusion approach, Ullberg and Herndon turned to boat manufacturer Vectorworks Marine and its naval architecture/design subsidiary Vectorworks Naval Engineering (Titusville, Fla.) to collaborate on infusion-optimized laminate designs.

Vectorworks, in turn, brought in the Composites Consulting Group (CCG, DeSoto, Texas), an independent composites design company within core supplier DIAB Group (Laholm, Sweden), as well as fiber reinforcements manufacturer Vectorply Corp. (Phenix City, Ala.) and resin systems suppler Interplastic Corp. – Thermoset Resins Div. (St. Paul, Minn.).

"CCG's expertise in infusion flow modeling and Interplastic's resin formulation experience were key to that 'comfort level' that we were going for," says Vectorworks' Kurt Hopf, senior VP of operations. "We have a longstanding, 20-year relationship with these partners, which helped us assemble a productive and competent team for this project, together with Bertram." Adds Bill Kulenguski, Vectorworks engineering manager, "It is a very scary moment when you've got many drums of catalyzed resin around you and it's time to infuse expensive reinforcements — we wanted to ensure the best outcome."

Vectorworks began by developing a new laminate design for a customer's *Bertram 64,* a model previously produced via hand layup and manual wetout with rollers. At 64 ft/19.7m long, with a beam of 18.2 ft/5.6m and a draft (the hull depth below the waterline) of 5.5 ft/1.7m, its outward appearance and major systems could not deviate from Bertram's legacy design. And a reputation as rugged and seaworthy in any weather dictated that all parts of a Bertram vessel be very solid. For example, the *soles* (deck panels) that span the supporting bulkheads to form the vessel's floors had to exhibit a minimum *300:1* length-of-span-to-deflection ratio.

The design, then, demanded special care. "We developed the vessel's laminate zones to meet the anticipated global loads as defined by RINA Services SpA (Genoa, Italy), a naval vessel classification society," Kulenguski recalls. RINA's *Rules for Classification of Pleasure Yachts* predict the overall loads, accelerations and pressures based on the vessel dimensions, dead-rise angle, displacement, draft and velocity. RINA rules were cross-checked with loads and design criteria from the International Organization for Standardization's (ISO, Geneva, Switzerland) ISO 12215 standard "Small Craft – Hull Construction and Scantlings." Use of classification rules provides for independent review and quality control of the engineering design and construction. Practically, it also "reduces insurance rates," he adds, "and if the vessel is going to be used for commercial charter in the U.S., it helps facilitate review and inspection by the U.S. Coast Guard." That said, Kulenguski and Hopf stress that classification society rules are no substitute for sound, independent engineering judgment. Ultimately, he asserts, "we took a 'first principles' approach in order to evaluate the structure in terms of safety factors on stress and strain."

LAMINATES TO MATCH THE LOADS

Hull laminate thickness was a key parameter. The hull has to withstand the anticipated bottom hydrodynamic pressure, as well as other loads that include boat storage considerations — keel blocks, lifting strap positions — and grounding loads created by the propellers' supporting struts. Kulenguski explains that overall loads include longitudinal and vertical bending moment and shear force ("hogging" and sagging conditions). Local loads, such as hull pressures, are dependent on longitudinal position along the hull and panel size — that is, the areal extent of a hull segment located *between* stringers and transverse frames. Slamming effects are included in the pressures, primarily mid-ship and forward. Deck and superstructure pressures are based on location: "RINA assumes top speed of 40 knots/46 mph at maximum displacement in a sea state with 4m/13-ft wave height."

Further, the arrangement and positions of transverse frames and bulkheads in the new design was constrained by the layout of the original cabin and staterooms, which was to be preserved unchanged. So bulkheads and other structures in the infused design ►

Source (all step photos not marked) | Vectorworks

1 After gel coat sprayup, and layup of a Soric barrier ply (from Lantor Composites, Veenendaal, The Netherlands) and the dry laminate stack, the foam core is layed up over the outer fiberglass skin stack.

2 The inner fiberglass skin is layed up over the core. (Previously, all Bertram models had a monolithic, *uncored* hull bottom.)

5 This photo shows the complexity of the infusion manifold and the more than 50 feed lines required for the hull infusion. MVR 8075 vinyl ester resin from Interplastic Corp. – Thermoset Resins Div. (St. Paul, Minn.) was the specified resin.

6 Resin has infused the hull bottom and is starting to move up the sides. CCG used grooved core to facilitate resin flow in areas without flow media. Note the vacuum ports on the top surfaces of the stringers.

had to be positioned in such a way that the interior walls would conceal them. Placement of stringers along the hull's length was dictated by the locations of engines, tanks and gyrostabilizers, which also were unchanged from the *64*'s legacy design.

Developed in-house, Vectorworks' design spreadsheets reflect the classification societies' rules and Bertram's own experiential rules. The company employs Vectorlam Cirrus software, from Vectorply, for material trade studies and for developing "smeared" laminate properties, says Kulenguski. (*Smearing* is designer parlance for combining all of the material properties of a laminate stack together to obtain a single value.) "Vectorlam has a good composite materials physical properties database, and the software has proven to be pretty accurate when you compare it to destructive test data."

To test the spreadsheet assumptions and put together ply-by-ply reinforcement stackups for the hull and decks, Vectorworks did finite element analysis (FEA) using NX Nastran with FEMAP, supplied by Siemens PLM Software (Plano, Texas). The FEA verified the Vectorlam data and first-ply failure, and identified problem areas, adds Hopf. It also gave Vectorworks the ability to model adhesively bonded joints and solve for the deflection and shear stress in the adhesive itself. The FEA also enabled a ply-by-ply look at stress and strain within the stack, which is particularly important when checking the gel coat safety factor. "Since gel coat is a relatively brittle material, we wanted a design that minimized strain on that outer cosmetic skin, with less than 1 percent elongation in the vessel," he adds.

A key aspect of the *64*'s design was Vectorworks' simultaneous CAD modeling along with the structural model. A complete 3-D model using Unigraphics NX (now Siemens PLM Software NX) was prepared that included all of the vessel's mechanical, plumbing and electrical systems fully integrated with the laminate design, a new design strategy that other boatbuilders are now starting to employ. This ensured that potential issues, such as equipment mounting points or hull penetration, were accounted for with extra fabric reinforcements or other structural modifications. "This kind of planning integrated into the laminate design really streamlines the construction process," says Hopf. All aspects of the laminate and CAD design were discussed with Bertram during the process, adds Kulenguski: "We worked out with them what could, or couldn't, change from the

3 Under the direction of CCG (DeSoto, Texas) consultants, workers lay peel ply and sacrificial flow media (darker green material) in advance of setting up the infusion manifold. Note that the four longitudinal stringers are prepped for co-infusion with the hull laminate.

Source | CCG

4 The hull, completely vacuum-bagged, with the infusion manifold partially in place. Blocks of wood hold the stringers in place. Note the irregular profiles of the stringers, from the bow (furthest away) to the stern.

7 The hull infusion is essentially complete, and resin can be seen working its way up through the manifold's vacuum lines.

8 Postcure, work progresses on the *64's* buildout, with installation of bulkheads and interior structures.

legacy layup." Although Bertram elected to use its existing composite mold for the first infused *64* hull, Vectorworks will produce the plugs and molds for future projects, using its CAD design data.

INFUSING THE NEW LAYUP

The design precipitated a big manufacturing change for Bertram's monolithic hulls, from a solid to a mostly cored sandwich construction. Kulenguski points out: "The move to infused laminates gave Bertram the opportunity to switch to a cored hull. The beauty of infusing a sandwich construction is that you can rest assured that the core-to-skin interface is 100 percent complete and void-free, minimizing the risk that every manufacturer of cored laminates faces."

Ultimately, the design generated a variety of laminate zones, based on the local loads and panel sizes: Hull laminate thicknesses range from 3/8-inch/10-mm to 2-inch/51-mm cored sandwich, with the majority at 1.5-inch/38-mm thickness. Thanks to the lower weight of the cored bottom, Vectorworks was able to reduce hull internal structure, since the cored panels have a much higher modulus and enable a larger panel size. Further, the main deck and flybridge are lighter, consisting primarily of 1.25-inch/32-mm cored sandwich construction.

When the laminate design was in place, materials were specified for the infusion. E-glass reinforcements, obtained through distributor Composites One (Arlington Heights, Ill.), included unidirectional as well as biaxial and triaxial noncrimp fabrics manufactured by Vectorply. Interplastic supplied low-viscosity MVR 8075 vinyl ester resin, formulated for infusion, with high heat-distortion temperature (HDT) characteristics. Also specified was DIAB H100 1-inch/25-mm thick closed-cell foam core material for the hull bottom, and H80 1.5-inch/34-mm thick foam core for the hull sides. The four longitudinal stringers contain high-density foam core, covered with the noncrimp fabrics. To reduce laminate print-through as much as possible, Soric from Lantor Composites (Veenendaal, The Netherlands) was specified as a print barrier.

"Vinyl ester resin, while it provides superior physical properties, generates a fair amount of exotherm during cure and exhibits higher shrink than some other resins," explains Hopf. "The Soric material as a first layer in the mold behind the gel coat helps prevent print-

Source | Vectorworks

A clear gel coat was specified for the hull's bottom surface, in order to allow a quality-control inspection of the laminate after infusion. The brownish color is the resin visible through the clear gel coat. Bottom paint will be applied prior to customer delivery.

through and guards the gel coat against the resin effects." For this first infused hull, Vectorworks specified a *clear* gel coat, supplied by Ashland Performance Materials (Dublin, Ohio) on the hull bottom, so that it could be readily inspected after cure to validate infusion results.

A number of test panels were fabricated per the design and infused, then destructively tested, not only to verify the Vectorlam and FEA modeling, but also to compare infused properties against Bertram's legacy open-molded laminate structure. According to Kulenguski, panel testing showed "very accurate" agreement of mechanical properties between the model and actual cured laminates, at 68 percent fiber content, with good panel-to-panel repeatability of properties. "And, the infused panels met or exceeded the legacy design, at a lower weight," he adds.

Infusion expert Belle Blanding, one of CCG's senior consultants, conducted infusion flow modeling. Polyworx (Nijverdal, The Netherlands) software enabled virtual infusion to determine best placement of resin runners, and injection and venting ports, and provided risk-free information on how the resin would move through the modeled laminate, explains Blanding. Concurrent with the flow modeling, Blanding also used Vectorwork's test panels for basic Darcy's Law permeability flow tests, to help confirm the Polyworx results: "This was a complex infusion to design, because of the many different laminate zones and the bends and twists in the stringers." The team opted to co-infuse the longitudinal stringers along with the hull laminate, an innovative approach that is gaining traction in the industry. "It makes it possible to get an integrated laminate with one cure cycle, and we were confident that the stringers would bond completely to the hull," Blanding recalls, pointing out, "It avoids a separate, time-consuming and labor-intensive bonding step."

With infusion planning underway, the team layed up the fabric-and-core "dry stack" and then CCG's process specialist, Dean Callander, supervised application of peel ply and the elements of the infusion "manifold" — the arrangement of resin feed lines, runners and vacuum ports into the hull layup, based on Blanding's Polyworx model runs. In all, more than 50 vacuum and resin flow lines, and two work days, were required for the manifold setup.

To ensure complete wetout of the complex longitudinal stringers, the manifold included vacuum ports along the stringer tops, where the heaviest stringer laminates were located. Blanding and Callander say this approach makes stringer infusion independent of, yet simultaneously with, the hull infusion. Otherwise, stringer infusion would follow hull infusion and extend total infusion time. Sacrificial flow media, Greenflow from Airtech International Inc. (Huntington Beach, Calif.), was placed along the sides of the stringers to facilitate resin flow along the stringer lengths. After all the manifold elements were placed, the entire hull was vacuum bagged and sealed.

When all was ready, the infusion took place on Nov. 8, 2013, and took about three hours. Interplastic representatives were on site to monitor resin mixing and initiator addition. After a room-temperature cure of several weeks, during which internal bulkheads and deep floors were installed, the hull was demolded on Nov. 26, using an overhead crane. "The clear gel coat gave us a good look at the infused laminate to validate the model and manifold," Hopf reports. "The laminate looks absolutely perfect — we couldn't have asked for anything better!" Given that outcome, all Bertram models will be made in this manner.

Infusion of the main deck and smaller flybridge decks was undertaken in December. And as *CT* went to press, hull build-out continued, including bonding of interior soles and flats.

"Moving forward," Herndon concludes, "we are ensuring the Bertram legacy by employing new manufacturing innovations and continuous improvement, and making every build better than the one before."

Adds Hopf, "Being able to bring this team together, with whom we have successfully completed so many vessels … was a tremendous boon to the project." | CT |

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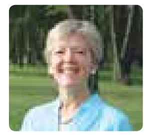

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PRESENTER

Dan Milligan
Technical Specialist
Composites

Simulating FAILURE in Composite Materials

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Imagine being able to replicate real-word failures of composite materials…on your computer. This webinar will cover WHY you would want to simulate the failure of a part or structure made from composite materials and HOW you can do that using Autodesk Simulation software. No longer is structural simulation limited to just looking at stresses, strains, and deflections. You can simulate the actual FAILURE of a composite part, and this can be done with minimal changes to your current simulation process.

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- Introduction to Autodesk Simulation
- Why Simulate Failure in Composites?
- What Makes Autodesk Composites Simulation Unique?

PRESENTER'S BIO:

Dan has been a Technical Specialist since joining Autodesk in March, 2013. He came to Autodesk through the Firehole Composites acquisition and his prior role at Firehole Composites was as a Composites Engineering Consultant. Dan has 8 years of experience with composite material analysis and simulation. Through his experience, Dan has developed an expertise in simulating failure of structures made from composite materials using finite element analysis. He has presented at multiple composites conferences and maintains an active presence in social media, sharing his knowledge of composites simulation.

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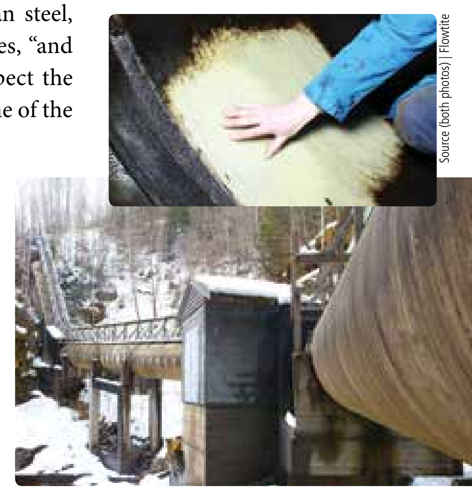
Applications

INSPECTION | 30-year-old fiberglass pipeline stands test of time

Thirty years ago, a 5-ft/1.5m-diameter, fiberglass/polyester pipeline was installed at the Vinkelfallet power plant, north of Lillehammer, Norway. The pipes were designed and filament wound in 1982 by APS Norway AS (Sandefjord, Norway). Since then, APS became, in turn, Veroc Technology, then Owens Corning Pipe Technology AS, and in 1998, Flowtite Technology AS. (The company is now part of Amiantit Company Group, Dammam, Saudi Arabia.) But when a detailed inspection of the pipeline was recently undertaken during a planned power plant shutdown, Flowtite was on hand: "As part of our followup of projects and quality assurance, we saw this as a good opportunity to be able to confirm pipe properties," says Flowtite CEO Thomas Anderson.

Glass fiber-reinforced polymer (FRP) was specified for this particular pipeline in 1982 when a plant upgrade was undertaken by its owners, Gudbrandsdal Energy, during which an existing steel pipe was replaced. Designed by APS/Flowtite with large safety margins, the pipes, says Gudmundur Palsson, Flowtite Technology's chief engineer, were validated by long-term laboratory testing.

"We had no experience with FRP at that time," recalls Stein Kotheim, the power plant's production manager. "Would it be strong enough, and live up to the claims?" were among the company's questions. "But, in view of the benefits, which included much easier installation than steel, we decided to try it," he notes, "and we've had no issues. We expect the pipeline to last for the lifetime of the plant, 60 years."



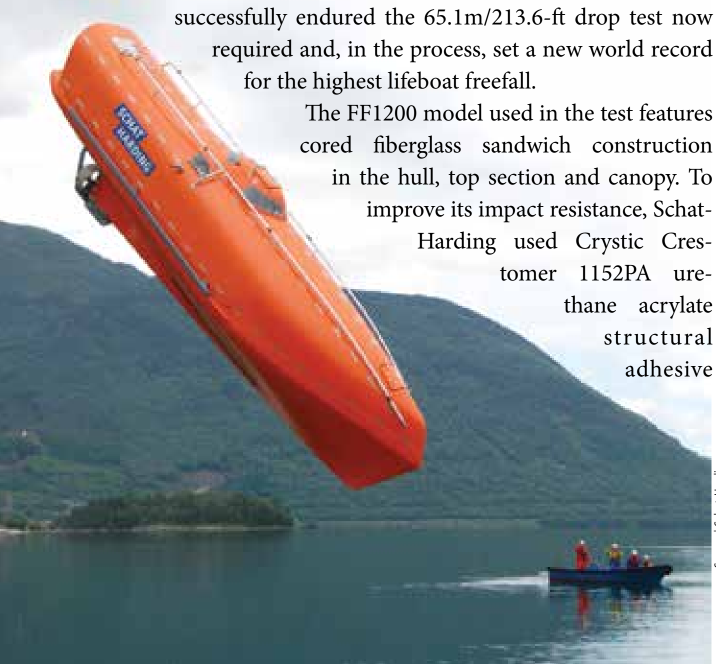
Source (both photos) | Flowtite

Although a thin layer of black soil covered the interior surface when inspectors entered the pipeline, it was easily washed away with water to reveal a smooth FRP inner surface, with *no signs of wear or damage*. Palsson says this confirmed that the pipeline had experienced no *head loss*; that is, its hydraulic properties had not been reduced by friction-related resistance to flow. "This observation matched our expectations *and* the published literature for FRP pipes," he claims.

For a company that has FRP pipes installed in hydropower, water and sewage applications at *thousands* of sites worldwide — and for the composites industry — that's very good news. ■

FREEFALL | Adhesive helps composite lifeboat achieve world record

Used for rapid evacuation from oil and gas rigs and offshore installations, freefall (FF)-class lifeboats must now conform to the revised Det Norske Veritas (Bärum, Norway) DNV-OS-E406 standard to ensure that they will survive launches from the greater heights and in the extreme weather/sea conditions they will see as offshore facilities grow in size. A composite FF lifeboat built by Umoe Schat-Harding Equipment AS (Schat-Harding, Rosendal, Norway) successfully endured the 65.1m/213.6-ft drop test now required and, in the process, set a new world record for the highest lifeboat freefall.



Source | Schat-Harding

The FF1200 model used in the test features cored fiberglass sandwich construction in the hull, top section and canopy. To improve its impact resistance, Schat-Harding used Crystic Crestomer 1152PA urethane acrylate structural adhesive supplied by **Scott Bader** (Northhamptonshire, U.K.) to bond bulkheads, hull stringers, composite interliners and the canopy to the hull. Automated bulk dispensing equipment and pneumatic handheld guns helped to achieve the required higher production rates.

Scott Bader reports that the pre-accelerated, MEKP-catalyzed 1152PA adhesive fills gaps as wide as 25 mm/1 inch, with a gel time of 50 minutes at room temperature. An alternative, Crestomer 1153PA, offers a gel time of up to 90 minutes for composite sections that have one or more dimensions larger than 25m/82 ft, and/or are processed at elevated ambient temperatures. According to published technical data, Crestomer 1152PA exhibits typical composite-to-composite lap shear bond joint strengths of 10 MPa/1,450 psi, with composite substrate failure — not adhesive failure — as the limiting factor.

For the test, the FF1200 lifeboat was internally loaded with weights (7 metric tonnes or more than 15,430 lb) to simulate its maximum capacity (in special seats with five-point harnesses) of 70 people who weigh an average of 100 kg/220 lb. On impact, the nose section must withstand a force of approximately 45 metric tonnes (99,200 lb), after which the boat fully submerges to a depth of more than 10m/33 ft, and then must be able to resurface and speed occupants away to safety.

The FF1200 is the first FF lifeboat to pass all the new full-scale DNV tests. "We have demonstrated through this new world record," says Schat-Harding CEO Geir Arne Veglo, "that our FF1200 is the frontrunner in meeting new stringent regulations." ■

Calendar

FEB

Feb. 24-26, 2014 — **SPE TOPCON 2014**
Tucson, Ariz.| www.4spe.org "conferences/webinars/events"

Feb. 25-26, 2014 — **Offshore Wind Power USA**
Boston, Mass. | www.greenpowerconfe-ences.com/windseries, click "upcoming events"

MAR

Mar. 6-7, 2014 — **12th World Pultrusion Conference**
Lisbon, Portugal | www.pultruders.com

Mar. 10-13, 2014 — **EWEA 2014**
Barcelona, Spain | www.ewea.org/annual2014/exhibition

Mar. 11-13, 2014 — **JEC Europe**
Paris, France | www.jeccomposites.com/events/jec-europe-2014

APR

April 8-10, 2014 — **Composites Manufacturing 2014**
Covington, Ky. | Composites.sme.org/2014

April 13-17, 2014 — **No-Dig Show**
Orlando, Fla. | www.nodigshow.com

MAY

May 5-8, 2014 — **Windpower 2014 Conference & Exhibition**
Las Vegas, Nev. | www.windpowerexpo.org

May 13-15, 2014 — **JEC Americas/Techtextil North America/Texprocess Americas**
Atlanta, Ga. | www.jeccomposites.com

JUN

June 2-5, 2014 — **SAMPE Tech 2014**
Seattle, Wash. | www.sampe.org/events

June 8-11, 2014 — **1st International Conference on Mechanics of Composites (MECHCOMP2014)**
Atlanta, Ga. | https://sites.google.com/site/mechcomp2014

June 11-12, 2014 — CW **CompositesWorld Thermoplastics Conference/amerimold 2014**
Novi, Mich. | sstephenson@compositesworld.com

June 26-28, 2014 — **Composites Pavilion – American Institute of Architects Convention 2014**
Chicago, Ill. | www.acmanet.org

SEP

Sept. 8-4, 2014 — CW **IMTS 2014/TRAM – Trends in Advanced Machining, Materials and Mfg.**
Chicago, Ill. | www.tram-conference.com

OCT

Oct. 13-16, 2014 — **CAMX – The Composites and Advanced Materials Expo**
Orlando, Fla. | www.thecamx.org

NEW Products

Nonsilicone rubber for tooling

Airtech International (Huntington Beach, Calif.) has developed Airpad HTX, an uncured, nonsilicone rubber that can be made into caul sheets and flexible mandrels. Airpad HTX has been formulated to provide enhanced performance in comparison to other rubber caul sheet materials. Airtech says the rubber bonds aggressively to bondable release film, resulting in a longer-lasting tool, and bonds to itself aggressively, making it easier to repair. Airtech also reports that heat-aging studies show longer life in high-temperature applications. Other features include high Shore hardness for better definition and resistance to solvents, resulting in greater tool durability. AIRPAD HTX can be released using standard release agents. Airtech says, however, that Airpad HTX material should be tested by the customer, using the customer's release agents and prepreg, before using it in a particular application. **www.airtechintl.com**

Surface-sealed balsa core material

CoreLite Inc. (Miami, Fla.) has introduced BALSASUD PC11, a new balsa product with a proprietary surface coating engineered for core applications in resin infusion, vacuum bagging, prepreg, and wet-layup processes. The coating reportedly reduces resin absorption in the core while it improves resin adhesion and bond strength in sandwich constructions. Said to be compatible with polyester, vinyl ester, and epoxy resin systems, PC11's sealed surface eliminates the need to pre-wet or prime the core with resin prior to laminating, and promotes more efficient resin flow in vacuum bagged open-mold and resin-infusion processes. Suitable applications include transoms, attachment points, floors, bulkheads, stringers, and more. It reportedly has excellent fastener pullout strength, high flexural strength and stiffness, and is 27 percent lighter than plywood. The BALSASUD SA facility in Ecuador has been Forest Stewardship Council-certified by the Rainforest Alliance. **www.corelitecomposites.com**

Green resins for CIPP

Interplastic Corp. (St. Paul, Minn.) now offers the ECO Series of green resins for cured-in-place pipe (CIPP), which reportedly eliminate the environmental concerns raised when contractors use CIPP to reline partially or fully deteriorated underground pipes. The resins are formulated free of styrene and other volatile organic compounds (VOCs) and are said to contain no hazardous air pollutants (HAPs). Said to be a proven solution in gravity pipelines, the resins reportedly exhibit fast wetout, trouble-free processing and — after cure — high strength and good flexural modulus. The product line includes CORVE8290, a styrene-free ECO Series vinyl ester resin; CORVE8295, a styrene-free, modulus-enhanced ECO Series vinyl ester; and CORVE8287, a styrene-free, ambient-cure ECO Series vinyl ester resin for laterals and point repairs. They reportedly meet ASTM F1216 requirements and reduce the likelihood of stress cracking and shrinkage with a lower exotherm in the enhanced version. **www.interplastic.com**

Heat sensor/controller for work surfaces

Master Appliance (Racine, Wis.) has introduced the Proheat STC Model PH-1600, a heat gun that senses, displays and controls actual work-surface temperatures. Designed for use in composites manufacturing, the heat gun features an electronically integrated infrared sensor, which provides continuous surface-temperature readings and automatically regulates heat to reach and maintain the target temperature, even if the heat gun's distance from the work surface changes. It features a Dual Laser Targeting System that guides the user to the proper field of view for accurate surface temperature measurement and control. An LED indicator also provides a visual display of progress. The LED displays green or yellow, during the heating process, and red when the target temperature is reached. The Proheat STC has dial-in, programmable surface temperatures that can range from 90°F to 500°F (40°C to 270°C), displayed in 10° increments, in either Fahrenheit or Celsius. Airflow rate is adjustable, from 4 to 16 ft^3/min. To prevent changes to temperature and airflow settings, the Proloc supervisory locking system, with a magnetic key, will lock the controls. The Proheat STC is said to be ideal for use in manual prepreg layup of composites and for rework. **www.masterappliance.com**

Nonflammable sheet molding compound

Molded Fiber Glass Industries (MFG, Ashtabula, Ohio) has announced the availability of a new, proprietary sheet molding compound (SMC) with nonflammable properties. Known as iNVENTA 616UL, the material received UL 723 approval from Underwriters Laboratories earlier this year. (UL 723 is recognized as the industry standard for evaluating the surface burning characteristics of building materials.) Initially formulated for HVAC (heating, ventilation, air conditioning) system components, iNVENTA 616UL is said to be well suited for applications where nonflammability is important and more than 10-ft^2/0.9m^2 of composites may be required. MFG notes that newly mandated safety regulations are forcing manufacturers in many industries to retrofit or redesign their product components or housings with fire-retardant materials, and says that composites are able, in many cases, to meet the challenge. Other potential benefits of the material include parts consolidation, acoustic damping, corrosion resistance and weight reduction. **www.moldedfiberglass.com**

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designing pressure vessels for

SEAWATER DESALINATION PLANTS

Safe high-pressure service challenges manufacturers of composite pressure vessels.

Seawater reverse osmosis (SWRO) desalination depends on membrane systems that serially cleanse water piped onshore from the ocean (see "Learn More," p. 56). These membranes must be encased in *membrane housings*. Filament-wound fiberglass pressure vessels are used almost exclusively for this purpose today, in quantities of as many as 6,000 per desalination plant. The Freedonia Group (Cleveland, Ohio) predicts demand for SWRO housings and related equipment will increase 6.9 percent per year. In the U.S. alone, the market will be worth $495 million annually by 2017.

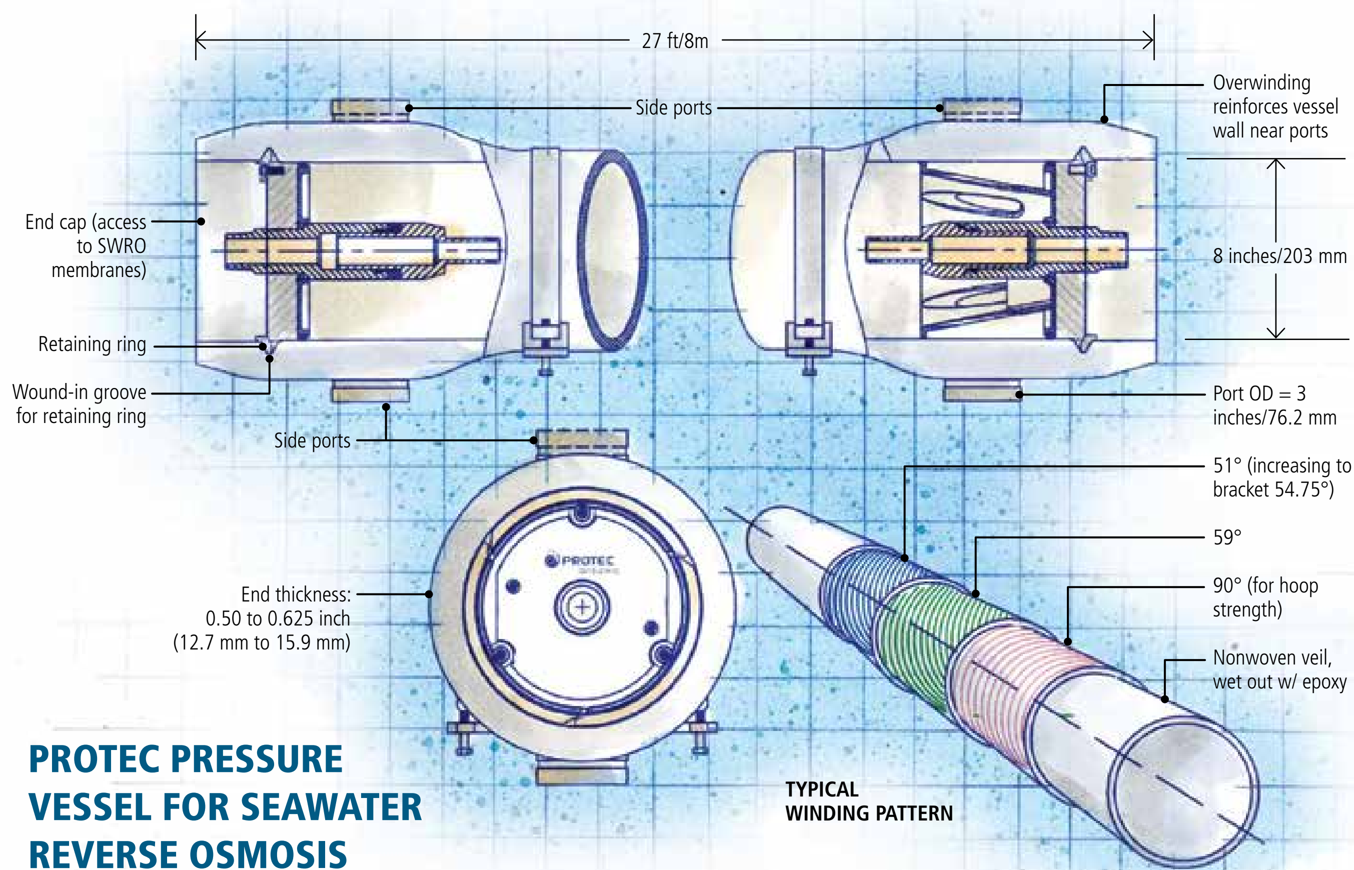
In the vanguard of this trend is Protec-Arisawa (Tokyo, Japan), which has filament wound SWRO vessels for desalination plants all over the world. It also operates in Spain and, notably, in Southern California, where extended droughts and "water fights" centered on environmental issues have taken their toll on the drinkable water supply, prompting San Diego County officials to authorize construction of a desalination plant. In mid-2013, Protec-Arisawa America (Vista, Calif.) received a SWRO pressure vessel contract for this plant. Proposed and developed by Poseidon Resources (Stamford, Conn.), it is now under construction by Kiewit Shea Desalination (Carlsbad, Calif.) and Kadima, Israel-based subcontractor IDE Technologies, a few miles away in ocean-side Carlsbad (see "Learn More"). When it is completed in 2015, it will be the largest desalination operation in the Western Hemisphere.

According to Protec-Arisawa America product manager Richard Chmielewski, the IDE Technologies order calls for 2,016 BPV-8-1200-MSP vessels (8-inch/203-mm diameter) rated at 1,200 psi/82.77 bar (see drawing, p. 55), plus 38 PRO-8-600 (600 psi/41.37 bar) and 182 PRO-8-450 (450 psi/31 bar) vessels. Each of these ~27-ft/8m long housings will contain eight standard 8-inch/203-mm diameter, 40-inch/1,016-mm long RO membranes. Today, the job is *almost* routine: Protec-Arisawa has, at this writing, more than *60,000* vessels in nearly 200 facilities. But it wasn't always so.

FROM STEEL TO COMPOSITES

In the mid-1960s, SWRO's early days, the focus was on the success or failure of the RO membranes, but it soon became apparent that the *housings* — then of welded carbon steel pipe — also required attention. "There were corrosion issues immediately," recalls Doug Eisberg, director of business development for Avista Technologies (San Marcos, Calif.) and an SWRO industry pioneer. "There were issues with weight," he adds, "and there were problems with the inside surface quality of the pipe." To ensure a tight seal on the vessel end-closures and the brine seals that fix membranes to the pressure vessel, a smooth, consistent inner surface is critical. The inner surface of steel pipe was neither.

Protec-Arisawa (Tokyo, Japan) has filament wound SWRO pressure vessels for desalination plants all over the world. Pictured is a bank of vessels in a plant located in Barcelona, Spain. The closeup (inset) shows the heavily overwound end on a vessel, the greater thickness of which ensures the vessel's integrity where the wall has been drilled to accommodate side ports.



PROTEC PRESSURE VESSEL FOR SEAWATER REVERSE OSMOSIS

Illustration | Karl Reque

ENGINEERING CHALLENGE:

Design a lightweight, corrosion-resistant, side-ported housing for seawater reverse-osmosis membranes (SWROs) that can withstand 1,000+ psi service yet offers easy access to membranes for maintenance.

DESIGN SOLUTION:

A filament wound E-glass/epoxy pressure vessel, with ends overwound to reinforce port openings and a wound-in circumferential groove for an end-cap retaining ring that enables membrane service.

By 1978, SWRO designers had turned to filament-wound fiberglass pipe. Although this immediately resolved the corrosion and weight issues and yielded a smooth inner surface, it took some time to develop designs that could handle the pressures. "At 600 psi," Eisberg recalls, "the end-closures began flying off the vessels and going through the buildings like cannons. Very destructive. We had this great material, now, but the question became, *What are we going to do to keep it safe*?"

CODE-COMPLIANT COMPOSITES

In the mid-1980s, the industry sought safety guidance in the *Boiler and Pressure Vessel Code* of the American Society of Mechanical Engineers (ASME). Section X, "Fiber Reinforced Plastic Pressure Vessels", establishes conditions that must be met, no matter how the composite vessel is configured. It calls for hydrostatic tests that cycle the vessel from zero to design pressure 100,000 times, at 150°F/65.5°C. The same vessel is then pressurized hydrostatically to a safety factor of *six times* the design pressure. With a target for safe service, pressure vessel winders were able to develop E-glass/epoxy architectures and ply schedules *specifically designed* to pass the Section X tests. (E-glass roving has demonstrated better performance in cyclic fatigue testing than corrosion-resistant, or E-CR, glass.)

Protec's Carlsbad order specifies code-stamped vessels, and Chmielewski says that's now no problem. By the end of the 1980s, most SWRO housing manufacturers, Protec-Arisawa among them, considered them the standard. "We design *all* our vessels to code," he explains. If a customer orders code-stamped vessels, an ASME inspector is called in to verify the manufacturing process and testing for the stamp, but if a code stamp is *not* required, Protec calls in an independent inspector for verification anyway. And Protec goes further: "We maintain all the material certifications, and we have a document that travels with each vessel that stipulates which winder it was made on, what batch or lot of glass and resin, the curing temperature logs, and so on."

CRITICAL POINT LOADS

A troubling design issue was how best to handle stress concentrations in the vessel ends, which are weakened by the various attachment techniques for end-closures and side-port fittings. At first, all filament-wound vessels had high-pressure feed and concentrate ports ►

Source | Protec-Arasawa

ASME Section X, Fiber Reinforced Plastic Pressure Vessels testing includes pressurization, hydrostatically (shown here), to a safety factor of six times the design pressure.

for the seawater at each end of the vessel. However, *side* ports were common in metal housings because they permitted unobstructed membrane access, and SWRO plant operators wanted them on composite housings, because they eliminate the need to disconnect the high-pressure feedwater piping to service the membranes and offer a simpler path for feedwater delivery to multiple RO systems.

Cutting side-port holes through the composite vessel wall, however, compromised vessel strength. In the late 1980s, Eisberg led a team at Codeline (now Codeline-Pentair, Minneapolis, Minn.) to address this risk. After a long development cycle, today's successful designs for 1,000+ psi service typically call for vessel ends to be *over*wound to build up the required strength, using localized filament winding (Protec's method) or reinforced by bidirectional mats, resulting in a dog bone-shaped vessel. For the end-closures, Protec either winds-in a metallic retaining ring attachment on the mandrel or overwinds a removable groove former for integrally winding in the grooves. Retaining rings have finger pulls to simplify end-cap removal.

REALIZING THE DESIGN

Today, Protec uses standard SolidWorks finite element analysis software from Dassault Systèmes SolidWorks Corp. (Waltham, Mass.), customized to design the filament wound shell and the head assembly for end-closure. Vessels are wound on equipment supplied by Entec Composite Machines (Salt Lake City, Utah), a subsidiary of Zoltek Inc. (St. Louis, Mo.), over outsourced, chrome-plated carbon steel mandrels that are ground to Protec's specifications.

Fabrication typically begins with application of a nonwoven polyester or other synthetic veil over the mandrel. The veil protects the inside surface so it can handle cycling test requirements. The veil is usually wet out with toughened epoxy resin, says Eisberg, noting that some manufacturers B-stage this layer before winding begins. In the resin bath, a toughened epoxy specially formulated for corrosion resistance, durability and dimensional stability is used. The goal is minimum 75 percent glass content.

Although Protec's fiber architecture and ply schedules are proprietary, Avista's Eisberg says there are general guidelines for meeting ASME requirements. Based on his 30+ years in the industry, fabrication follows a familiar pattern: When the veil is in place, he says, winding typically starts with a circumferential layer for hoop strength and to reinforce a smooth and consistent inside surface. This is generally followed by layers of high angle winding, up to 59°, for axial reinforcement and to strengthen the ends of the vessel for attachments and cutouts. After that, Eisberg continues, the structural layers are wound, starting around 51°, in bandwidths between 2.5 and 5 inches (63.5 mm and 127 mm). As the diameter of the vessel increases on the mandrel, the wind angle is slowly increased to adjust to the new diameter. Eisberg explains that the goal is to bracket (that is, wind with an equal number of passes at angles greater and less than) 54.75° because "this is the ultimate 2:1 wind angle for this type of product." Nominal wall thickness is typically 0.50 inch to 0.625 inch (12.7 mm to 15.9 mm) on the overwound ends for vessels intended for seawater service.

When winding is complete, Protec transfers the mandrel and vessel to an oven, where the part rotates while it is cured. "To verify cure, we weigh every vessel, do a Barcol hardness test and take a sampling of the glass/resin ratio," Chmielewski says.

Protec then precision mills holes for the side ports and machines and installs those fixtures. For the Carlsbad job, IDE specified Sandvik 254 SMO high-alloy super-austenitic stainless steel drill tools supplied by Sandvik AB (Sandviken, Sweden) for 3-inch/76.2-mm side port fixtures. Protec then tests one vessel assembly of each model/size to the ASME X standard, with end-closures installed and mechanical plugs in the side ports. Chmielewski notes that Protec can fabricate about 100 8-inch diameter, 27-ft long vessels per day.

DANGER IN HIGH DEMAND

For 25 years, ASME Code Section X has been considered the minimum safety standard. Although the increase in desalination plant construction is welcome, industry leaders say low-cost vessels that have *not* been rigorously pressure tested are entering the market and could, again, damage plants and inflict injuries if they fail. "If this were to happen," says Eisberg, "it would negatively affect the entire desalination market." He warns that the industry must remember its past or repeat it. | CT |

Senior Writer Emeritus

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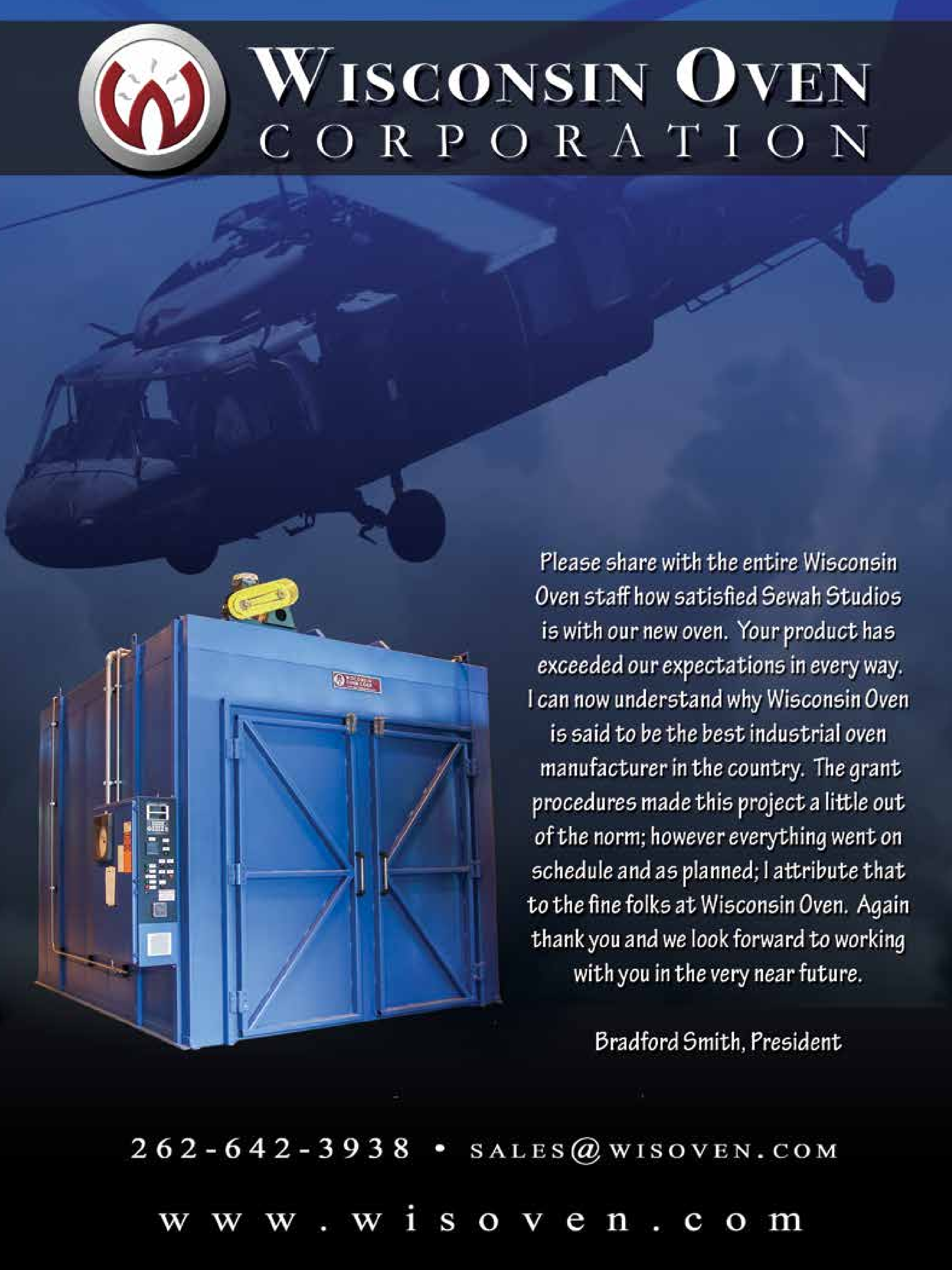
Read this article online at short.compositesworld.com/Eldesal.

For a detailed explanation of the seawater reverse osmosis (SWRO) process and the composites-intensive systems that facilitate it, see "Composites slake the world's thirst," *CT* February 2013 (p. 26) or visit short.compositesworld.com/0WEMaTCs.

Read more about the Carlsbad SWRO project in "Seawater desalination plant approved for Southern California," online at short.compositesworld.com/SoCaldesal.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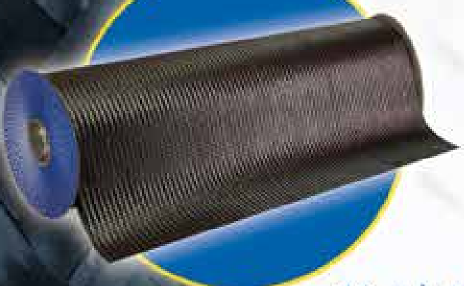

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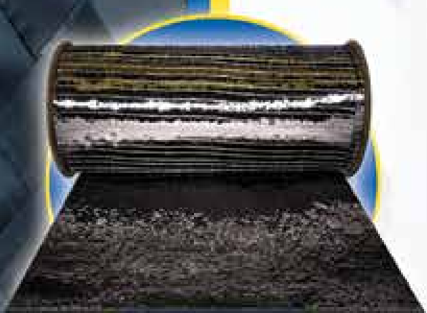

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