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MARCH 2015

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VOL 1 № 3

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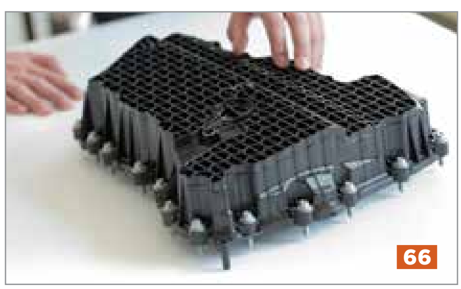

FEATURES

» ON THE COVER

Composite cables are the new standard of excellence in mast and sail rigging for high-end yachts. The pictured 30.5m *Chrisco* racing yacht, for example, is rigged with Hall Spars and Rigging's (Bristol, RI, US) SCR *airfoil* rigging, which differs from standard round solid cable in that it has a low-drag aerodynamic configuration that not only reduces windage but also runs quieter (see p. 60).

Source / Hall Spars and Rigging

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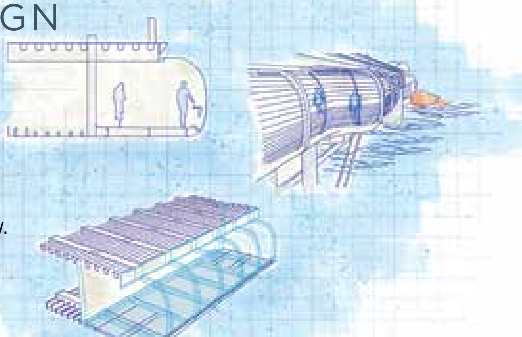

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Camel photos courtesy of Kenway Corporation

Few would expect to see a camel, the workhorse of the desert, floating in water.

A different sort of camel will do just that as the workhorse berthing the fleet of naval submarines.The Navy's Universal Composite Submarine Camels, made by Kenway Corporation, are structures that maintain separation between a submarine and a waterfront facility, preventing damage and absorbing energy as tides, currents, winds, waves or other ships pass by.

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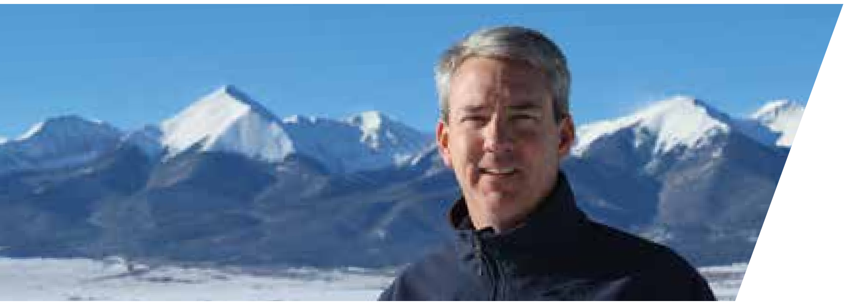


I am reading a book called *The Aviators*, by Winston Groom. Engagingly written, well researched and insightful, it tells the story of the three aviators who, Groom argues, are most responsible for the survival and development of the US aviation industry, especially in its nascent period in the early 20th Century: Eddie Rickenbacker, Jimmy Doolittle and Charles Lindbergh.

Every paradigm-shifting invention throughout human history has been met with skepticism.

One of the things I find so intriguing about the study of such a history is the opportunity to understand people and events in the *context* of their time. Too often, when we study historical events, we are (whether we know it or not) biased by the outcome. We know, for instance, who won the war, but we don't appreciate that those fighting in the war didn't have that certainty of outcome; in fact, they labored under great uncertainty, fear and distress. (This is why historians so highly value diaries and journals — they are untainted by hindsight.)

Today, when we look at the aerospace industry, we see the result of 100-plus years of innovation, daring and technological advancement that have led, apparently, to this point: Global, trans-ocean, high-speed passenger travel; supersonic, super-weaponized fighters; stealthy, nimble unmanned aircraft; manned and unmanned spacecraft.

There was, however, a time when such an outcome was inconceivable and, thus, unlikely. Groom makes clear in *The Aviators* that governments and private industry struggled, early on, to understand if and how the airplane could be useful as a vehicle for commercial or military use. The United States military, in particular, was reluctant to incorporate aircraft into its arsenal, even after the success fighter pilots enjoyed in World War I.

This uncertainty is one reason why Lindbergh's nonstop, transatlantic flight from New York to Paris in 1927 was so monumental. When Lindbergh landed in Paris, he almost single-handedly ushered in a new mode of human travel. Indeed, today it's extremely difficult for us to imagine what our lives would be like without the speed and convenience of air travel. It seems like it was inevitable. But before Lindbergh took off, very few people thought it could be done. No less than Wilbur Wright, one of the inventors of the first airplane, in fact, believed that such a flight in an airplane was *impossible*. Lindbergh succeeded because he was willing to apply technology and ideas that others hadn't: He flew a more aerodynamic *mono-wing* plane; he flew alone (no navigator); he eschewed extra weight (he even trimmed the edges off of his navigation maps!); he flew what was, effectively, a fuel tank with wings.

Of course, the aerospace industry is not unique. Every paradigm-shifting invention throughout human history has been met with skepticism. Even the wheel itself, one can imagine, must have induced much head-scratching before its potential was realized. Composites are no different, and it would be helpful if we could zip 50 years into the future to get a glimpse of where carbon fiber and glass fiber structures are headed. Instead, we're here, in the moment. In context. And what is that context? Over the past 40 years, composites have seen tremendous growth and evolution, but in some quarters, they're still that poorly understood "niche" material — the square peg manufacturers want to squeeze into the round hole now occupied by metals and concrete and other established materials.

The times require Rickenbackers, Doolittles, Lindberghs — people willing to evangelize, innovate, take risks and apply composites in "impossible" ways. The good news is that the composites industry already has such leaders. We just need to let them fly.

JEFF SLOAN — Editor-In-Chief

Applying the Internet of Things to composites production efficiency

» The Internet of Things, or IoT, is defined as the technology of connecting devices, systems and services that goes *beyond* mere machine-to-machine communications. Its means of oversight — data collection, analysis *and* decision-making — does not necessarily require human intervention in the moment, yet it *does* include supervision not only of machines but also of materials, tools, process parameters *and the people that handle the materials, make the tools and run the machines*. Its significant benefits are cost and time savings and reduction of waste. This new "take" on technology is now setting footprints in various forward-thinking sectors, such as healthcare, transportation, energy, aerospace and composites manufacturing. In fact, it is my contention that it has become a *necessity for survival and competitiveness* in the aerospace and composite component manufacturing industries.

The goal of every leading aerospace manufacturer is to increase quality, productivity and traceability. This is an especially challenging proposition because building an aircraft requires collecting hundreds of thousands of data points throughout the entire build process.

Although economies of scale are expected to reduce the unit cost as the production volume increases, in many cases the opposite is the result, due to loss of process control. This causes an accelerated increase in waste. *Research shows that the waste is estimated at hundreds of thousands to millions of dollars per year for a mid-size fabricator.*

Such losses can be eliminated by bringing the world of IoT to composite parts fabrication. Two practical tools enable IoT implementation: Radio frequency identification (RFID) technology and the more recently introduced mobility technologies, e.g., tablets and smartphones. Leveraging these two tools makes it possible to automatically track and manage materials, kits, tooling, assemblies *and staff* on the production floor. By combining best-of-class engineering and manufacturing practices with these technologies, OEMs and fabricators can further push the productivity envelope, reducing their buy-to-fly ratios.

Step 1: Regain control and see the complete picture

RFID tags and scanners enable real-time, accurate information about material kits and rolls, in and out of the freezer, and provide alerts before they reach expiration thresholds. Mobility platforms, including not only tablets and smartphones but *wearable devices*, replace paper forms and barcode scanners and enable real-time reporting, online collaboration and the ability to take immediate action without relocating personnel for a meeting.

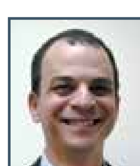
Throughout the production line, assets inherit information from "parent" assets: assemblies inherit data from kits, and kits inherit data from materials. In fact, the data set that travels with the component part includes data collected not only from each station on the production floor (preforming, molding, curing, machining, etc.) but also from tooling, assembly, kitting and even as far back as the originating material roll! Having access to such a gigantic collection of data points over a variety of timeframes, however, is of limited benefit without the ability to use that data to make decisions and take appropriate actions.

Step 2: Context-aware, real-time, data-driven action

Current practices rely on serial decision-making by separate teams of people who operate in loosely integrated systems. This can be too slow, and few teams see the whole picture. Some actions, if not taken at the right time, are no longer beneficial and, in some cases, can result in loss of precious time and material. What's missing is intelligent automation that can detect events, recognize context and act accordingly on the production floor in order to take real-time, data-driven *actions*. IoT brings to the production floor an opportunity to practice this as a holistic approach, making "context-aware" decisions, that is those that to a great degree are *dictated* by the data and, therefore, *don't need human supervision*. Examples of context-aware decisions that can arise following a holistic approach include which material to use based on expiration date, ETL (exposure time left) or roll length; triggering of work orders based on availability of tools; creation of optimized cut plan and update of roll length, according to actual work on the production floor and tool maintenance plan; and purchasing decisions and submission of bids based on real-time data. To make IoT useful, however, one must leverage the data. This requires a fully integrated, software-based, total production optimization system, which bridges the gap between engineering and manufacturing, together with full tracking of assets on the production floor, to create a true, real-time, holistic, optimized decision framework.

Turn your data into decision-making

Leading aerospace companies are now deploying advanced control and measurements applications that leverage the benefits of the IoT. To make the Internet of Things useful, one must turn that data into knowledge, and then move up to context-aware, optimized decision-making. Get your assets to start talking and collaborating. Implement the Internet of Things in your production plants.



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Avner Ben-Bassat is the president and CEO of the aerospace-industry production automation and optimization software solutions provider Plataine Ltd. (Waltham, MA, US). He has 15 years of experience in the field of complex, multi-dimensional optimization software. Ben-Bassat holds an MBA with distinction from Duke University's Fuqua School of Business and a BSc (Magna Cum Laude) in mathematics and computer sciences from Tel Aviv University.

Incremental thinking just won't cut it!

» In January, I participated in an American Composites Manufacturing Assn. (Arlington, VA, US) roadmapping workshop that identified hurdles to further penetration of composites in a range of markets. Many are familiar: lack of standards, little confidence in predictive modeling, absence of recycling infrastructure, well-entrenched legacy materials, slow composites processing, end-product variability and industry fragmentation.

There is an old axiom: "If you don't know where you're going, then any road can take you there." So, when we're asked to define an ideal future state of the industry, we typically think in terms of how we already do things, and just think about doing them faster, better and cheaper. Then we draw roadmaps that reflect this incremental thinking. I believe if composites are truly to succeed, then we cannot settle for a future that depends on incremental change. We need to make big leaps, which require serious "out of the box" thinking.

.... we cannot settle for a future that depends on incremental change.

In their seminal 1994 book, *Competing for the Future*, strategists Gary Hamel and C.K. Prahalad state: "Companies that create the future do more than satisfy customers, they constantly amaze them." They describe a consortium of electronics companies (including Apple) whose founders "dream of a world in which individuals can use a pocket sized device to cruise the streets of a typical 'downtown,' visiting the virtual travel agent, bank or library. Users will be able to send 'information agents' zipping into cyberspace to book airline reservations, check on a stock price or review the menu of a local restaurant." Published in 1994, that vision was probably articulated several years earlier. At that time, few of us even imagined the functionality it described. Today, my iPhone enables all of these things and much more, including watching live events and making video calls.

Getting out in front of the market certainly involves risk. But new technologies can be introduced on a small scale to start. Although I have no insight into BMW's automotive roadmap, I'm fairly confident that the carbon fiber composite-intensive *i3* is not a side street, but rather the on-ramp for the use of carbon fiber in BMW's main-thoroughfare *5*- and *3*-series platforms. Many think BMW's carbon fiber efforts started six or seven years ago, but they introduced the first production carbon fiber roof panels for the low-volume M-version vehicles back in the early 1990s, using a resin transfer molding process much less sophisticated than the one they use today!

Our OEM customers often articulate how easy it is to buy steel or aluminum, from multiple suppliers, that all conform to established specifications, and I have heard my colleagues in composites suggest, of late, that the composites industry should likewise develop common specifications that all suppliers can meet and then compete in the same way as metals suppliers. But I believe that would make composite materials *less* competitive.

We must stop thinking of composites as wood, metal or concrete replacements, and stop trying to imitate those same shapes (*à la* black aluminum). Instead, we should be promoting the ability of composites to assume unique forms and provide greater functionality — and, yes, the resulting product might not look like a traditional airplane, automobile or bridge. *Why should it?*

Instead of common material properties, why don't we agree on what properties are needed for design purposes, and have every material supplier provide those, and then let the most innovative and cost-effective of them (rightly) win market share? Further, a common complaint is that thousands of coupons (and millions of dollars) must be expended to obtain design allowables. But is that true? With today's computing power, that should not be necessary. I am particularly intrigued by Prof. Stephen Tsai's proposal, in the July 2014 issue of *CW* predecessor *High-Performance Composites* (short.compositesworld.com/TsaiCerTst), that all necessary allowables could be obtained with *less than 100 coupons*, and, perhaps, a *single* molded panel. Others have proposed similar approaches. This is one way to get out of the box, and I hope we can find a way to make his proposal a reality.

Here's another out-of-the-box thought: We assume that "traditional" materials have little-to no-variability and process flawlessly. The truth? Wood is far from consistent. Steel sheet from different suppliers, in fact, has slightly different behavior, and concrete properties depend very much on the weather. It's just that these industries have developed processes robust enough to accommodate such variation. We need to go beyond that, with processes that measure material variability in situ and modify the molding conditions on the fly to achieve a consistent end-product.

If we are to build a future that maximizes the potential inherent in composite materials, we have no choice but to set big goals and take the risks necessary to achieve them. Otherwise, we'll remain on the road we're on, arriving too late, accomplishing too little. CW

ABOUT THE AUTHOR

Dale Brosius is the head of his own consulting company, which serves clients in the composites industry worldwide. Services include strategic planning, market analysis, assistance in mergers and acquisitions activities and technical support. His career has included positions at US-based firms, Dow Chemical Co. (Midland, MI), Fiberite (Tempe, AZ) and successor Cytec Industries Inc. (Woodland Park, NJ), and Bankstown Airport, NSW, Australia-based Quickstep Holdings. For three years he also served as the general chair of the Society of Plastics Engineers' annual Automotive Composites Conference and Exhibition. Brosius has a BS in chemical engineering from Texas A&M University and an MBA.

Integrating NDI into manufacturing: Online inspection of CFRP prior to cure

» The composites nondestructive inspection (NDI) community has identified *online* NDI as a concept that, if conveniently developed and implemented, could benefit its manufacturing processes. During the four-year TARGET project, awarded by the Centre for Industrial Technology Development (CDTI, Madrid, Spain) in 2010 to 14 industrial partners led by Airbus Operations (Getafe, Spain), Tecnatom (Madrid, Spain) investigated how to integrate NDI into the composites manufacturing process *prior* to cure stage.

FIG. 1 UTA TRANSMISSION

Source / Tecnatom

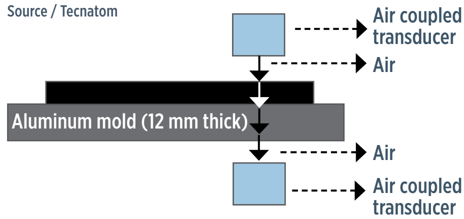
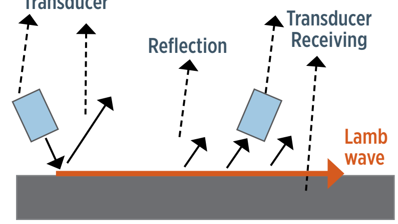


FIG. 2 UTA PITCH AND CATCH



Tecnatom's goal was to identify where NDI integration adds value, increases effectiveness and reduces cycle times and/or the need for repeated manual inspections. This resulted in three main objectives:

1. Detection of defects, enabling early mitigation and avoidance of their systematic repetition in the parts that remain in the production sequence;
2. Reduction of NDI tasks that are mandatory today in composite parts production;
3. Reduction of cycle time by automating inspection as part of the build process.

The candidate methods considered most adequate and reliable for uncured materials were the following:

Laser-generated ultrasonics (LUS). This method uses a generator laser and an interferometry detector, which is also based on a laser (the bandwidth of the detector is 1-10 MHz). Controlling the energy density on the surface of the sample (spot size) without damaging it is a key requirement for LUS systems. It is also necessary to synchronize in space and time both lasers (generation and detection) to obtain the maximum information from the generated ultrasounds. Test results showed that this method is not appropriate for inspecting uncured CFRP composites because the heat of the ultrasound generation and detection lasers partially cures the layups.

> Tecnatom investigated how to integrate NDI into the composites manufacturing process prior to cure stage.

Air-coupled ultrasonics (ACUT). A study of ACUT was completed in collaboration with the Spanish National Research Council (CSIC, Madrid). This study used various types of pulsers/receivers, plus an oscilloscope and several pairs of transducers, with frequencies of 0.25 MHz and 0.65 MHz. An aluminum mold was used to represent the tooling, which will exist beneath the actual layups during manufacturing. This method allows inspection without a coupling medium, the ultrasounds being propagated through the air, as its name suggests. Two techniques were tested: normal incidence transmission (longitudinal waves) and pitch and catch from a single face (Lamb wave), as shown in Figs. 1 & 2, above. Prior to this investigation, little information was available about the ultrasonic properties of uncured CFRP. Therefore, a detailed study of prepreg layups was first performed to determine ultrasound velocity and attenuation, and these properties were used to model ultrasonic propagation through the system to define the appropriate inspection configuration. The results showed that wide-band (>25%) and low-frequency (<0.5 MHz) transducers are required to avoid the problem of very high attenuation in uncured CFRP. Likewise, a very high sensitivity (<-30 dB) is required in order to have a sufficiently high signal level transmitted.

Samples then were fabricated, using hand layup of up to 30 plies and different compaction schemes, with Teflon inserts to simulate the presence of defects. Inspections were performed throughout fabrication, evaluating the technique for uncured materials with different degrees of compaction and also to test the influence of ply count. It was expected that areas lacking compaction, though not a real defect (they would be removed during autoclave cure), would significantly affect the inspection, as would a larger number of plies. It also was expected that due to the high attenuation of the uncured material, inspection would be required for every new ply.

Comparing the amplitude of the received signal with a different number of plies after the same compaction procedure, it was possible to estimate the attenuation coefficient in the laminate, which was highly dependent on compaction. From these results, the maximum number of plies that can be inspected with this configuration was determined. For example, after a short compaction (less than 1 hour), inspection limit is 2-3 plies, but for uncompacted material, this is reduced to one ply. By comparison, after a long compaction (more than 15 hours) it should be possible to inspect 5-6 plies.

Results obtained using the transmission technique show that it is possible to identify, isolate and register the signal transmitted »


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FIG. 3:

Infrared thermography data acquisition (ACQ) of inclusions in multi-ply layup.

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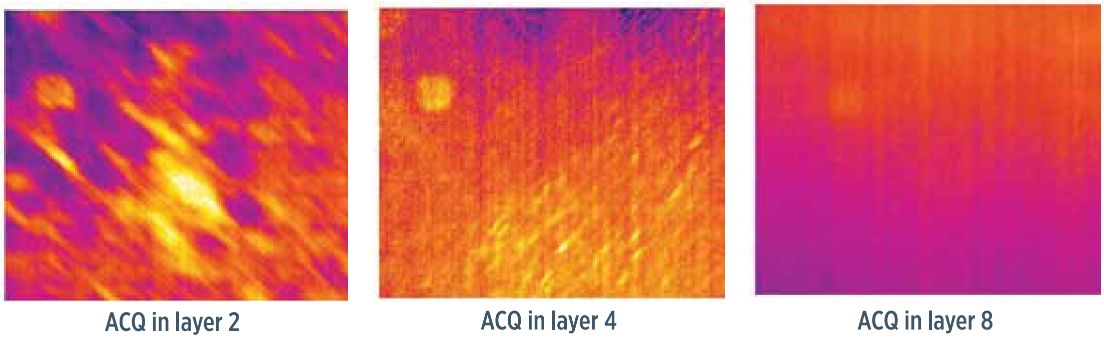


through the material and differentiate it from the multiple reflections that might appear. The presence of defects in the material causes a loss in the energy transmitted, which is seen as a drop in the amplitude of the transmitted signal. Thus, it was possible to detect 10- by 10-mm Teflon inserts at different depths compared to insert-free areas. Significantly, it was not necessary to inspect after every ply for *compacted material*, so this method can, indeed, reduce inspections and, thus, increase efficiency, if the method is used correctly.

The ACUT results for pitch and catch, however, reveal low signal amplitude and a very poor signal-to-noise ratio for uncured CFRP. This ACUT technique, therefore, ought only to be used when access to the part is limited to one side, and even then, the signal will require preamplifiers and other hardware and software tools to improve results.

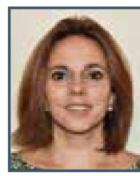
Phased-array ultrasonics (UTPA)**.** Tests were performed using electronic phased-array ultrasonics, with 16 full parallel channels and 64 multiplexed channels. Shoes (interface wedges used to steer longitudinal waves at relatively low angles) of different materials and thicknesses (16-30 mm) were used as well as several types of coupling media and transducers of different characteristics: Phased-array, wheels (phased-array probes embedded in a wheel made of a special rubber, and filled up with water) and frequencies between 0.185 mHz and 5 mHz. »

This method is limited by contamination. Different inspection strategies were tested without using liquid coupling media, but these prevented the transmission of the ultrasounds between the part and the transducer. The poor results obtained effectively ruled out this technique, since the ultrasounds are incapable of passing through the vacuum bag, which is essential to prevent contamination of the uncured material during the manufacturing process.

Infrared Thermography (IT). Equipment includes an infrared camera with a 640 by 480 pixel long-wave detector, 24° lens and thermal sensitivity of 30 mK at 30°C, as well as a 1,500W halogen spotlight for heating that is programmable to control duration of the pulses. The camera is connected to a computer for direct acquisition of images at 50 Hz (50 frames per second). In the tests, the camera and the halogen spotlight are placed on a plane parallel to the specimen to be inspected, with suitable focusing. The objective is to achieve a maximum percentage of inspection and a uniform beam of light.

Valencia University (Valencia, Spain) assessed different pulse durations at different distances to compare the degrees of ply compaction in subsequent analysis. Inspection testing showed that, depending on the increase in temperature (the longer the heat pulse, the higher the temperature) and the number of frames (the longer the inspection time, the higher number of frames), greater degrees of compaction result in greater heat transfer. Thus, to automate this technique for efficient defect detection, the heating excitation must be controlled according to both thickness *and* compaction. With such control, this method detected Teflon inserts in the fourth or fifth ply from the one in which they were positioned (see Fig. 3, p. 12).

To date, the two most promising pre-cure NDT candidates are IT and ACUT. Tecnatom has made detailed studies of online integration requirements for both techniques in a production environment, and has already adapted ACUT to its commercial robot-based Rabit systems, which were installed at customer facilities in 2014. Initial evaluation of IT/robot integration also has been completed, and a working procedure for online integration is established. Other technologies are still under investigation. CW



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Esmeralda Cuevas is the head of nondestructive testing (NDT) technologies for aeronautical components at Tecnatom SA (San Sebastian de Los Reyes, Spain). She has 13 years of experience in NDT, eight researching innovative technologies, including those presented here, shearography, and simulation tools, such as Civa, where the ultrasound beam is modeled to understand its energy profile and interaction with simulated defects. She holds an MSc in chemistry specialized in physics, spectroscopy and quantum mechanics, with Level II certifications in ultrasonic testing (metallic, nonmetallic and aeronautic, UNE 473) and NDT inspection (UNE 4179).

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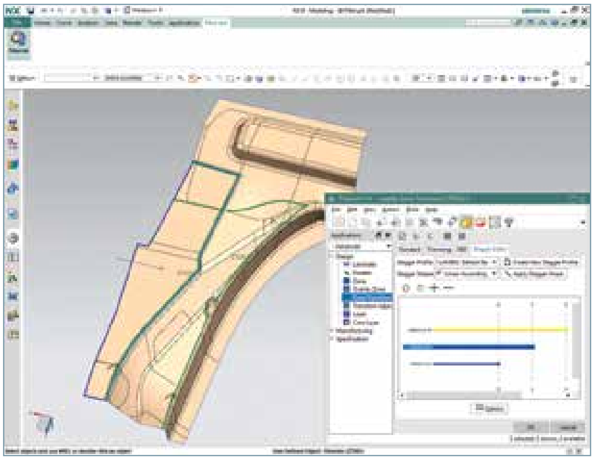

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CW Business Index at 51.9 – Three straight months of US growth

» At 51.9 in January 2015, the *CompositesWorld* Business Index showed that the US composites industry had expanded for a third straight month. Prior to that, the Index had hovered around 50.0 from July through October 2014 — the industry had been virtually flat. But, in the last two months of the year, the industry began to expand. Although the Index indicated expansion in the short term, compared to the same period one year earlier, the industry had shown contraction in two of the final four months of the period. The annual rate of change was growing in January but the rate of growth had decelerated during the previous four-month period.

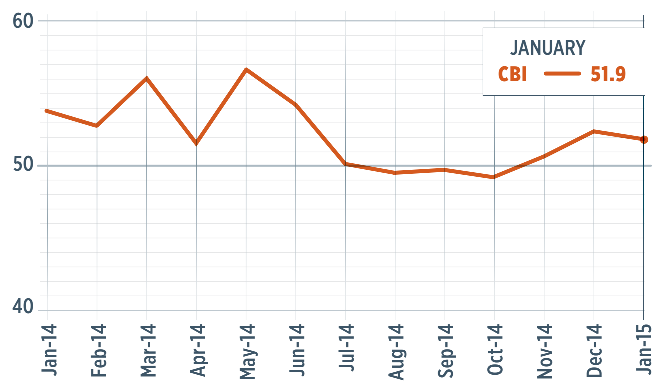
New orders, however, grew for the 14th consecutive month in January. The rate of increase in new orders had been accelerating since July. Production had expanded for almost as long — 13 months. The rate of increase improved markedly in January, and the production subindex was at its highest level since July. Backlogs had contracted every month but one since May 2014. Compared to one year earlier, backlogs contracted 8.9% in January. The trend in backlogs indicated that the industry was very near its peak rate of growth in capacity utilization. That, in turn, indicated that capital spending should peak later this year. Employment continued to grow, but the rate of growth was very modest in January. Exports continued to contract, thanks to the strengthening dollar. Supplier deliveries lengthened at their fastest pace since April 2012.

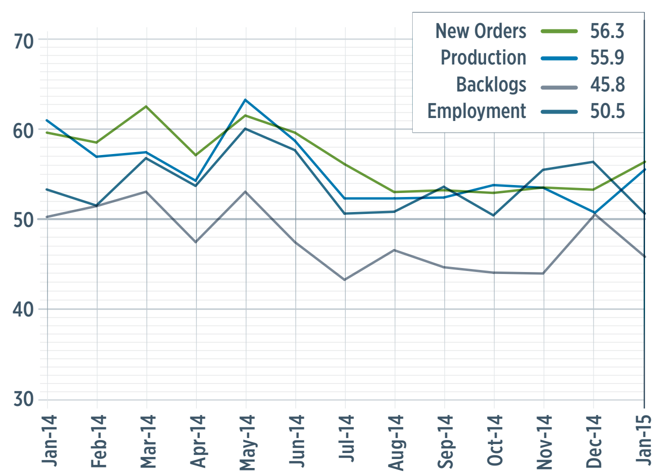
The rate of increase in material prices had slowed dramatically in the months prior to January. The material prices subindex was at its lowest level since September 2012. Prices received increased for the second month in a row and, indeed, had been increasing, generally, since December 2013. Future business expectations decreased in January, but the general trend had been upward since August 2014.

Facilities with more than 100 employees continued to expand at a very fast rate. Both size categories above 100 employees had indices that ran above 60. Plants with 50-99 employees also expanded and did so at their fastest rate since February 2014. Fabricators with fewer than 50 employees, however, contracted aqain, and did so at a faster rate than they did in December 2014, continuing a decline begun several months earlier.

Regionally in the US, the North Central – West was easily the fastest growing sector for a second month in a row. By Feb. 1, it had expanded in three of the previous four months. It was followed by the North Central – East and the West. The latter had mounted the longest stretch of expansion of any US region. The Northeast and Southeast regions, by contrast, both contracted for a second month in a row.

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





Future capital spending plans were above US$1 million for only the second time since June 2014. But compared to one year earlier, they were *down* 13% in January. The month-over-month rate of change had contracted six of the previous seven months. The annual rate of change had contracted at an accelerating rate in both December 2014 and January 2015. CW

ABOUT THE AUTHOR

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

It's politics as usual with the US PTC, Bombardier tables its innovative, composites-intensive *Learjet 85*, IACMI takes its fledgling first steps and a SOLAS ship's composite cargo hold cover earns its first flag fire approval.

ENERGY

US wind energy PTC extension uncertain ... again

Source | TPI Composites

Progressive minds in Europe and Asia must wonder at times what can be the matter with those Americans, but it is their special gift, it seems, to make public/private innovation efforts — especially those concerned with energy innovation — unusually fraught with uncertainty. The Production Tax Credit (PTC), long a bone of contention in the US Congress, is a perennial case in point. Despite clear and overwhelming evidence as to its usefulness in stimulating *private* investment in clean energy in the form of wind- and solar-generated electricity, the PTC is often extended only after much hand wringing, and often at the 11th hour, to dire warnings, in some quarters, about the ill effects it will have on the economy.

This all seems unnecessary. In fourth quarter 2014, alone, just for example, the American Wind Energy Assn. (AWEA, Washington DC, US) reports that 1,789 wind turbines, each with three massive blades molded from composites, were installed in a total of 32 wind farms in 14 US states, totaling 4.85 GW. But that was *well short* of the *13* GW installed during the same period in 2012 when Americans were still pulling themselves out of the worst recession since the Great Depression and the PTC, as part of emergency economic stimulus efforts, *had been extended for multiple years.* In 2014, it had not.

Given an opportunity to dispel that uncertainty in 2015, as *CW* went to press, the US Senate instead rejected Senate Amendment 133, proposed to a bill that would fund the controversial Keystone XL pipeline project. The pipeline would bring oil pumped from Canadian oil deposits into the US. The amendment, proposed by US Senator Heidi Heitkamp, a Democrat from the US state of North Dakota, who is a strong supporter of the pipeline project, would have extended the PTC for *five years.* (If you're not familiar with the US political landscape, Democrats are not usually high-profile oil-industry advocates.)

Although Heitkamp's amendment was defeated in a 47-51 vote, she defends her "all-of-the-above" approach as part of a forward-thinking effort that refuses to see the future as a choice *between,* with oil and coal on one side, and wind and solar on the other. AWEA senior VP of federal legislative affairs and *Into the Wind* blogger Jim Reilly says Congress should act to extend the PTC as soon as possible, for as long as possible and agrees that "Senator Heitkamp's amendment to extend the PTC could have encouraged a constructive, bipartisan conversation about how to do that. Instead the amendment ... was viewed as a political issue rather than an opportunity to advance important policy and America's energy security. Wind energy has bipartisan appeal among voters across the country and in Congress."

Wind energy technology and composites have striking advantages that, in the end, make them very similar in terms of their ultimate value. Wind is a free, abundant and clean resource. Oil is a primary source of the world's pollution, and is a finite and dwindling resource. Composites, ironically enough, are made, in part, from oil, but once made, do not rust or pollute, show greater strength- and stiffness-to-weight and fatigue resistance than competing materials, do not corrode like metals, and in terms of lifecycle cost *have always been the best economic choice*. The fact that a Middle Eastern oil cartel recently reduced the price of crude oil in the world marketplace changes none of that.

The oil industry has enjoyed, almost from its inception, unbroken tax protection granted by the US government. That fact helped jump-start and maintain the US industrial powerhouse in the late 19th and early 20th centuries. One has to wonder if that same courtesy, extended to the wind and solar energy industries, could secure the same for America's future.

MARINE

Composites replace steel in hatches

Replacing the steel in hatches and other components on large cargo ships with fiber-reinforced plastic (FRP) would reduce costs associated with corrosion, but for ships that sail from Safety of Life at Sea (SOLAS) countries (signers of an international maritime safety treaty) fire regulations based on steel have, thus far, stifled efforts because FRP advocates must be able to demonstrate fire safety equivalence. According to Tommy Hertzberg, fire researcher at SP Technical Research Institute of Sweden (SP, Borås, Sweden), Panama's flag authority for ships has become the first to approve a composites conversion, based on equivalence to steel demonstrated by SP. This first use in a SOLAS ship is described as a breakthrough and will be on a cargo vessel owned by the Danish shipping company Nordic Bulk Carriers AS.

"We have contributed our know-how to the Norwegian group and DNV-GL [the Høvik, Norway-based global ship and offshore classification society], which in conjunction with the Japanese shipyard Oshima, has produced a clever, lightweight design that resolves many of the problems with steel hatches," adds Hertzberg. SP presented its latest results at the International Maritime Organization's February conference on Ship Design and Construction.

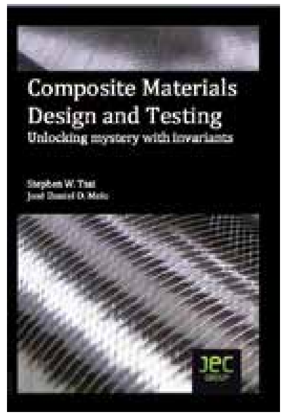
Read more online | **short.compositesworld.com/FRPhatch**


WE'RE MOVING!
Please visit us at
JEC Europe, Paris,
Hall 7.3, Booth F31

AEROSPACE

Tsai book expands on invariant-based method for material characterization

In the July 2014 issue of CW's *High-Performance Composites* magazine, Dr. Stephen Tsai, professor research emeritus in the Department of Aeronautics & Astronautics at Stanford University, suggested an invariant-based method for accelerating aerospace certification testing. He identified *trace* (the sum of three components of stiffness, plus that of shear) as the one and only property of composites that can make composites easier to understand, and design and testing of composites simple and straightforward.



Now, Tsai and José Daniel Diniz Melo, a consulting professor at Stanford, have expanded on this topic in their upcoming book, *Composite Materials Design and Testing - Unlocking mystery with invariants*. There, they explain that for all carbon/epoxy composites in use today, the stiffness of all laminates is simply a fixed fraction of trace. For example, they say, longitudinal stiffness is 88% trace, and stiffness of [ϖ/4] is 34% of trace — all within an error of 1.5% or less. So, according to Tsai, if one measures the value of trace for each material, then one can predict the stiffness of *all* the laminates that material will make.

Among Tsai and Melo's recommendations are homogenization through use of thin plies, continuous as opposed to discrete ply angles, a ranking procedure to reach optimal profile and ply drop, bi-angle instead of unitape building blocks, tapered edges to reduce scrap and edge delamination, and others. Such strategies, they say, will make composites more competitive, and make simultaneous weight and cost savings possible.

Chapter titles from the book include: Stress-Strain Relations, Ply Stiffness, In-Plane Stiffness, Flexural Stiffness of Symmetric Laminates, Stiffness of General Laminates, Micromechanics, Failure Criteria, Strength of Laminates, The Invariant-Based Approach to Stiffness, The Invariant-Based Approach to Strength, New Opportunities in Design and Testing and Mechanical Testing of Composites.

Composite Materials Design and Testing - Unlocking mystery with invariants is available for sale now (US$110) at **http://stanford.edu/group/composites**.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JEC Europe 2015: Innovation Award winners

The JEC Group is calling it its 50th European meeting, and expects JEC Europe 2015 to fill up three halls of Pavilion 7 at the Paris Expo, in Porte de Versailles, Paris, France. One of the highlights of the event, held this year March 10-12, is the display on the trade show floor of winners and also-rans in the JEC Innovation Awards. This year's jury has selected what it considers the best composite innovations, based on technical interest, market potential, partnerships, financial and environmental impact, and originality. Eighteen composites manufacturers and their partners were recognized and will receive awards during the JEC Europe awards ceremony. "For this edition, we have received more than 80 applications from 20 different countries," says Frédérique Mutel, JEC Group president and CEO. The JEC Innovation Awards Program is sponsored by Cytec Aerospace Materials (Tempe, AZ, US) and supported by *JEC Composites* magazine and *Aviation Week* (a Penton publication, New York, NY, US).

Winners, in JEC's categories are as follows:

REINFORCEMENTS: Xedera e.U. (Vienna, Austria), for combining improved hybrid yarn technology with advanced textile weaving and processing methods.

RESINS: AkzoNobel Polymer Chemistry (Amsterdam, The Netherlands), for its novel water-insensitive curing systems for bio-fiber-reinforced composites.

SEMI-PRODUCTS (that is, semi-finished products): Faurecia (Nanterre, France), for its long flax fiber/acrylic uni tape, used in a sandwich construction for multi-position trunk load-floors or structural floors.

LABORATORY EQUIPMENT: Pole de Plasturgie de L'Est (PPE, Saint-Avold, France), for its "3D permeability bench," a method for measuring the permeability of reinforcements in multiple directions, which was launched at JEC Asia in 2014.

PROCESS: BA Composites (Wiefelstede, Germany), a subsidiary of Broetje Automation Group, for its automated fiber placement work cell/center for the production of carbon fiber parts.

HEAVY MACHINERY: National Aerospace Laboratory (Amsterdam, The Netherlands), for hybrid composite solutions for heavy-duty construction equipment, including a front-end loader bucket.

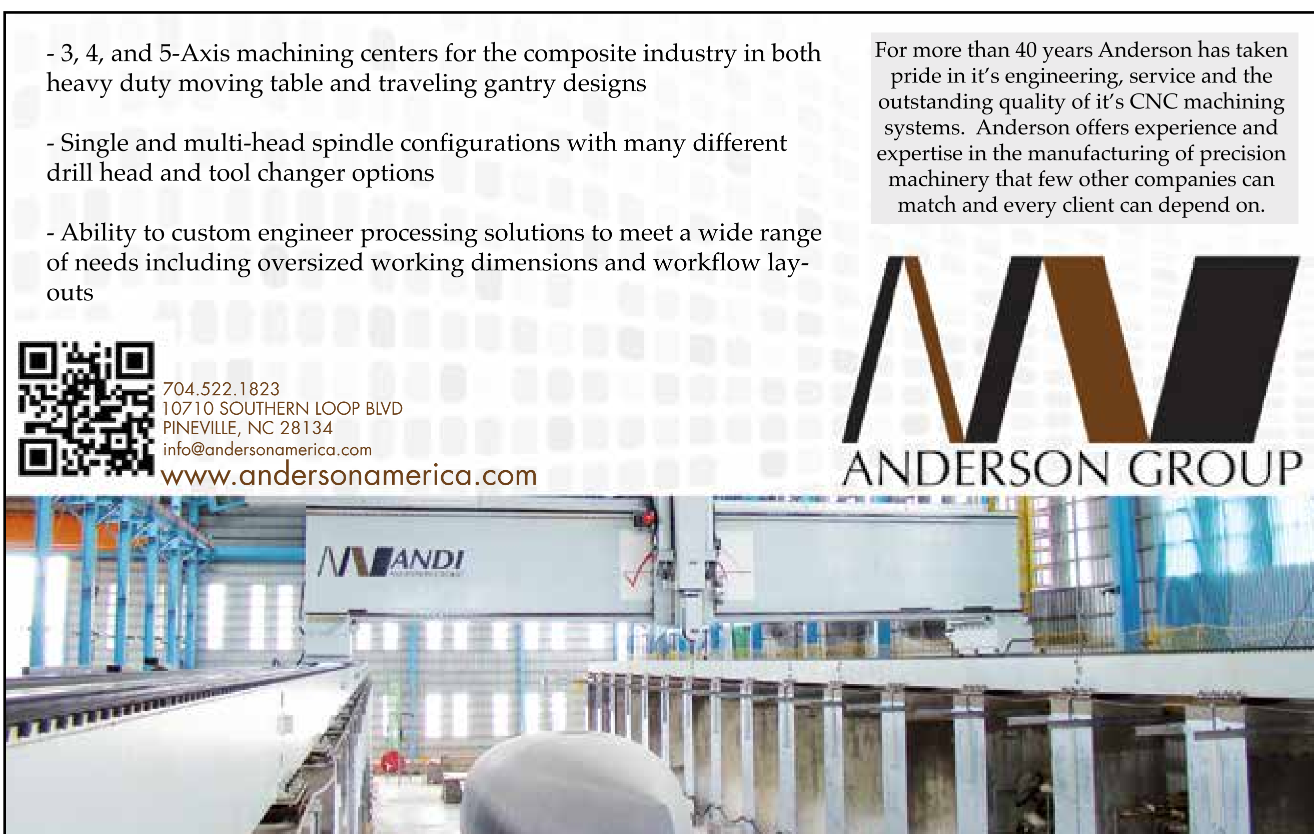
BUILDING (or Architectural): MVC Solutions in Plastics (São José dos Pinhais, Brazil), for a composite-based structural system for constructing buildings, planned for launch in 2016.
CONSTRUCTION: Arup Deutschland (Düsseldorf, Germany) and GXN Innovation (Copenhagen, Denmark), for the BioBuild façade system, formed with bio-composites.
TRANSPORTATION: MAN Truck & Bus AG (Munich, Germany) for its carbon fiber-reinforced polymer air spring beams for city buses.
AUTOMOTIVE BODY-IN-WHITE: Automaker PSA Peugeot Citroën (Paris, France), for its design and manufacture of a 100%-composite, self-supporting front floor module.
AUTOMOTIVE SAFETY: Hyundai Motor Europe Technical Centre (Rüsselsheim, Germany), for a curved front bumper crash beam, produced in a reactive thermoplastic pultrusion process.
AERONAUTICS: Hexcel (Stamford, CT, US and Les Avenières, France), working with partner Aerolia SAS, for its role in the conception, design and testing of a self-stiffened aircraft fuselage panel demonstrator, made with Hexcel's HiTape dry reinforcements in a vacuum infusion process.
UAV (or Unmanned Aerial Vehicle systems): Rapid Composites (Myakka City, FL, US), for its amphibious quadcopter UAV drone.
TELECOMMUNICATIONS: DCNS (La Montagne, France), for a composite antenna embedded into a motorhome roof for television reception.
SUSTAINABILITY: EcoTechnilin (Kimbolton, Cambridgeshire, UK), for its bio-sourced, fast-curing, structural composite for aircraft applications.
SPORTS & LEISURE: Blackstone Tek (Randburg, South Africa), for a generic carbon fiber motorcycle wheel.
JURY PRIZE: Hyundai Motor Co. (Republic of Korea), for its carbon fiber composite frame design for an automotive body-in-white.
JEC COMPOSITES MAGAZINE SPECIAL PRIZE: VX Aerospace (Morganton, NC, US), for its VX-1 *KittyHawk* aircraft, which employs C-ply reinforcements from Chomarat (Le Cheylard, France).

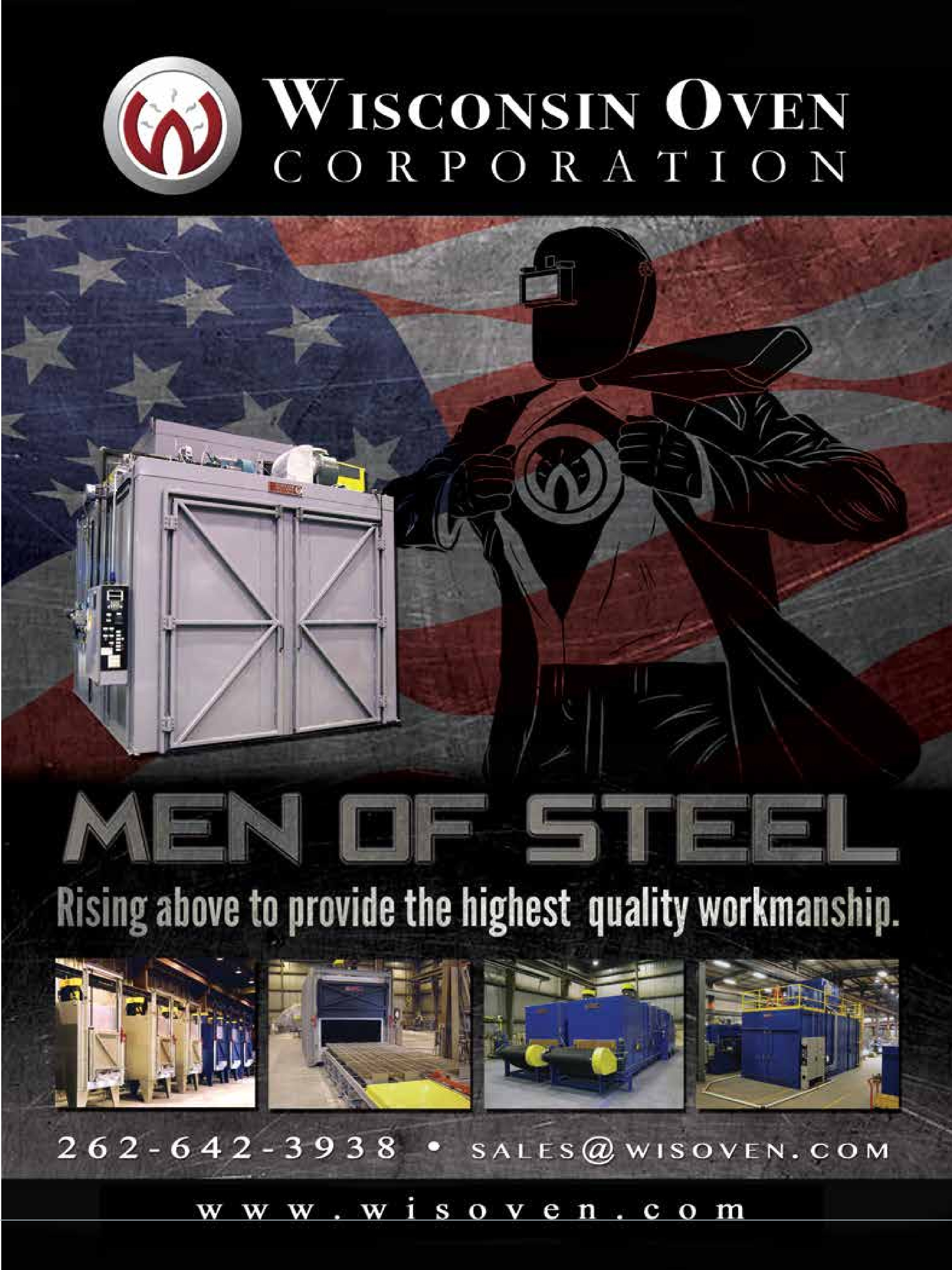
If you're attending the JEC Europe show, don't forget to stop by and visit the *CW* staff. We'll be located in Pavilion 7, Hall 3, Stand A35.

CONSTRUCTION

No small feat: Epitome composite foundations code-certified

In residential home construction, building codes rule the day. Materials used must be authorized by whatever code-issuing authority holds power. Thus, what on its face seems like modest news, actually has some real import for the composites industry. Composite Panel Systems LLC's (CPS, Eagle River, WI, US) Epitome-brand composite foundation walls have met the guidelines of an in-plant quality program and successfully completed the testing and building code requirements set by NTA Inc., accredited by the International Accreditation Service (IAS), a subsidiary of the International Code Council (ICC). This means that the product certification mark grants Epitome quality foundation walls national code compliance for residential foundations. This could be a major jumping-off point for the Epitome product, which is designed to replace concrete foundation walls with prefabricated composite panels. Epitome combines structure, continuous insulation, a double top plate, integrated stud cavities, waterproofing *and* a vapor barrier all in a single product. Plus, it installs in a fraction of the time that concrete requires, with far less labor. CPS founder Glenn Schiffmann claims Epitome is the greatest thing to happen to home construction since the advent of plywood. He could be right.

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MONTH IN REVIEW

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

Hydrasports' fishing boat receives MIL-TOUGH rating
Hydrasports' new *53 Sueños* center-console fishing boat features Structural Composites' single-skin transom and single-skin hull.
02/09/14 | short.compositesworld.com/53Suenos

AeroMobil flying car in flight testing
The composites-intensive *AeroMobil 3.0*, made in Slovakia, is in flight testing and could be available in two to three years.
02/09/15 | short.compositesworld.com/AeroMobil3

Pinette supplies R&D platform to Canada's National Research Council
Pinette Emidecau's equipment will support the development of thermoplastic and thermoset composites using press molding technologies, including HP-RTM.
02/09/15 | short.compositesworld.com/PEI-NRC

MHI Vestas begins hiring for 80m wind blade manufacturing
The 80m blades will be fabricated for DONG Energy's 258-MW Burbo Bank Extension project, off the coast of Liverpool Bay in the UK.
02/09/15 | short.compositesworld.com/Vestas80bl

Deakin University carbon fiber center earns quality certification
Australia-based Deakin University says its Carbon Nexus carbon fiber research center has earned the ISO 9001:2008 quality certification.
02/09/15 | short.compositesworld.com/DeakinCFC

Boeing begins erection of 777X wing manufacturing plant
The *Puget Sound Business Journal* reports that the 120,774m^2 building is taking shape, and manufacture of the carbon fiber composite wings will start in 2016.
02/09/15 | short.compositesworld.com/777Xplant

Sikorsky S-97 *RAIDER* begins ground testing
This 100% industry-funded military helicopter features coaxial counter-rotating main rotors and a pusher propeller and can fly as fast as 220 knots.
02/09/15 |short.compositesworld.com/97Raider

Vanguard achieves Nadcap accreditation
In addition to recent delivery of critical structures for Lockheed Martin's AEHF space program, the company also received the quality certificate.
02/09/15 | short.compositesworld.com/VanguardNC

Albany Engineered Composites and Ricardo announce automotive partnership
The partnership will investigate introduction of advanced 3D fabrics and composites into automotive applications, for lightweighting.
02/09/15 | short.compositesworld.com/AECAuto

Carbon nanotubes might toughen ceramic matrix composites
Japanese researchers explore what has hindered CNT performance and new discoveries that produce CMCs with unprecedented properties.
02/03/15 | short.compositesworld.com/CNTs4CMCs

Report assesses outlook for automotive composites through 2024
Visiongain's Automotive Composites Market Forecast 2014-2024 evaluates current and prospective use of composites in auto manufacturing.
02/02/15 | short.compositesworld.com/VG-A14-24

F-35 Lightning II near completion of all-weather climatic testing
The composites-intensive jet is nearing the end of six months of trials in wind, solar radiation, fog, humidity, rain, freezing rain, icing, clouds and snow.
01/26/15 | short.compositesworld.com/F35WTests

IACMI takes first steps following US$70 million DoE award

The big news in January was the announcement that the University of Tennessee (Knoxville, TN, US) will lead the new Institute for Advanced Composites Manufacturing Innovation (IACMI), a US$259 million public/private partnership. The Institute's funding reflects a US$70 million commitment from the US Department of Energy (DoE) and US$189 million from IACMI's partners, including a US$15 million commitment from the Tennessee Department of Economic and Community Development. Supported by the Advanced Manufacturing Office in the DoE's Office of Energy Efficiency and Renewable Energy, IACMI joins four other institutes backed by the Obama Administration in a recent push to accelerate advanced manufacturing.

The overall emphasis of IACMI will be on reducing composites manufacturing costs — in part, by reducing composites manufacturing energy consumption — and improving the technologies and processes for recycling of composites. We do know that IACMI is organized around five areas: vehicles (Michigan); wind turbines (Colorado); compressed gas storage (Ohio); design, modeling and simulation (Indiana); and composite materials and processing technology (Tennessee, supported by Kentucky).

The question now is, "What's next?" Winning the investment was one thing, but IACMI has to organize the work to be done — in short, to confirm who's doing what.

IACMI's research will be guided by universities in each of the "anchor" states, as well as governmental organizations, such as Oak Ridge National Labs (ORNL, Oak Ridge, TN, US) and the National Renewable Energy Laboratory (NREL, Boulder, CO, US). Also at the table will be several "charter" investors, which have contributed most significantly to the IACMI. They are Dow Chemical Co. (Midland, MI, US), Ford Motor Co. (Dearborn, MI, US), Volkswagen (Herndon, VA, US), Dassault Systèmes (Waltham, MA, US), Lockheed Martin (Bethesda, MD, US) and DowAksa (Marietta, GA, US).

IACMI's geographical/topical areas will pursue projects with practical ends in mind. On the automotive side, for example, the Michigan-based group will mount a concerted effort to develop a low-cost — that is, not conventional PAN-based — carbon fiber manufacturing technology that will be used as feedstock in the production of a new prepreg material. This prepreg then will feed a 1,000-ton, pilot-scale compression molding press to assess the material's suitability for automotive body panels and other components. The effort is expected to graduate to a full-scale, 3,000-ton compression press.

Also in the works by IACMI are several efforts aimed at workforce development: a K-12 science, technology, engineering and math (STEM) education program, and a workforce retraining and internship program, which will be developed at the university and community college level.

To see a full list of the partners involved in IACMI, visit the CW Web site | **short.compositesworld.com/IACMIlsit**
To view a video about the IACMI, go here | **http://manufacturing.gov/iacmi.html**
Read *CW* editor-in-chief Jeff Sloan's February commentary on the IACMI partnership online | **short.compositesworld.com/Ed-IACMI**

AEROSPACE

Bombardier tables Learjet 85 development

Bombardier (Montreal, Quebec, Canada) announced in mid-January that it is pausing the development of the composites-intensive *Learjet 85* and laying off 1,000 employees in Wichita, KS, US, and Querétaro, Mexico, who were working on the program. As a result, the company will record a pre-tax special charge in the fourth quarter of 2014 of approximately US$1.4 billion, mainly related to the impairment of the *Learjet 85* development costs. Bombardier pointed to the sluggish business jet market as the reason for the action.

Source | Bombardier

"Bombardier constantly monitors its product strategy and development priorities," says Pierre Beaudoin, president and CEO, Bombardier. "Given the weakness of the market, we made the difficult decision to pause the *Learjet 85* program at this time. We will focus our resources on our two other clean-sheet aircraft programs under development, *CSeries* and *Global 7000/8000*, for which we see tremendous market potential. Both programs are progressing well."

Although careful use of the word *pause* in its official statements leaves open the option of resurrecting the *Learjet 85* program, it's also possible that Bombardier is finally cutting its losses and simply moving on.

Its *Learjet 85* troubles first surfaced not with slow sales but, instead, technical challenges. After its stunning announcement that it would fabricate the fuselage using out-of-autoclave prepreg, it determined to do so in Querétaro, where, at an altitude of 1,828m, available vacuum consolidation pressure was 20% lower than that possible at sea level, testing Bombardier's process severely. Still, when Bombardier's Pierre Harter reported on the *Learjet 85's* composites work at SAMPE 2013, it sounded to observers like this and other technical hurdles had been cleared. Bombardier went on to report void content of <1% in oven-cured fuselage structure. Further, carbon fiber wingskins and spars for the plane were being fabricated in Belfast, Northern Ireland, using *an in-autoclave* resin transfer infusion (RTI) process — also new.

Whether or not the program survives, there's no argument that Bombardier was unusually ambitious in the application of composites to the aircraft — particularly one of its relatively small size. Such progressive methods, it is hoped, can be applied elsewhere (perhaps not in Queretaro) even if they don't bring to life the *Learjet 85.*

AUTOMOTIVE

Fasteners for CFRP automotive parts

One issue raised by the continued expansion of lightweight CFRP in automobiles is attachment. A leading supplier of automotive fasteners in Europe for a century, Nedschroef's (Helmond, The Netherlands) Techno Centre R&D facility saw a need to develop and mass-produce fasteners for CFRP automotive parts. It tested a wide variety of thermoset and thermoplastic laminates from OEM and supplier sources, including samples made from unidirectional, multiaxial and woven fabric laminates in a range of disparate layups. Surface pressure testing, in which a high-strength steel cylinder is pushed into the CFRP laminate until visual indentation, showed that as stronger fasteners are used, they must be designed with larger bearing surfaces in order to avoid indentations in CFRP counter plates. Results from friction tests included that friction of standard automotive fasteners on CFRP plates is 40-50% lower than on metal plates.

To meet the challenge of galvanic corrosion, Nedschroef investigated nonmetallic coatings to enable mating of CFRP with steel and aluminum rather than resort to expensive solutions like titanium. When standard automotive coatings failed, untypical automotive solutions, including ceramic, insulation and nanocoatings were investigated. Potential solutions, which showed promising results after more than 1,000 hours of salt spray testing, included the following:

- A new insulation coating for EN AW 6056 aluminum fasteners;
- Two new coatings for steel fasteners;
- A special heat treatment for stainless steel-grade 316 fasteners.

Based on this large testing project, Nedschroef is not only modifying its current portfolio to provide faster and more cost-efficient CFRP fastening solutions, but is also introducing completely new fasteners for CFRP components that reportedly allow transfer of greater forces than other fastening solutions and the best possibility for success in exploiting the benefits of lightweight CFRP for automotive components.

After significant testing using CFRP plates (laminates representative of those in the BMW *i3* are shown in the photos on p. 34), Nedschroef has developed fastener solutions that include coatings for an aluminum bolt (center fastener, top photo) and for steel bolts (left and right pairs in bottom photo) which survived more than 1,000 hours of corrosive salt spray testing.

Read more online | http://short.compositesworld.com/Bolts4CFRP

Carbon Fiber 2014 Conference Report

Alternative PAN precursor, carbon fiber supply and demand, and carbon composites on commercial aircraft top the bill at December's event on the US West Coast.

By Jeff Sloan / Editor-in-Chief & **Sara Black** / Technical Editor

West Coast Convocation

CompositesWorld's annual Carbon Fiber conference was held in early December 2014 in La Jolla, CA, US.

Source | CW / Photo | Jeff Sloan

Alternative Precursor Research

Oak Ridge National Laboratory's Connie Jackson reviewed ORNL's progress in the area of creating low-cost carbon fiber from unmodified, ultra-large tow (300-610K) textile PAN material, supplied by Kaltex (Naucalpan, Mexico).

Source | CW / Photo | Jeff Sloan

» CompositesWorld's annual Carbon Fiber conference was held in early December 2014 in La Jolla, CA, US. Editors Jeff Sloan and Sara Black were there and offer this report on the proceedings.

Composites industry consultant Tony Roberts, principal of AJR Consultant (Orange, CA, US), presented to the conference his estimates of carbon fiber supply and demand over the next several years. He foresees carbon fiber demand more than doubling in the next decade, reaching 170,000 MT by 2025 (see break out figures in chart on p. 40).

Leading the effort to meet this demand will be Toray Industries (Tokyo, Japan), followed by Toho-Tenax and Mitsubishi Rayon Co. Ltd., all headquartered in Tokyo, Japan, with production facilities there and in North America and Europe. Supply of carbon fiber out of China, a new and growing phenomenon, is the most difficult to forecast, he said, noting that precursor quality and supply problems in that country have made consistent production of quality carbon fiber difficult to maintain. Roberts predicted that the industrial carbon fiber market, dominated by automotive and wind energy, will continue its growth throughout this decade and into the next. His overall message regarding carbon fiber supply and demand was positive: "I feel the industry has really moved forward now, and we're well-set for the future."

Low-cost carbon fiber research

At recent conferences, alternative precursors that might enable production of less-expensive carbon fiber have been on the agenda. The 2014 meeting was no exception. Connie Jackson, manager of Oak Ridge National Laboratory's (ORNL, Oak Ridge, TN, US) carbon fiber facility, reviewed ORNL's progress in the area of creating carbon fiber from unmodified textile PAN material supplied by Kaltex (Naucalpan, Mexico). The ultra-large tow (300K to 610K) fiber has a kidney/dog-bone shape with "a lot of surface area" and "modest" properties: Since issues with fused filaments were addressed, said Jackson, "we've achieved approximately 500 ksi in fiber testing." The group is tailoring the fiber, which can be split to lower tow counts, to specific applications that don't require aerospace-grade fiber. In addition, three other textile PAN sources will be evaluated in FY2015, she reported, along with methods to reduce precursor crimp. In the face of some pointed questions, Jackson defended the group's work, pointing out that ORNL is trying to lower market entry barriers for groups interested in making fiber.

Hailing from Australia's Future Fibres Research and Innovation Centre (AFFRIC) located at Deakin University (Geelong, VIC, Australia), Shaun Smith described work there on improving carbon fiber. The group's Carbon Nexus fiber-manufacturing facility, a pilot line that is open to groups engaged in advanced-fiber research, aims to dispel the "mystique" surrounding carbon production, which has stymied innovation by current producers and presented a high barrier to entry for startups. AFFRIC has been investing in the application of RAFT (reversible addition fragmentation-chain transfer) monomer technology, which reportedly has the ability to create longer, more consistent carbon chains during fiber production. Scale-up is in progress, reported Smith, and he aims to answer the question "is RAFT PAN precursor better than traditional PAN?"

Mike Canario, VP and GM Americas at Hexcel (Stamford, CT, US), addressed the opportunities and challenges associated with his company's role as a carbon fiber supplier to the composites industry. He noted, first, that since the mid-1980s, carbon fiber demand in the aerospace industry has been fueled, in part, by several important but relatively low-volume military programs, including the B-2, V-22, F-22 »


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Carbon fiber demand (all tow sizes, all types)	
2015	65,000 MT
2020	120,000 MT
2025	170,000 MT

Market share, 2020	
Aerospace/defense	18%, 21,600 MT
Industrial	69%, 82,800 MT
Sports/leisure	13%, 15,600 MT

Carbon fiber suppliers, 2020 (nameplate)	
Toray	50,000 MT
Toho-Tenax	20,000 MT
Mitsubishi Rayon Carbon Fiber & Composites	15,000 MT
SGL Group	14,000 MT
Hexcel	13,000 MT
China	12,000 MT
Rest of World	5,000 MT

Carbon Fiber Supply & Demand (2015-2025)

Composites industry consultant Tony Roberts, principal of AJR Consultant (Orange, CA, US), presented his estimates of carbon fiber supply and demand over the next several years.

Source | AJR Consultant

and F-35. In commercial aircraft, carbon fiber had seen only limited use on a variety of Boeing and Airbus planes for many years until the Boeing 787 and the Airbus A350 XWB were developed and firmly established its place in the aerospace industry. These two planes, taken together at full-rate production, said Canario, will consume more carbon fiber in one year than the F-35 program will during its entire life.

Canario went on to say that the industry should expect 40,000 MT of *additional* carbon fiber demand in the next five years, adding that construction and commissioning of a new carbon fiber plant can take 12-18 months, which prolongs return on capital expansion investment. Given the current economic model, fiber producers must minimize risk and cover their capital costs, and Canario contended that a carbon fiber manufacturer will expand capacity only if a sustainable rate of return can be guaranteed. That means the emphasis will be on long-term contracts — like that which Toray has with Boeing for the 787 and Hexcel has with Airbus for the A350 XWB.

Reality behind the headlines

One of the headliners on day one was John Byrne, VP aircraft materials and structures at Boeing Commercial Airplanes (Seattle, WA, US). Byrne was optimistic to start, offering several data points designed to highlight the health of passenger air travel. Boeing itself is also doing well; his company is currently building 63.3 planes a month (all models) and has a record backlog that is mixed »

Optimism … with misgivings

Boeing Commercial Airplanes' John Byrne was optimistic about the health of passenger air travel and its effect on aircraft builds, but not so encouraging about composites in future Boeing aircraft.

Source | CW / Photo | Jeff Sloan

geographically and categorically in terms of aircraft model. The company is building 10 of its composites-intensive 787s a month, and plans to increase that to 14 by 2018.

Yet, when it comes to composites and the 787, Byrne was less sanguine, offering his take on several problems: The composites industry supply chain (compared to that for metals) is relatively immature. Composites are not fully understood by Boeing designers and engineers and, thus, are not always employed optimally. As a result, the same basic combination of fiber reinforcement and resin matrix were applied on all parts and structures on the 787. The crux of the problem, then, said Byrne, is that composites industry immaturity has made Boeing's capital outlay unusually expensive. This might be tolerable at the right volume, but the 787 build rate has incrementally increased more than anticipated, which has driven material prices higher than Boeing expected. Byrne went as far as to state that if Boeing knew then what it knows now, "material decisions might have been very different on the 787."

Byrne noted specifically that materials standardization in metals allows Boeing to avoid sole sourcing, which keeps costs low and the supply chain moving. He suggested that carbon fiber suppliers to the commercial aerospace industry should, like aluminum suppliers, provide a product or products that meets a given and established set of mechanical specifications, regardless of source. Looking further ahead at the next big commercial aerospace programs — replacements for the A320 and 737 — there appears to be in the carbon fiber community resignation to the fact that the fuselages of these craft will likely be aluminum, even if the wings are composite. But such programs, noted Byrne, are probably more than a decade away, which Byrne said gives composites materials time to mature and "once again earn their way onto aircraft."

For more news from this year's conference, including a review of this year's panel discussion on automation, see "Learn More."

Carbon Fiber 2015 returns to Knoxville, TN, US, this December. Watch for updates on the *CW* website: www.compositesworld.com. CW

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Additive manufacturing: Can you print a *car?*

Collaborative demonstration dispels doubt about 3D printing's disruptive potential for direct-to-digital manufacturing of just about anything BIG.

By Ginger Gardiner / Senior Editor

» The undisputed highlight of the 2014 IMTS show (Sept. 8-13, Chicago, IL, US) was the world's first 3D-printed composite body for an automobile. Conceived as a showcase for large-scale additive manufacturing capabilities developed through a public/private partnership anchored by Oak Ridge National Laboratory (ORNL, Oak Ridge, TN), the passenger cell or tub (seat frames, cockpit, hood and tail) and four fenders — five pieces total — for the 680-kg, battery-powered two-seater *Strati* were printed in 44 hours. The car subsequently was assembled in two days and driven off the IMTS Emerging Technology Exhibit stand before show's end to cheers from the crowded exhibit floor.

The demonstration project, conceived by Local Motors (Chandler, AZ, US) CEO John B. Rogers, Jr., as the 3D Printed Car Design Challenge, took advantage of the large-format printing capabilities of the Big Area Additive Manufacturing (BAAM) machine, built by Cincinnati Incorporated (Harrison, OH) in cooperation with ORNL.

"We are a research institution, and not in the business of making cars," notes Dr. Lonnie Love, head of ORNL's Manufacturing Systems Research Group. "But *Strati* was a good test case. If you can print a car," he quips, "you can print *anything*." With 3D-printed parts already flying on commercial aircraft and being tested for jet engines, the implications of this direct-to-digital manufacturing (DDM) vehicle

3D Printing the Winning Design

Conceived as a showcase for large-scale additive manufacturing capabilities, the 3D Printed Car Design Challenge culminated in a live demonstration: 3D printing of the passenger cell or tub (seat frames, cockpit, hood and tail) and four fenders — five pieces total — for this 680-kg, battery-powered two-seater, the *Strati*, designed by Challenge winner Michele Anoé.

Source | Local Motors

are, indeed, large and won't be limited to aerospace and automotive applications.

"Can you print a *car?*"

The large-scale additive manufacturing concept originated with Lockheed Martin (Fort Worth, TX, US) back in the late 1990s. The ultimate vision was a "lights out" process for forming aircraft from advanced thermoplastic composites, using multiple, robotically controlled extrusion deposition heads. Sometime later, the US Department of Energy (DoE) tasked its Manufacturing Demonstration Facility (MDF) at ORNL with developing what is popularly known as 3D printing into an industrial-scale process. By 2013, Lockheed Martin had partnered with ORNL and moved its equipment to the MDF lab. Progress, however, was slow. "With robotic arms, small motions at the shoulder caused big motions at the tip, changing the accuracy and resolution," explains Love, "Extruders are also heavy; so we adapted the system to a large gantry, which provides the necessary stiffness and support."

In early 2014, Local Motors and Cincinnati Inc. entered the picture. "We had been asked by show organizers at the 2012 IMTS what we could do to challenge the machine tool manufacturing industry," recalls Rogers. "We thought the concept of hitting a 'print' button and having a car come out the other end was very attractive." Coincidentally, Cincinnati Inc. was seeking new markets. Both companies visited MDF in February 2014. Love recounts that Cincinnati Inc. reps said, "We can make and sell these." Love's team visited the machine manufacturer and agreed. Rogers' visit was punctuated by questions about speed, cost and if prefab parts could be embedded, ending with, "Can you print a car?"

Cincinnati Inc. signed a cooperative R&D agreement (CRADA) with ORNL and Rogers committed all three companies to headline the 2014 IMTS Emerging Technology Center exhibit. Local Motors announced its 3D Printed Car Design Challenge in March and recognized the winner on May 24. Meanwhile, Cincinnati Inc. and ORNL worked to assemble the machine that would print *Strati's* parts.

Fused deposition modeling on steroids

Although most 3D printers build parts the size of a shoebox, the print envelope of the resulting BAAM machine is almost 10 times larger, measuring 2m by 4m by 0.9m (x, y and z axes). A Cincinnati Inc. laser platform — CO_2 and fiber lasers are among the 50,000+ machines built during the company's 100-year history — provides the BAAM's frame, motion system and control. Its linear motor drive enables BAAM to maintain a level bed while delivering positioning accuracy of ±0.025 mm per axis at deposition speeds up to 5,080 mm/sec.

"Laser-cutting and 3D-printing machines are similar in that both have a head that moves in space according to CNC »

Additive Manufacturing in Large Format

Strati's CFRP one-piece body/chassis was printed in 44 hours on the IMTS show floor, using the Big Area Additive Manufacturing (BAAM) machine, adapted for 3D printing from a gantry-based laser cutting machine built by Cincinnati Inc. (Harrison, OH, US) fitted with extruders developed by Oak Ridge National Laboratory (ORNL, Oak Ridge, TN, US). At the show, BAAM featured a 2m by 4m by 0.9m print bed and its motion controlled gantry delivered accuracy of ±0.025mm at printing speeds up to 5,080 mm/sec.

Source | Oak Ridge National Laboratory

Source | Cincinnati Inc./Local Motors

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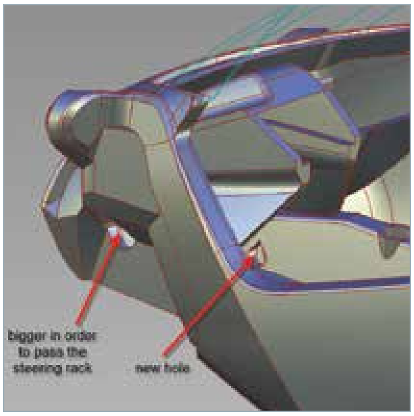

1 Local Motors first modified contest winner Michele Anoé's *Strati* 3D CAD files to ensure that all areas of the body design were printable in layers, compatible with BAAM parameters, and would enable assembly, as shown here.

Source (step photos 1-9) | Local Motors

2 The BAAM system melts and extrudes low-cost thermoplastic pellets (see inset) used for injection molding. For *Strati*, these were 15% carbon fiber-reinforced ABS, applied as 5-mm tall by 9-mm wide beads.

3 Here, BAAM builds up the laminate in 212 layers to form the car's main structure, including frame, seats, cockpit, hood and tail.

4 At only 454 kg, the printed CFRP tub is easily transported to another booth on the IMTS show floor for machining.

5 The tub is machined where surfaces require smoothness and tight tolerances for mating parts, using a Thermwood Inc. (Dale, IN, US) 5-axis CNC router.

6 The machined tub is returned to the exhibit booth for further assembly.

7 Technicians add suspension, wiring, powertrain, brakes and wheels.

8 *Strati's* fenders, printed separately on BAAM and machined, went on over the wheels.

9 Finally, *Strati* is outfitted with windshield, roll bar, lights and seat covers.

10 Completed as planned, on schedule, the *Strati* is driven off the IMTS Emerging Technology Exhibit stand and out of the exhibit hall.

Source | Local Motors

programming," explains Cincinnati Inc. marketing manager Matt Garbarino. "Our system, with the laser removed, provided plenty of range in the x- and y-axes, but still needed more than the typical 0.5m of movement in the z-direction." So Cincinnati Inc. built a table that travels vertically to provide 0.9m of z-axis range.

In place of the laser, ORNL installed on BAAM its extruder and feeding system, which allows application of heated thermoplastic »

■ 3D Printed 2015 *Shelby Cobra*

The front fenders, headlight enclosures, hood and grille, printed in one piece on BAAM for a 50th Anniversary edition of Ford's *Shelby Cobra* sportscar are prepped for primer and paint. The gleaming finished product speaks for itself.

Source | Oak Ridge National Laboratory

compound, layer by layer. Described affectionately as "an FDM machine on steroids," BAAM with ORNL's extruder/feeder has a deposition rate of 17 kg/hr — 200-400 times faster than the average 3D printer.

"Where FDM normally uses a spool of plastic thread," Garbarino explains, "BAAM uses plastic pellets, similar to those for injection molding, so parts are also affordable." These pellets are vacuum fed from a 2m by 2m by 2m hopper through a dryer into a single-screw extruder, which melts and forces the thermoplastic — with or without fiber reinforcement — through a standard 8-mm-diameter nozzle. "The bead is roughly 5 mm tall by 9 mm wide and round as it exits," adds ORNL's Love. "A tamping device vibrates up and down to push the bead into a rectangle and achieve a good bond with the layer below." The printed layer thickness for *Strati* was ~4 mm.

"BAAM was designed to accommodate a wide variety of materials," says Garbarino, "allowing more options for flexibility and low cost." Trials to date have included acrylonitrile butadiene styrene (ABS), polyphenylene sulfide (PPS), polyphenylsulfone (PPSU or PPSF), polyetheretherketone (PEEK), polyetherketoneketone (PEKK), and polyetherimide (PEI). Both carbon and glass fiber reinforcements have been used, showing improved strength and thermal stability in printed parts. "Typically, fibers in these pellets are 5-7µ in diameter and 500μ to 0.5 mm in length, depending on the pellet size because the fibers are co-extruded with the polymers," notes Love. ORNL also has tested polymers loaded with nanofibers and graphene, supplied by tailored injection compound specialist Techmer (Clinton, TN, US). *Strati* was printed using SABIC's (Pittsfield, MA, US) LNP STAT-KON AE003, an ABS compound based on its CYCOLAC resin and containing 15% chopped carbon fiber.

Winning design to manufacturable print

Local Motors selected the Challenge winner, Italian designer Michele Anoé's *Strati* (Italian for "layers" and pronounced "strotty"), from more than 200 entries submitted from 30 countries. It then began optimizing *Strati*'s 3D CAD files — developed using Solid Edge from Siemens PLM Software (Plano, TX, US) — for printing (see Step 1, p. 46). "We had to make sure that all of the areas were printable," explains Rogers. "For example, if a wall was set as 19-mm thick but we could only print in 4-mm layers, then we needed to alter that dimension [to 20 mm] and make sure the whole design worked."

"You also can't just print in free space," Love adds, "Wherever you have an overhang, you have to support it."

Rogers concedes that this was a fairly manual inspection process, "but it was also the first time we had used a large-area additive manufacturing machine." After this, Local Motors worked with ORNL's in-house slicing software — now being transitioned to a commercial entity. "We sliced the designed solid into layers the machine could print," says Rogers.

But one problem remained: "We had been growing parts at 4.5 kg/hr, so we were already two orders of magnitude faster than most 3D printers," recalls Love. But with only 3-4 weeks to go, "this still wouldn't be fast enough to assemble and drive the car off the stand before the show ended." The team wasn't ready to give up. "We had been working on a new extruder," says Love, "and one week before IMTS, we swapped it into the system. We ran a trial print and it worked! We reached almost 18 kg/hr."

Print, assemble, drive

Printing started on Sunday morning at 7 a.m. (Step 2), and by 6 a.m. Tuesday the car body's main structure was completed as a single 454-kg piece of carbon fiber-reinforced plastic (CFRP). This was then transported by forklift (Step 4) to a 5-axis CNC router supplied by Thermwood Inc. (Dale, IN, US), where surfaces requiring smoothness (e.g., for application of decals) or further dimensioning were machined by the end of the day (Step 5). "For example, where a control arm must mate to a surface," explains Rogers "you need to mill that to the exact dimensions, which is easy to do." The machined tub was then returned to the exhibit booth on Thursday and staged for assembly (Steps 6, 7, » 8). Mechanical components (wheels, wiring, brakes and suspension) were sourced from a variety of suppliers, including an electric powertrain from a Renault *Twizy* city car. With roll bar, windshield, lights, trim and seat covers in place (Step 9) — *Strati* was ready to roll (Step 10) at 9 am Saturday, Sept. 13. Right on schedule, Rogers drove *Strati* off the stand and out of the convention center.

Driving the process farther down the road

ORNL started trials of its next-generation extruder in January, capable of laying material at 45-68 kg/hr — it would reduce *Strati*'s print time to *one day* (see "Learn More," p. 51).

Meanwhile, Cincinnati Inc. has expanded BAAM's working envelope to 6m by 2.4m by 1.8m, increasing x-axis range by 50%, y-axis by 20% and *doubling* the z-axis travel (part height). This BAAM 100 ALPHA Size 2 machine, now installed at ORNL, replaces the Size 1 machine that has been relocated to Local Motors' headquarters. Cincinnati Inc. also has sold a machine to SABIC for defining material processing parameters and another ALPHA Size 1 to a large aerospace entity. While the company pursues multiple ALPHA sales leads, it is finalizing a BETA version, geared for high-speed production and first deliveries later this year.

At the 2015 Detroit Auto Show (Jan 12-25, Detroit, MI, US), the partners demonstrated not only BAAM's new speed and early crash test results, but also how to *finish* 3-D printed parts, showcased by ORNL's 50th anniversary *Shelby Cobra*, with a Class A, painted surface (p. 56). The 635-kg vehicle (lightweight and kit versions average 1,070 kg) features 227 kg of parts printed from 20% carbon fiber-reinforced ABS over 25 hours. Only eight hours were required for the 3-D printed tooling, which was machined in four hours and cost $250. Built at the MDF using the BAAM 100 ALPHA Size 2, the tooling benefited from a 5-mm diameter nozzle that extruded a smaller bead, reducing surface variation to ±0.5 mm. TruDesign (Knoxville, TN, US) was a key partner, having investigated materials and methods for improved bonding between 3D printed layers and with coatings. "They completed several series of tooling for us," says Love, "and performed the post-print machining and finishing."

Rogers is confident that this technology is disruptive not only for the auto industry but also for manufacturing overall.

Composites and further paradigm shifts

"Carbon fiber is a game changer for additive manufacturing," says Love. "It changes not only the stiffness and strength you can achieve, but also the coefficient of thermal expansion (CTE). By adding CF to the polymer, you can significantly limit the curl and warp of the final parts." Aerospace tools for autoclave-cured parts must handle high temps with low CTE. Love's group has demonstrated this ability by printing CFRP tooling for Cherry Point Marine Corps Air Station (Havelock, NC, US) where techs maintain aircraft no longer in production. "It cost more and took longer to ship these than it did to manufacture them," Love notes and he points out that the military isn't the only organization with this kind of need. "The appliance industry is massive. Manufacturers keep warehouses of tooling for 15 or 20 years, in case they have to make parts for out-of-production models. What if they could replace that with a digital archive and just print a tool when needed?"

Love says multiple automotive OEMs are thinking along the same lines for test vehicles, which can require up to US$50 million in tooling to output a short run of cars for a single new model. "What if you could simply 3D print these in composites vs. steel or aluminum? It would not only cut tooling costs, but also that model's overall cycle time to production."

Rogers, however, is serious about printing cars. "A lot of people will see this as a science project or prototype, but these are real vehicles that can be made in less than 12 months from design to drive on the road." The design and build for the *Strati* took only *six*, and required only about 200 parts, compared to *20,000* in a typical car. "There are no tools, dies or patterns, saving tens of millions of dollars and months of lead time," explains Rogers. "There are also no materials wasted." Local Motors' business plan is to reduce print and production time, enabling a target price of US$18,000 to US$30,000 and production of *custom designs* in micro-factories that it hopes to station around the world.

And Lockheed Martin's original vision of "lights out" aircraft printing? Garbarino concedes, "This is not a lights-out process right now. But we are moving very quickly, and," he claims, "we can definitely see that on the horizon." CW

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ABOUT THE AUTHOR

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Cobham Composites: San Diego, CA, US

An aerocomposites force since the dawn of the 1980s, this fabricator's Big Idea is to move from quality control to in-situ process control on the strength of metrics powered by Big Data.

By Jeff Sloan / Editor-in-Chief

» Like most of the companies operating as composites fabricators, Cobham Composites in San Diego, CA, has a rich and long history that includes ownership changes and name changes. But on the shop floor, the expertise that brought the company thus far lives on, and is updated and fine-tuned to help position the company for substantial growth.

Cobham Composites – San Diego started life in 1979 as Sparta Composites, specializing primarily in fabrication of composite parts and component assemblies for antennae, electronics and munitions. Subsequently, jet-engine components became an emphasis at Sparta, and the company eventually won work with Pratt & Whitney (East Hartford, CT, US), compression molding carbon fiber/bismaleimide (BMI) parts for the F119 engine, which went on the F-22 *Raptor* fighter jet. Following this came similar parts for the F135 engine, on the F-35 *Lightning II*.

Meanwhile, aerospace and defense giant Cobham plc, headquartered in Dorset, UK, was looking to expand its composites capabilities and, in 2008, bought Sparta Composites and renamed it Cobham Composites.

Aerospace & Defense Emphasis

Founded in 1979 as Sparta Composites, this facility in San Diego, CA, US, now bears a new logo but has a long history in composites fabrication for antennae and electronics applications, and has recently taken on work molding stators and other parts for the F119 and F135 jet engines. The company's specialty is multiaxial compression molding — a rare and unique process in the world of composites manufacturing.

Source | Cobham Composites – San Diego

The San Diego facility is, today, one of three plants in the group. The other two can be found in Leicestershire and Hertfordshire, UK, and between the three locations there are about 360 employees.

The San Diego plant comprises two buildings. One occupies about 3,300m^2 and is home to Cobham Composites – San Diego's ply cutting and kitting, assembly, coordinate measurement machine (CMM)-inspection and compression-molding operations and its business offices. The other, at 3,667m^2, accommodates two large cleanrooms, machining and additional assembly and compression molding activities.

Birth of operational discipline

In 2008, Cobham Composites – San Diego embarked on a three-pronged strategic growth program. Since then, the first prong has emphasized the optimization and solidification of legacy materials and processes; the second prong has emphasized application and process diversity to even out the ebb and flow of the legacy work; and the third prong has emphasized product development, to help customers make the transition from the lab to production with prospective projects.

Michael Louderback, GM, says the company emphasizes "operational discipline" to maintain accountability. "When any road blocks or production issues arise that hinder the scheduled delivery of product from any of the value streams, these issues are immediately promoted to a management accountability meeting and these issues are assigned to department managers for resolution". This has not only changed the company culture, it has catapulted the company forward in achieving its three-pronged strategic growth plan.

Dave Hahn, Cobham Composites – San Diego sales engineering manager, served as *CW's* tour guide. Hahn explains that, practically speaking, Cobham's diversification effort has revolved primarily around getting out of the autoclave, which has led to increased use of resin transfer molding (RTM) and expanded use of *multiaxial* compression molding, a very rarely seen and highly specialized composites fabrication process — one we would become more well-acquainted with later. Along the way, the company has opened its eyes to the value of process and quality control, as well as waste minimization, with heavy emphasis on accountability, continuous improvement, root cause and corrective action measures and technology »

Cobham Composites at a Glance

The San Diego facility's jet engine and missile work — unusually, all out of the autoclave — weaves together a unique collection of suppliers, materials, molding processes and processing aids.

Capability	Types
Resin matrices	Epoxy, BMI, polyimide, phenolic, vinyl ester, SMC, BMC
Fiber types	Carbon, glass, aramid
Fiber forms	UDs, wovens, 3D preforms
Design software	CATIA, Solidworks, Pro/ENGINEER (PTC), UG, Fibersim, ANSYS, NX
Processes	Compression molding, multiaxial compression molding, RTM
Suppliers	Cytec, TenCate, Hexcel, Renegade, Textile Engineering and Manufacturing (TEAM), Sigmatex, Dassault Systèmes, Renishaw, Siemens, Unigraphics, PTC, Ansys, Grieve, GOM, TA Instruments

FIG. 1 R&D with Pre-production Flare

Cobham Composites' R&D area houses several Carver compression presses and Grieve ovens. The company does pre-production work in this room, including the compression molding of phenolic composite flares for the F-35 fighter jet. Source | *CW* / *Photos* | Jeff Sloan

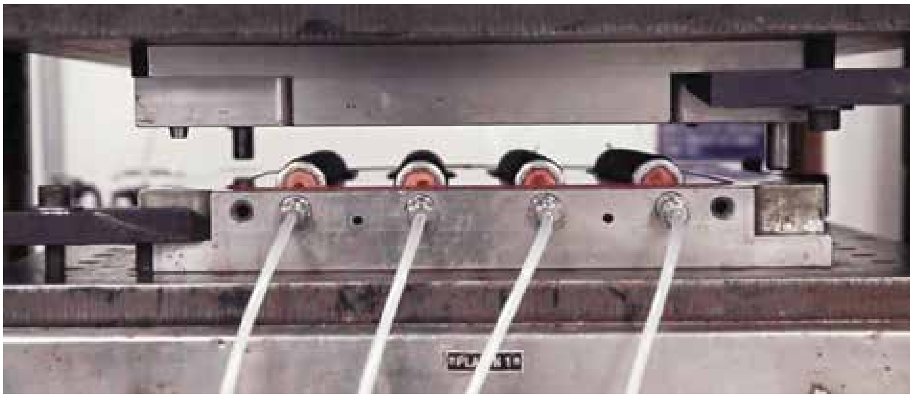

FIG. 2 Resin Transfer Molding

Resin transfer molding (RTM) is being used increasingly by Cobham Composites - San Diego as the company looks for ways to minimize autoclave use. Source | Cobham Composites – San Diego

FIG. 3 Laser-based Inspection

Cobham Composites – San Diego relies heavily on robot-based laser inspection technologies to verify part dimensions. Source | Cobham Composites – San Diego

application designed to help the company mitigate risk. This has led, as well, to systematic emphasis on the collection, analysis and application of manufacturing data to help improve manufacturing efficiency.

Spinner complexity

Hahn's tour began in the smaller building's R&D area, which houses Cobham Composites – San Diego's low-rate production operations. The room (Fig. 1, p. 53) is home to five small Monarch presses (from Carver Inc., Wabash, IN, US) and several Grieve (Round Lake, IL, US) ovens, used to manufacture phenolic composite flares for the F-35. At full-rate production, Cobham Composites-San Diego will make more than 4,000 munition housings a month, likely via resin transfer molding (RTM). The program represents, says Hahn, "a nice consumable that keeps volumes high for us for a long time."

We were led next into the spinner tool room, where Cobham Composites – San Diego does complex hand layup of spinner caps and spinner assemblies for Pratt & Whitney next-generation turbofan engines. Most complex is the spinner assembly, which is bladder compression molded and comprises DuPont (Wilmington, DE, US) Kevlar-brand aramid fiber and glass fiber prepregged with epoxy. Prepreg for the spinners is cut and kitted on a semi-automated cutting table supplied by AGFM (Chesapeake, VA, US). Kitted pieces are then hand layed in a spinner tool. The tool is "clocked" around its rim (markers are etched in the tool) to show workers how and where the 150-plus plies should be located and overlapped as they're placed. »

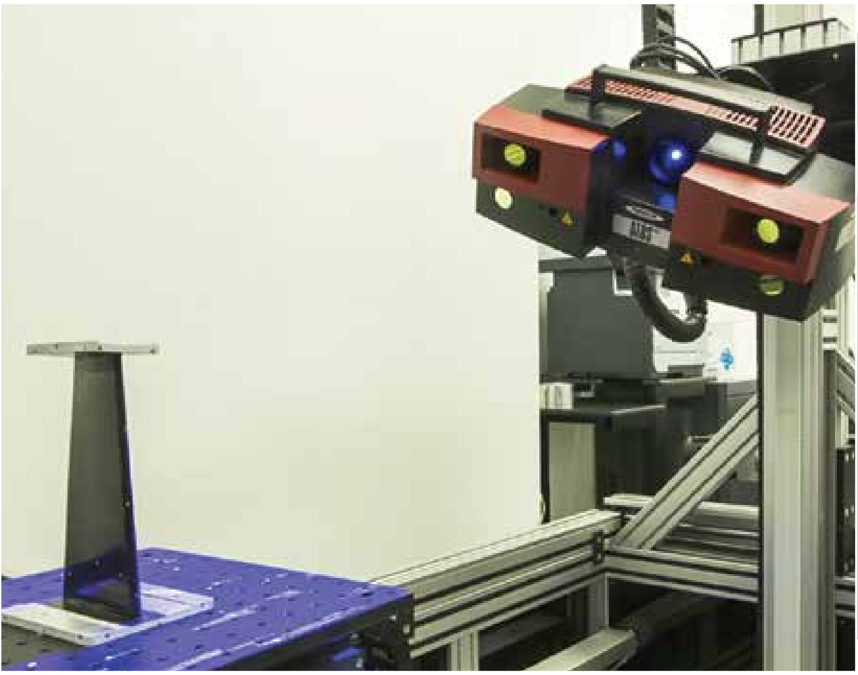

FIG. 4 **Blue Light Part Scanning**

This ATOS Triple Scan blue light scanner, manufactured by GOM GmbH (Braunschweig, Germany), is used by Cobham Composites – San Diego to measure parts. The system is effective because it can provide precise measurements regardless of environmental lighting conditions. Source | Cobham Composites – San Diego

FIG. 5 **Resin Quality Control**

Part of the company's quality control program calls for verification of resin properties before it's put into production. It uses an ARES-G2 rheometer, made by TA Instruments (New Castle, DE, US), to check resin viscosity properties.
Source | Cobham Composites – San Diego

FIG. 6 Optimizing Jet Engine Part Layup

The Pratt & Whitney layup room is where technicians do all of the hand layup for the manufacture of stators, inlet guide vanes and exhaust flaps for the F119 and F135 engines. The company uses pulse clocks to help keep work on schedule and prominently displays production data to help employees optimize their work environment. Source | *CW* / Photo | Jeff Sloan

Manufactured alongside the spinner assemblies are the spinner caps, also compression molded using epoxy and Kevlar.

Hahn says the labor required to manufacture spinner assemblies is significant, and Cobham Composites – San Diego has developed some potential tooling changes for Pratt & Whitney that could streamline and optimize the process. The company is in line to manufacture about 1,000 spinner assemblies annually at full-rate production.

Next up was what the company calls the Javelin room, where the company fabricates the four cylinder sections used to assemble the FGM-148 *Javelin* anti-tank missile, built by the Javelin Joint Venture Co., co-operated by Raytheon (Waltham, MA, US) and Lockheed Martin (Bethesda, MD, US).

This missile housing comprises a nose section, two center sections, and a tail section, all made with carbon fiber/epoxy. Hahn describes this compression-based legacy cylinder manufacturing process as "heavily mechanized," and, indeed, Cobham Composites – San Diego has developed highly specialized tooling and consolidation presses exclusively for this application. First, prepreg is layed up around a male core mold, which is placed in a load frame on a four-sided vertical tool, with a cartridge heater on each side. These tools are then shuttled into one of 12 closer stations (compression presses) for consolidation. Molded cylinders are then machined, drilled and trimmed to spec.

All in vane

We were led next into the larger building to view what Hahn called the Pratt & Whitney layup room (Fig. 6, above), where Cobham Composites – San Diego does hand layup for the manufacture of jet engine stators, guide vanes and exhaust flaps for the F119 (on the F-22 fighter), and a newer version for the F135 (on the F-35 fighter). The company supplies these engine parts and fabricates more than 5,000 units per year. During *CW's* visit, 10 technicians were doing layup in the room. Each »

FIG. 7 *Multiaxial* Compression

Many F119 and F135 parts are molded via multiaxial compression molding, in which pressure is applied on six sides of the mold. Cobham's multiaxial compression molding operations are rare and unique in the world of composites fabrication. The company is using second-generation machines right now, but hopes to roll out third-generation technology soon that will include pressure transducers to help monitor process performance. Source | Cobham Composites – San Diego

FIG. 8 Letting the Data Talk

This Spinner Accountability Board is used to help workers identify and track tool, material and process issues. The company is employing what it calls Big Data to help it drive waste and inefficiency out of manufacturing, thereby reducing cycle times and increasing product quality. Source | CW / Photo | Jeff Sloan technician's actions were governed by a pacing clock the company uses to encourage a steady workflow.

The part exiting this room at the highest volume is the stator. Stators look like fans, with small blades radiating from a central core section. They are stationary in the engine, located between fans to help build air pressure as it accelerates through the engine. The stators are molded in doublets, in cube-shaped molds, and then 20-plus doublets are assembled to create one unit. Cobham Composites-San Diego makes two sizes of stator, both for the F135 — carbon fiber prepregged with BMI for one, and carbon fiber prepregged with polyimide for the other.

The method used to mold the stators is Cobham Composites – San Diego's previously noted multiaxial compression molding process. Rare and unique, these systems compress the mold from multiple sides simultaneously (see Fig. 7, p. 57). The challenge with the stators, says Hahn, is that polyimide foams and outgasses as it cures. Therefore, a method had to be devised to allow gasses to escape the mold. This led Cobham Composites – San Diego to develop what it calls a "foaming gap," where the mold is held slightly open in the initial stages of compression to let gasses release before full closure and final consolidation.

After molding and postcure, stators are trimmed, cut and finished on a Haas Automation Inc. (Oxnard, CA, US) Super VF CNC machine. Cobham Composites – San Diego also applies an erosion coating on the flow surface of some vanes.

From QC to PC

Finally, each stator must go through extensive quality assurance steps (see, for example, Figs. 3 and 4, pp. 54-55). "There's a very tight tolerance on vane thickness," Hahn notes, pointing to a six-axis robot as it guides a Renishaw (Wotton-Under-Edge, Gloucestershire, UK) probe over a stator blade. Such a check, he says, "gives me one or two datapoints before we make too many other off-spec parts. This material is $300-plus per pound, plus labor. So, out of the mold, we've almost spent the majority of the budget on this part. We can't afford to make many defective parts, so in-process inspection is critical." Cobham Composites – San Diego's yield rate on the stators is greater than 95%, Hahn adds.

The company hopes, eventually, to move quality control closer to process control by implementing in-mold sensor technology that will let the multiaxial press monitor and track mold performance in situ. In so doing, the press could track stator blade thickness variation and signal an alarm when the specification is violated. The multiaxial presses in use today are second-generation versions, designed and built in-house. Hahn says the company is working on third-generation press technology that will provide higher levels of control and, possibly, eliminate the need for postcure.

No such thing as too much data

Over-arching everything that Cobham Composites – San Diego does is the collection, analysis and application of what the company calls Big Data. The belief, says Hahn, is that composites manufacturing can and, indeed, must be driven by metrics that the company can use to increase throughput and efficiency, drive down cost, improve quality, reduce waste and push high-quality product out the door faster.

"We're basically running a big science experiment," quips Ray Ringleb, director of sales and marketing. "And it's being driven by SPC [statistical process control] and quality control. We're trying to develop a more stable, less risky process."

As part of this effort, Cobham Composites – San Diego has begun rheological testing of all resin when it's delivered (see Fig. 5, p. 55).

"Sometimes we find that a resin characteristic falls at one or the other end of the specified spectrum. And if we know the rheology, then we can find ways to adjust our processes to accommodate variations in resin spec," says Hahn.

On the shop floor, Cobham Composites – San Diego has begun a concerted effort to put manufacturing data in plain view, so that employees can readily see how the quality of their work affects company performance. The pulse clocks in the layup room (Fig 6, p. 56) are one example. Another is the Spinner Accountability Board (pictured in Fig. 8, p. 57), used to track production issues with spinner assemblies. Hahn admits that, initially, employee reaction to such use of data was not entirely positive. But that was then. "Now," he says, "it allows us to bid to the minute. It helps employees talk about how to get back on schedule when they're behind."

Ringleb says, "Our employees have begun to embrace this and see it as a positive. We've made it visible, and the data becomes a point of pride. Measurables give employees a chance to see where improvement opportunities are."

Going forward, the company plans to digitize data that is currently displayed on paper — such as that on the accountability board. Cobham Composites – San Diego is also implementing radio frequency identification (RFID) technology to help track material, equipment and parts, from start to finish.

Cobham Composites – San Diego is correct that the collection and application of manufacturing data is required if composites fabrication is to remain relevant and competitive, and the company seems properly poised to leverage its data-based strategy into long-term growth. CW

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Yachtbuilding composites: Rigged for success

Rigged for Racing Success

ECsix rigging, by Composite Rigging (North Kingstown, RI, US), was used for all the America's Cup AC45 fleet in the 2013 Red Bull Youth America's Cup race in San Francisco, CA, US.

Source | Composite Rigging/Southern Spars

Carbon composite cabling in several forms races ahead of dry fibers and stainless steel in high-end sailboat rigging.

By Donna Dawson / Senior Writer Emeritus

The sailing world is already a strong market for composites. Hulls, decks, masts — even steering wheels, tillers and boarding systems (see "Learn More," p. 65) — are now constructed of glass, aramid and carbon fiber-reinforced polymers. But a growing portion of that market, today, is *standing rigging*, the relatively rigid cables that stabilize sailboat masts and, to a lesser degree, *running rigging*, the more flexible cables used to move and control the sails. Carbon fiber's light weight, strength and stiffness, combined with its environmental resistance and durability, contributes to superior performance in cables, compared with the dry fiber cables and stainless steel cables used in conventional rigging systems. Carbon fiber composite sailboat rigging, today, typically relies on standard, intermediate-modulus carbon fibers, such as Toray Industries' (Tokyo, Japan) T700 standard tensile modulus (230 GPa) and T800 intermediate tensile modulus (294 GPa) — although standing rigging is trending toward higher-modulus fibers in the range of 324 GPa.

First carbon rigging: Bundled pultruded rods

Carbon composite has become the standard rigging material for high-performance offshore race boats and superyachts, says Rob Sjostedt, partner and CEO of VectorSum (Irvine, CA, US). An avid sailor and a composites specialist, Sjostedt is generally credited as the person who brought carbon fiber to the rigging world. "My goal, 13 years ago, was to make standing rigging out of something other than heavy stainless steel rod and corrosion-susceptible wire rope." He came up with the idea of bundling very small-diameter pultruded carbon-fiber composite rods, combined with a conical end-fitting.

This idea led, ultimately, to the successful carbon composite rigging developed and now produced under the registered trademark ECsix by Composite Rigging (North Kingstown, RI, US), part of the Southern Spars Group (Auckland, New Zealand), owned, in turn, by the North Technologies Group (Milford, CT, US).

Scott Vogel, president of Composite Rigging, says ECsix cable has been installed on more than 500 yachts, ranging from 3.4m *Moths* to *Volvo 70s* and 61m-and-longer superyachts (see Fig. 1). It's also undergone *millions* of loading and unloading cycles. "In just 10 years, ECsix has sailed over 1 million nautical miles in all conditions," he claims, "and has not had a single failure due to age, wear, waves, weather or water." Sjostedt adds that there also has never been an ECsix *end-fitting* failure (Fig. 2). "The bundle of small rods has proven to be very damage-resistant and can handle compression buckling on the leeward side of the mast," he claims.

ECsix comprises a bundle of 1-mm rods, which are pultruded by Air Logistics (Monrovia, CA, US), using Toray's T800 carbon fiber in an epoxy resin matrix. "We receive the rods on a spool," explains Tony Reaper, sales manager for Composite Rigging. "We cut them to the required length and then bundle the correct quantity of rods for the specified rigging, terminate the bundle in titanium end-fittings and install interface hardware, such as eyes, jaws and turnbuckles." The bundle is then pulled through a braiding machine to encase it within a protective fibrous jacket. The company has used all types of yarn for the jacket, including aramid and ultra-high molecular weight polyethylene (UHMWPE); these tough, high-performing fibers are used when rigging will be subject to significant abrasion, such as when it is used as headstays and running backstays.

Reaper believes carbon composites are virtually indispensable in high-performance racing yachts and the so-called superyachts, which are, as they say, "too big to fail." "Superyachts have gotten so big that the naval architecture doesn't work out unless a lightweight mast/rigging package is specified," he explains. The key to tall-masted yacht stability is concentrating weight low in the water. "Most of these boats, today, actually *must* have some sort of composite standing rigging, rather than steel, to maintain the center of gravity."

Rigid and flexible carbon rigging

Southern Spars recently acquired another leading provider, Future Fibres Rigging Systems. Started in the UK in 1997, Future Fibres moved to New Zealand for the 31st America's Cup in 2002-2003, and then to Valencia, Spain, for the 32nd race in 2007. It's unknown how the acquisition will affect Future Fibre's future production but, for now, the company makes two carbon fiber rigging products, one rigid and the other flexible.

Its Thermoset Carbon (TSC) rigging (the rigid system) is designed for use as standing rigging. It's made by looping a single continuous epoxy prepreg tow around two titanium end-terminations mounted apart from one another at a fixed distance equal to the specified cable length — a system Future Fibres notes was pioneered in 1996 by company founder Tom Hutchinson. The carbon fiber is HexTow IM9, from Hexcel (Stamford, CT, US), with a 303 GPa tensile modulus, slightly higher than that of Toray's T800. The looped cable is loaded under tension, shrink-taped »

FIG. 1 ECsix Rigging on 66m Superyacht

Looking up into the rigging, the vertical (uppermost in photo) and diagonal stays meet the mast. Vertical stays are supported by the spreaders on this five-spreader rig. Round wheels are radar and communications equipment.

Source | Composite Rigging/Southern Spars

FIG. 2 Strong Cable, Secure Connection

ECsix typical assembly: The pultruded carbon rod bundle terminates in a resin cone, called a *frustum*, overwrapped with a carbon fiber/epoxy prepreg hoop-wrap. The end-fitting's socket is titanium, typically used to avoid galvanic corrosion, which is common if carbon fiber is in direct contact with aluminum or steel for long periods.

Source | Composite Rigging/Southern Spars

FIG. 3 Rigid and Flexible Rigging Cables

Future Fibres Rigging System's (Valencia, Spain) TSC rigging flies on the 22m *Shockwave* racing yacht, among others. The company makes two carbon fiber rigging products, one rigid and the other flexible.

Source | Future Fibres / Photo | J. Renedo, Sailingstock.com

FIG. 4 Solid Carbon Composite Cabling

Hall Spars and Rigging's (Bristol, RI, US) continuous winding machine for manufacture of SCR solid carbon rigging (above) and carbon epoxy prepreg tow wound in a "sling" around end-pins (see inset at right).

Source | Hall Spars & Rigging

to consolidate the layup, and then cured in an oven ramped up at intervals to 180°C for two to four hours. TSC cables terminate in a small end-diameter, which helps to reduce *windage*, that is, the frictional force created by air on an object. The end size depends on the application; for a high-performance racing design, such as a Grand Prix *Transpac 52*-class (TP52) yacht, the first cable (running from the deck to the first spreader on the mast) would be about 9.3 mm in diameter. Its breaking strength would be approximately 13,400 kg.

The high-modulus fiber offers good protection against ultraviolet (UV) light, so Future Fibres says the resulting TSC generally does not need a braided protective layer; the cured cable is more often sanded and then finished with a wax or a clearcoat of varnish.

TSC typically has been used for standing rigging in high-performance boats (see Fig. 3, p. 61) but the company also manufactures a flexible version, FlexC, made by the method and using the same carbon fiber, but with a *different,* proprietary resin for the prepreg that lends the cable flexibility. It can be used for either standing rigging or running rigging, and reportedly is most suitable for a boat that is rigged out every year.

FIG. 5 Airfoil Configuration Reduces Windage

The pictured 30.5m *Chrisco* racing yacht is rigged with Hall Spars' SCR *airfoil* rigging, which differs from its standard round solid cable in that it has a low-drag *aerodynamic* configuration (close-up) that not only reduces windage but also runs quieter.

Source | Hall Spars & Rigging

Seamless carbon rigging

Also at the forefront of carbon composite rigging innovation is Hall Spars and Rigging (Bristol, RI, US). Opened in 1980, its history began, says owner and CEO Eric Hall, with stainless steel cable for rigging, made using swaging machines. In the late 1990s, the company tested the bundled pultruded rods produced by Air Logistics for a brief period before Southern Spars took over the technology in an exclusive contract. Hall also considered other forms of pultrusion ("fantastically expensive tooling") as well as dry carbon ("it pulls itself apart"), and a carbon/thermoplastic prepreg. Then, after three years of development, Hall introduced, in 2008, its *own* unique system for making carbon composite masts, booms, spars *and* standing rigging called Seamless Carbon Rigging (SCR).

SCR is a *solid* carbon composite cable made using epoxy prepreg tows with intermediate-modulus carbon fiber from Mitsubishi Rayon Carbon Fiber and Composites Inc. (Composite Materials Div., Irvine, CA, US). Hall makes the SCR by "a form of filament winding," using a machine that continuously winds the tow around end-pins, creating a loop, or sling (see Fig. 4, top left). When the winding is complete, the sling ends are pulled into conical end-fittings, and a wedge is inserted inside the loop, then pulled back into the fitting, mechanically securing the part. It is then consolidated with shrink-wrap and oven-cured. Hall uses only titanium end-fittings to avoid electrolytic reactions between carbon and aluminum or stainless steel.

Hall compares a solid SCR rod with the equivalent Nitronic 50 stainless-steel rod it replaces: "Comparing rods with a nominal breaking strength of 41,270 kg, the SCR rod has an almost identical diameter — 19.9-mm diameter compared with 19.5-mm diameter for the stainless steel rod — at about *one-sixth* the weight." »

Because SCR is without the spaces between rods typical of bundled pultruded-rod systems used by some competitors, Hall notes it has a smaller frontal area subject to less windage.

Although standard SCR is *round*, Hall Spars also produces a low-drag *airfoil* configuration for high-performance applications. Its more aerodynamic shape means even less windage (see Fig. 5, p. 62). Thus, “it’s a good product for cruising-boat applications, as well, because it’s quieter,” he adds. “All rigging vibrates, and the smaller the boat, the higher the vibration.”

SmartRigging BV (Joure, The Netherlands) was founded in 2004 for manufacture of composite yacht rigging. The company produces only standing rigging, a carbon composite cable called C-Evo, for yachts from 11m to 64m long. SmartRigging sales director Constantijn Weber says the C-Evo incorporates, variously, Toray T800, T1000G (294 GPa/42.7 Msi tensile modulus) or Tenax-E-IMS65 (290 GPa/42.1 Msi) from Toho Tenax Europe GmbH (Wuppertal, Germany), or even higher modulus fibers in an epoxy towpreg. The cables are made by SmartRigging’s endless winding system, a fully automated, computer-controlled production process. “All fibers are laid parallel in endless loops,” says Wilco van Zonneveld, business development manager for FibreMax, SmartRigging’s 2009 spin-off subsidiary, with which it shares technology and production staff to produce cables for industrial applications (e.g., heavy-lift cranes and bridge cables). “The tension on individual fibers is kept constant and equal with an accuracy of 0.1%,” says van Zonneveld, adding that end terminations can range from 2-300 mm or more, depending on the cable’s required breaking strength.

FIG. 6 Reformable Cable Ends Ensure End Fits

Introduced in 2011, Navtec Rigging Solutions’ (Guildford, CT, US) TFC cable is pultruded as small-diameter rods. But it is different in that its carbon fiber is preimpregnated with a proprietary *thermoplastic* matrix. That enables Navtec to fuse the cable ends and then reform them into a head that will fit specified cable end-fittings, such as these deck turnbuckle terminations on the *Swan 90* yacht called *Alix*.

Source | Navtec

CF/thermoplastic rigging

Navtec Rigging Solutions (Guildford, CT, US) has been a leading producer of sailboat rigging since 1970, when Ken King formed the company in West Concord, MA, US, for the purpose of improving stainless-steel rod rigging technology. Today, in addition to rod rigging and dry fiber rigging, Navtec produces Thermo Fused Carbon (TFC) rigging, introduced in 2011. Like others, TFC cable is pultruded as small-diameter rods. But it is different in that 310 GPa tensile-modulus HexTow IM8 carbon fiber from Hexcel is preimpregnated with a proprietary *thermoplastic* matrix. Navtec bundles the pultruded carbon fiber/thermoplastic rods together, in the size and number necessary to meet rigging specifications, and then loads them evenly across the bundle. Using a Navtec-patented process that entails very high temperatures and precision-machined steel, the company fuses the strands at the cable ends into a solid bar and then *reforms* the existing solid bar into a head that mates with the specified end-fitting (see Fig. 6, p. 64).

The thermoplastic matrix allows Navtec to mold the same composite material that forms the midspan structural rigging into a configuration that physically interlocks into the titanium end-fitting, providing compact terminations that reduce both weight and windage. The thermoplastic also makes the cable more flexible in mid-span, so it can be coiled for shipping.

Mike Curtin, Navtec engineering manager, says TFC rigging can be used for standing rigging, although "TFC does not handle a very small bend radius as well as Kevlar and PBO," he says. It can be used in some running rigging applications, depending on the bending that will be experienced.

The consensus among rigging manufacturers is that carbon fiber composites are the future for their high-end market. But the big question is: When will they penetrate the much wider small racing yacht and recreational sailboat sectors? Here, performance *can't* trump price, so carbon fiber's high cost keeps it out of reach. For now. Carbon fiber manufacturers are working avidly to change the price equation, particularly in automotive and industrial applications. It's possible the sailing world will benefit as well. CW

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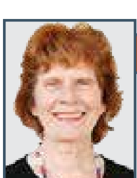

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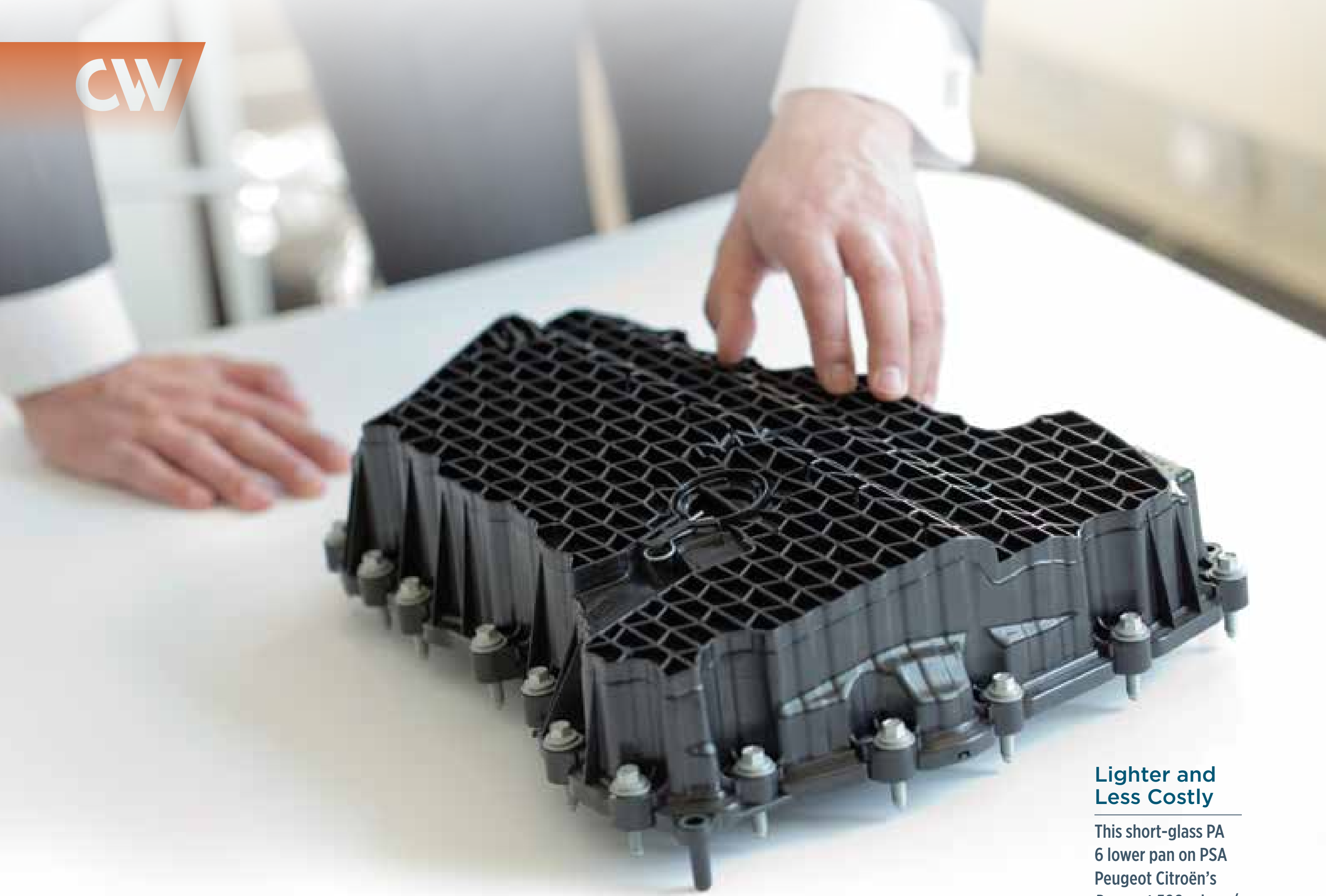


Lighter and Less Costly

This short-glass PA 6 lower pan on PSA Peugeot Citroën's *Peugeot 508* saloon/sedan was 60% lighter as well as less costly than the metal version it replaced.

Source | Royal DSM

AUTOCOMPOSITES UPDATE: Engine oil pans

As thermoplastic composites make inroads into these complex, modular parts, weight and cost go down, functionality goes up.

By Peggy Malnati / Contributing Writer

» A key engine component on all internal combustion engine-powered heavy-, medium- and light-duty trucks and passenger cars, the oil pan endures long-term exposure to hot oil. Because it is located on or near a vehicle's underbelly, it's also subjected to corrosive water and road salts, and abrasion from dust, gravel and stone impacts, particularly on high-carriage and off-road vehicles.

Metal pans are heavy, prone to corrosion/rust and denting, feature numerous subassemblies (e.g., oil pick-up tube, windage tray, filter, pump, etc.) and require secondary machining, welding and painting. This is, therefore, just the kind of application where composites can integrate subcomponents, reduce assembly costs and roughly *halve* pan weight at a time when there is great pressure to improve fuel efficiency and reduce emissions. Further, composites naturally dampen noise/vibration/harshness (NVH) values.

The sheer complexity of vehicles and the host of mandates they must meet means that the auto industry can seem slow to embrace change. However, composites are beginning to displace cast aluminum and stamped steel in engine oil pans. The OEMs who, thus far, have ventured into this arena are finding that thermoplastic composites offer better part performance, plus mass and cost savings. For example, an injection-molding tool typically lasts *three times longer* than aluminum casting tools. Given how long engine programs tend to run, the per-unit cost savings on medium- to high-volume platforms add up fast for OEMs. Cost savings also accrue thanks to the famous design flexibility and components integration for which plastics/composites are renowned, because reducing part counts and assembly steps positively impacts the bottomline. Further, in many cases, oil sump volumes can be increased in the same packaging space, extending engine life and decreasing oil-change intervals for operators.

Despite this compelling value proposition, metal-to-composite conversion has evolved slowly because OEMs are cautious about changes that — should they not work — could ruin expensive engines and lead to high warranty costs. Also, many oil pans perform a structural function, stiffening the lower side of the engine block, so car and truck manufacturers require extensive validation studies, complete with long-term and on-vehicle testing, before technology is "green-lighted" for commercial application. Despite these qualification obstacles, composite oil pans that are now on the road point to significant opportunities on a variety of trucks and cars.

Form & function

Oil pans are of two major types — structural and nonstructural — and several different pan architectures are in use. Some pans are designed as two-piece, enclosed shells, featuring an upper pan directly connected to the engine and transmission, and a lower pan that holds the majority of the oil at any given time. The upper and lower pans are joined with a seal/gasket and bolts. Other pans are one-piece structures that bolt directly to the bottom of the engine block. Nonstructural pans are often made from hybrid materials, with cast aluminum uppers and stamped steel lowers and little added integration. They typically are found on engines with *bed plates* — ring structures that encircle the bottom of the block to increase stiffness for rear-wheel drive (RWD) vehicles or for high-pressure diesel engines on RWD or front-wheel drive (FWD) vehicles. Structural pans are usually one-piece cast aluminum, with little integration other than oil baffles. They're designed to contribute stiffness to the engine block and transmission (via powertrain bending modes) and are found on most FWD vehicles.

> This is the kind of application where composites can integrate subcomponents and … halve pan weight.

A Thermoplastic Composites "First"

This first thermoplastic oil-pan module (short-glass PA 6/6) made its debut in 1998 in Europe on the *Actros* long-haul, Class 8 truck by Daimler AG. This large, one-piece injection-molded structural pan held 30% more oil in the same package space than either the aluminum or sheet-molding compound (SMC) versions it replaced. Source | SPE Automotive Div.

Oil pans must exhibit significant strength. OEMs often require that they hold the static weight of the engine plus transmission (454-681 kg for a large V-8 engine) without breaking, because engines/transmissions often are serviced in this position outside the vehicle. And some OEMs require oil pans to pass dynamic engine drop tests. Engine oil pans also serve a number of important functions and, therefore, must:

- Seal out environmental contamination (dirt, water) for the engine's expected life.
- Offer high use temperatures (110-120°C for continuous use and brief excursions to 140-150°C);
- Provide long-term chemical resistance to hot oil (particularly used/oxidized oil, which is more acidic), fuel by-products (ethanol or more aggressive methanol on flex-fuel vehicles) and road salts (sodium chloride in North America and calcium chloride in Europe and extreme northern sections of North America).
- Avoid transmitting noise from engine or gearbox.
- Resist damage from impact by road debris or contact with speed bumps, curbs or parking barriers.

Impact resistance is particularly important. There have been cases in which dents in steel pans closed off oil pick-up tubes, literally starving engines of oil.

First thermoplastic oil-pan module

The dominance of metals in oil pans began to change in the 1990s, when commercial truck manufacturer Daimler AG (Stuttgart, Germany) initiated a five-year co-development program with Tier 1 supplier/molder Minda KTSN Plastic Solutions GmbH & Co. »

Tough Two-piece Truck Pan

In 2009, North America's first thermoplastic oil pan was installed on the 6.7L power-stroke turbo-diesel Scorpion engine on heavy-duty *F-250* and *F-350* pickups from Ford Motor Co. This injection-molded, two-piece, nonstructural pan measured 38 by 25 by 10 cm, but weighed only 1.5 kg fully dressed. It featured a new short-glass PA 6 material and a new waffle-rib configuration, both optimized for stone impacts. Source | SPE Automotive Div.

Pan for Off-road-capable Climber

North America's second thermoplastic oil pan module, also in 2009, premiered on 5.7L/V-8 Hemi engines for the *WK Jeep Grand Cherokee* SUV by Chrysler LLC. Specifically designed for trail-rated vehicles, it could channel oil uphill on a 60% grade to ensure engines weren't suddenly without lubrication on a steep climb. Source | SPE Automotive Div.

KG (Pirna, Germany) and materials supplier BASF SE (Ludwigshafen, Germany). The goal was a thermoplastic composite oil pan for its *Mercedes-Benz Actros* Class 8 truck. Much study and testing yielded a large 64 by 36 by 45 cm, one-piece, injection molded structural pan that could hold 30% more oil in the same package space as the aluminum and sheet-molding compound (SMC) versions it replaced. Launched in 1998, its increased sump volume meant that oil-change intervals could be extended by 50%. This reduced maintenance costs, extended engine life and kept commercial trucks on the road longer — making their owners more money.

To mold the 6-kg part with its deep undercuts, a large, complex tool was required. Equipped with slides and other tooling action, the mold weighed 30 MT and was produced by Hause Presswerkzeugbau Großdubra GmbH (Großdubrau, Germany). BASF's Ultramid A3HG7 35% short-glass polyamide 6/6 (PA 6/6) exhibited excellent flow during the molding cycle and showed high resistance to stone impact, hot oil and heat aging during use. The pan also was 1 dB quieter, weighed 50% less, eliminated corrosion and — during impact testing with a 100g/25-mm projectile fired at 80 kph — proved tougher than benchmark aluminum.

> The *Mecedes-Benz Actros* Class 8 truck pan could hold 30% more oil and extended oil change intervals by 50%, compared to pans of legacy materials.

North American wins and loses

Based on the success of the *Actros* application, BASF looked for ways to expand the technology to other customers and segments. Its North American team believed passenger cars and light trucks offered greater potential than commercial trucks, so it developed its own design concepts for oil pans and marketed them to Detroit's carmakers in the early 2000s. Unfortunately, fuel prices were down and the post-9/11 market was slow. Paying extra for weight savings wasn't high on OEM wish lists, so the concept didn't gain traction. "Eventually we realized the only way we'd get a commercial program was if we did a proof-of-concept project to prove feasibility and drive interest," remembers Scott Schlicker, powertrain market segment manager, BASF Performance Materials (Wyandotte, MI, US). "We felt that, from a technical standpoint, thermoplastic pans would work, and that with enough components integration, we could make a strong business case vs. metals."

BASF entered into a three-year engineering, tooling and marketing program with Dana Corp. (Maumee, OH, US) on a 46- by 25- by 20-cm oil pan for the 3.7L V-6 engine on the *Dodge Durango* sport-utility vehicle (SUV) in 2005. The OEM, which was then DaimlerChrysler AG and is now (as of December 2014) FCA US LLC (Auburn Hills, MI, US), provided technical specifications and tested engines equipped with the composite oil pans, first on the dynamometer and then on actual vehicles. Results were positive: the technology was approved as "implementation ready," and efforts began on the first commercial program.

As work got underway at DaimlerChrysler in 2007, a parallel program involving BASF and Dana started at Ford Motor Co. (Dearborn, MI, US) on the automaker's 5.4L/3V (three-valve) V-8 engine for Ford's *F-150* pickups. This three-year effort yielded a 56- by 28- by 20-cm pan that, minus hardware, weighed only 2.24 kg. Also approved for implementation, this effort led to the team's first North American commercial opportunity, on the 6.7L power-stroke turbo-diesel Scorpion engine in heavy-duty *F-250* and *F-350* pickups. The Scorpion engine was selected because Ford engineers wanted to integrate an oil level/temperature

Premier Passenger Pan Posts Multi-category Pluses

The first thermoplastic composite oil pan for a passenger car appeared in Europe in 2007 on *Mercedes-Benz C-Class* 4-cylinder diesel sedans from Daimler AG. The multi-functional, two-piece lower pan, injection molded in short-glass PA 6/6, integrated a windage tray, which reportedly reduced oil vapor around the crankshaft and improved horsepower by 5%. It was 1.1 kg lighter and 20-25% less costly than the benchmarked all-aluminum design. Source | SPE Automotive Div.

Precise Fit for Tight Seal on Big Truck's Big Pan

This long-haul truck lower pan/sump, launched in Europe on 440- and 480-hp, 13L Euro 6 diesel engines from Scania featured injection-molded, short-glass PA 6/6 resin for excellent fill and fast cycle times, plus property retention even after long-term exposure to hot oil. Careful prototyping ensured warpage was minimized, which helped maintain a consistent, tight seal between the sump and engine across the large part. Source | DuPont Automotive

sensor in this engine's 38 by 25 by 10 cm, 1.5-kg (fully dressed with hardware) nonstructural pan — something that would've been difficult in stamped steel but straightforward in composites.

Launched in 2009, it was reportedly the first composite oil pan designed for exposed use (typical of North American vehicles without full underbody shields) thanks to a new material (Ultramid B3ZG7 OSI 35%-short-glass/PA 6) and a new waffle-rib configuration. The latter, for which BASF has patents pending, was developed and validated via extensive computer-aided engineering (CAE) analysis and impact testing. A proprietary modification package optimized the resin for stone impacts to -40°C and stabilized it against long-term heat aging in hot oil, bio-diesel and calcium chloride road salts (which normally attack polyamide). Although earlier composite pans had featured sacrificial ribs, this new rib design stood up to multiple stone impacts in BASF testing. Struck by a 100g steel impactor at 113 kph, the PA 6 lower pan sustained no damage, faring far better than legacy aluminum. Pan mass was reduced by 45%, NVH values were similar to aluminum and the pan didn't rust or corrode. Several components were integrated to reduce assembly cost and it featured the first plastic drain plug, with a cam-lock element to prevent over-torquing and breaking the plug's screw threads.

Despite these "firsts," the global economy collapsed as the program progressed, so the oil level/temperature sensor was "de-contented," leaving only a composite pan. Disappointingly, but not surprisingly, the production pan returned, after two years, to stamped steel to save money, reinforcing the team's belief that composite pans were only competitive when they offered higher value via significant parts integration.

Meanwhile, back at what by now was Chrysler LLC, another commercial oil pan, also three years in development, was launched in 2009 on the company's 5.7L/V-8 Hemi engines for the *WK Jeep Grand Cherokee* SUV. The supply team included BASF and MAHLE North America (Troy, MI, US). Notably, this 61- by 25- by 23-cm, 3.4-kg (fully dressed) pan was specifically designed for trail-rated vehicles and could channel oil *uphill* on a 60% grade to ensure hardworking engines weren't suddenly without lubrication on a steep climb. The Hemi engine's architecture made it possible for the nonstructural pan with an aluminum bracket to incorporate new levels of parts integration, including a windage tray (oil deflector) with cam-scraper function, an oil pick-up tube, seals, fasteners and an oil plug in an injection-molded PA 6 assembly that was joined via vibration and infra-stake welding. The highly integrated composite lower pan replaced a pan assembly that incorporated stamped steel, Quiet Steel (a steel/plastic/steel sandwich trademarked by Materials Science Corp., Horsham, PA, US) and cast aluminum. The composite reduced weight and tooling cost by 41% and 50%, respectively, and eliminated four assembly operations.

Since the Ford and Chrysler programs launched, additional development projects have been conducted, and North American automakers have recently launched commercial programs and have others scheduled in the next couple of years. However, program pace has been slower than hoped: typically three years development prior to approval followed by three years to commercialization.

European trends: Trucks to cars and back again

As the concept used in the *Actros* was applied in North America, DuPont Automotive (Geneva, Switzerland) and Daimler AG were at work in Europe on the first thermoplastic-composite engine oil pan for passenger cars. It, too, was a multi-year project. It made its debut on *Mercedes-Benz C-Class* 4-cylinder diesel sedans in 2007 — almost a decade after the *Actros* launch. The shell-type unit, produced by tier integrator G. Bruss GmbH (Hoisdorf, Germany), featured an upper pan of cast aluminum combined with a multi-functional lower pan injection molded from Dupont's Zytel 70G35 »

Lighter and Quieter Truck Pan

This pan, for 4- and 6-cylinder diesel engines from an unnamed "international truck manufacturer," reduced weight by 50% vs. aluminum predecessors (4.5 and 6.3 kg each for the 4- and 6-cylinder engines) and was 2 dB quieter.

Source | DuPont Automotive

Proliferating Pan Programs

One of several European passenger car programs to adopt a composite pan in 2012, the *Mercedes-Benz S-Class* full-size luxury sedans from Daimler AG use an injection-molded short-glass PA 6 resin to meet challenging tests for vibration, stone impact, and engine-drop tests while reducing mass by 50% and saving money over the previous metal sump. Source | Royal DSM

HSLR 35% short glass-reinforced PA 6/6. The module integrated a windage tray, which reportedly reduced oil vapor around the crankshaft and improved horsepower by 5%, plus oil baffles that improved flow and reduced oil sloshing. It also reduced oil air entrapment and decreased friction, extending bearing life. The composite pan was 1.1 kg lighter and 20-25% less costly than the benchmarked all-aluminum design. Significant CAE work was done by Bruss and DuPont to refine rib positions that would boost overall stiffness in a critical flat section. The pan's rear section formed the sump for approximately 6L of oil, so high ribbing in this area ensured its necessary stiffness and functioned as baffles to calm oil turbulence. Warm-embedded brass inserts also were used here to hold the oil discharge screw and oil-level switch. In contrast, the front section of the pan had to be flatter to fit into available space near the chassis and steering gear, which reduced bending stiffness. To prevent potential warpage/leakage at the joint to the upper aluminum pan and ensure the composite pan fit the tight space, a sandwich design was created in the part's flat section by welding an injection molded PA 6/6 oil deflector in place. Like the high ribs in the sump area, the deflector helped calm and direct oil churned up by crankshaft and balance shaft, and stiffened the part. Due to the resin's high melt-flow properties, only a single, center gate was needed to fill the 46- by 41- by 13-cm part. This minimized weld lines and reduced cycle time and tooling cost. The part passed challenging tests, including 1,000 hours' exposure to hot oil at 150°C, and survival of a dynamic engine drop test.

+ LEARN MORE

Read this aricle online |
short.compositesworld.com/OilPans15

Meanwhile, several commercial truck pans were launched. In 2011, truck OEM Scania (Södertälje, Sweden) used composite pans for its 440- and 480-hp, 13L Euro 6 diesel engines, which complied with new European Union (EU) legislation. The injection-molded pan was developed in Sweden by tier integrator Plastal Group AB (Gothenburg) and DuPont. The lower pan/sump used the same Zytel PA 6/6 resin mentioned above. Careful prototyping minimized warpage, so a consistent, tight seal was maintained between sump and engine across the large 85- by 47- by 20-cm part. Ribbing on the sump's underside again played a key role in maintaining tolerances and resisting stone impact damage (parts were hit by progressively heavier steel balls, fired at 80 kmh via compressed-air cannon at a 45° angle until they broke). The final part reduced mass by 50% (6 kg) vs. the aluminum benchmark, helping it comply with new Euro 6 diesel-engine standards that phased in during 2013-2014. Other commercial truck programs have since deployed in Europe.

Composite oil pan programs continued to proliferate on European passenger cars and several went into production in 2012. The *Peugeot 508* saloon/sedan from PSA Peugeot Citroën (Paris, France) is said to be the first to use a pan made from Akulon Ultra-flow K-FHG7, a 35% short-glass/heat-stabilized PA 6 resin with very good flow properties from Royal DSM (Heerlen, Netherlands). Injection molded by Tier 1 molder Steep Plastique (Saint-Maurice-de-Beynost, France), its uniquely ribbed, nonstructural lower pan was 60% lighter and less costly than the metal version and, thanks to extensive CAE work by Steep, was specifically designed to pass very demanding application trials, including stone and curb impacts and an engine drop test.

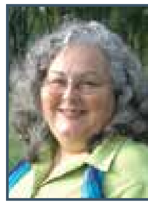
Another composite pan, produced by Tier 1 supplier BBP (Marbach am Neckar, Germany) for Daimler's *Mercedes-Benz S-Class* full-size luxury sedan, proved less costly and 50% lighter than the previous metal sump, using the same Akulon PA 6 grade. It exhibits good resistance to engine oil and meets challenging *Mercedes* vibration, stone impact and engine-drop tests. Reportedly it uses the same design as the earlier PA 6/6 pan on the *C-Class,* but is less costly.

What's next?

Engine oil pans, at least in North America, appear to be evolving from nonstructural to structural designs. A development project underway between Ford, the US Department of Energy (DoE, Washington, DC, US), and the Vehma Engineering and Prototype Div. (Troy, MI, US) of Magna International (Aurora, ONT, Canada) is investigating a multi-material lightweight vehicle (MMLV) based on a C/D segment sedan where the goal is to produce a drivable prototype weighing 25% less than the benchmark (Mach I), and then create a "virtual" concept vehicle that is 50% lighter than the benchmark (Mach II). One target area for lightweighting on this program is a V6 structural oil pan that will contribute to overall powertrain stiffness. The Mach I design is a two-piece, glass-reinforced PA pan with a carbon fiber-reinforced composite bracket. The Mach II phase will evaluate a one-piece, 50% long carbon fiber-reinforced PA 6/6 oil pan. Study goals include pan mass reduction by 30% (Mach I) and then 50% (Mach II) on a cost-neutral or better basis while maximizing powertrain bending frequency. BASF and Montaplast of North America (Auburn Hills, MI, US) are working on the Mach II pan. Reportedly, several unnamed structural pans at other OEMs are under development as well.

An intriguing application for composite oil pans outside the automotive industry is on stationary backup-power generators produced by MANN+HUMMEL Group (Ludwigsburg, Germany). Although some of the more rigorous impact requirements for pans on vehicle applications don't apply here, the size of these pans —117 by 41 by 31 cm at a weight as low as 9 kg — is impressive.

Although the pace is slower than many would hope, developments in composite oil pans for commercial and light-duty vehicles are clearly continuing to proliferate. Composite pans are delivering tangible improvements in mass reduction (40-60%) and damage tolerance. And when engine architecture permits and designs teams are able to take advantage, significant cost savings also can be gained via component integration and follow-on assembly-step reductions. Transportation OEMs will certainly feel increasing pressure to shed mass and improve the efficiency of their vehicles. Assuming economic conditions continue to improve, the pace and frequency of composite oil pan introductions should go up. CW



ABOUT THE AUTHOR

Contributing writer Peggy Malnati covers the automotive and infrastructure beats for *CW* and provides communications services for plastics- and composites-industry clients.
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Composites Events

March 9, 2015 — Paris, France
SAMPE Europe Summit
www.sampe-europe.org

March 10-12, 2015 — Paris, France
JEC Europe 2015
www.jeccomposites.com

March 15-19, 2015 — Dallas, TX, US
NACE Corrosion 2015
http://events.nace.org/conferences/c2015/index.asp

April 13-15, 2015 — Cologne, Germany
8th Int'l Conference on Bio-Based Materials
www.biowerkstoff-kongress.de

May 14-16, 2015 — Atlanta, GA, US
Composites Pavilion – American Institute of Architects Convention 2015
http://convention.aia.org/event/homepage.aspx

May 18-21, 2015 — Baltimore, MD, US
SAMPE Baltimore Conference and Exhibition
www.sampe.org (click "events")

May 18-21, 2015 — Las Vegas, NV, US
WINDPOWER 2015
www.windpowerexpo.org/wp15

June 2-4, 2015 — Houston, TX, US
JEC Americas/Techtextil North America/Texprocess Americas
www.jeccomposites.com/events/jec-americas-2015-houston

June 16-17, 2015 — Stade, Germany
9th Int'l CFK-Valley Stade Convention
www.cfk-convention.com

June 17-18, 2015 — Rosemont, IL, US
ameri*mold* 2015
www.amerimoldexpo.com

July 12-18, 2015 — Chengdu, China
ICCE-23, 23rd Annual Int'l Conference on Composites and Nano Engineering
www.icce-nano.org

July 19-24, 2015 — Copenhagen, Denmark
ICCM20- 20th Int'l Conference on Composite Materials
www.iccm20.org

Aug. 17-20, 2015 — Edmonton, AB, Canada
CANCOM 2015
http://cancom2015.org

Sept. 8-10, 2015 — Novi, MI, US
SPE Automotive Composites Conference and Exhibition (ACCE)
www.speautomotive.com/comp.htm

Sept. 15-17, 2015 — Louisville, KY, US
IBEX 2015
www.ibexshow.com

Sept. 15-17, 2015 — Amiens, France
SAMPE Europe Conference 2015
www.sampe-europe.org

Sept. 15-18, 2015 — Husum, Germany
HUSUM Wind 2015
www.husumwind.com/content/en/start/welcome-2015.php

Sept. 21-22, 2015 — Stuttgart, Germany
1st Int'l Composites Congress
www.avk-tv.de/events.php?page=&year=2015&month=09

Sept. 22-24, 2015 — Stuttgart, Germany
Composites Europe
www.composites-europe.com/startseite_1.html?sprache=englisch

Oct. 20-21, 2015 — Knoxville, TN, US
Additive Manufacturing 2015
www.additivemanufacturinginsight.com/conferences/am-workshop

Oct. 26-29, 2015 — Dallas, TX, US
CAMX – The Composites and Advanced Materials Expo
www.thecamx.org

Dec. 8-10, 2015 — Knoxville, TN, US
Carbon Fiber 2015
www.compositesworld.com/conferences/compositesworlds-2015-carbon-fiber-conference

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MODULAR COMPOSITE TANK KITS

This fluid-storage tank component supplier employs Europe's largest reusable vacuum bag

In 2013, Toro Wastewater Equipment Industries (Valladolid, Spain) made the decision to incorporate composites into the manufacture of its newest patented product, the trademarked W-Tank. An all-composite modular storage tank available in multiple sizes, W-Tank is delivered to customers as a kit of slightly curved panels that can be readily assembled and mechanically fastened together on site.

Toro turned to **Magnum Venus Products** (MVP, Kent, WA, US) and its distributor in Spain, MVP-España. MVP's resin transfer molding (RTM)/infusion technical specialist Charles Tur helped the company develop a complete and efficient resin infusion process for the large panels the tank kits would require. MVP supplied its Flex Molding Process, which incorporates an integrated resin injection system and accessories, together with a method for custom-building a reusable silicone membrane, which would allow Toro to avoid the use of consumable vacuum-bagging materials while still minimizing VOC release into its shop.

Using MVP's Patriot Duo 1:1 two-part silicone system spray applicator, which is part of the Flex Molding Process package, a strong, thin silicone membrane was built up by spraying a series of thin silicone films on Toro's existing panel mold, with an embedded technical cloth reinforcement (MVP calls it Flex-Cloth) in the center. The addition of Flex-Cloth cuts finished weight (less silicone is needed) and extends bag useful life by reducing silicone's tendency to stretch over time, allowing it to better maintain its shape. Toro Equipment was able to construct its first reusable membrane in one day, and start production with it the next day, for W-Tank panel parts 8m by 3m in size.

That success prompted the company to once again contact MVP to see if it could take on a larger challenge: a 12m by 3m ($36m^2$) part, using a larger reusable silicone membrane. MVP teamed with Toro Equipment to manufacture the larger membrane, which is only 3 mm thick. Without the technical cloth incorporated into the membrane, a thickness of 5 mm would have been necessary, making the membrane significantly heavier, and approximately 40% more expensive.

The new membrane is now in production for larger W-Tank side panels shipped to customers who fabricate tanks for a wide range of fluid storage applications.

See a YouTube video about Toro Wastewater Equipment Industries and the parts they produce | https://www.youtube.com/user/Torowastewater. CW

Toro Wastewater Equipment Industries (Valladolid, Spain) molds and ships W-Tank side panels to customers who fabricate large tanks like this one on site for a wide range of fluid-storage applications.

Magnum Venus Products (MVP, Kent, WA, US) supplied, as part of its Flex Molding Process, a custom-built, reusable silicone membrane, which enables Toro to avoid use of consumable bagging materials.

MVP helped Toro graduate to infusing 12m by 3m ($36m^2$) parts, using this larger reusable membrane that, because it is reinforced with MVP's FlexCloth, is a mere 3 mm thick. Source (all photos) | MVP

COMPOSITE MANHOLE COVERS

UK utility trials ultralight access covers to reduce worker injuries and resulting compensation claims

Back injuries caused by lifting and moving traditional metal or concrete manhole covers is a real health concern that costs utilities everywhere significant worker compensation claims. Indeed, a fact sheet issued by the League of Minnesota Cities in the US says that less than 10% of the US male population has the physical ability to manually move a manhole cover safely. Facing similar concerns, United Utilities' cover and frame manager Sammy Nelson contacted Structural Science Composites Co. (SSC, Barrow in Furness, UK), which has designed and manufactured composite manhole covers for 10 years, to participate in an extended trial program to evaluate the benefits of switching to *composite* access covers, to replace conventional ductile-iron or steel-and-concrete covers.

SSC supplied its patented and trademarked Thrubeam cover design. It combines a proprietary, prefabricated dry fiberglass reinforcement, which incorporates composite stiffening "beams," with a specially developed Crestapol acrylic resin from **Scott Bader Co. Ltd.** (Wollaston, Northamptonshire, U.K.) in a resin transfer molding (RTM) process. The molded covers exhibit high strength-to-weight and the typical surface details and required anti-slip finish. The composite covers are corrosion-resistant, nonconductive, and eliminate theft for scrap value, which is a real issue with metal covers. Thrubeam covers also meet British Standard BS EN124:1994 Group 4 Class D400, which specifies that an access cover must withstand a 40-MT static test load.

Says Nelson, "SSC's composite covers can be as little as one-third the weight of a ductile-iron cover, and as much as 80% lighter than a steel-and-concrete cover. In addition they provide a superior anti-skid surface, are lockable, and do not corrode; they also look great in ground." The biggest benefit? "There has been a huge reduction in the risk of back injury for United Utilities inspection teams and installation contractors, in that the covers can be moved by one person when installed, using the SSC ergonomically designed lifting tool," concludes Nelson. CW

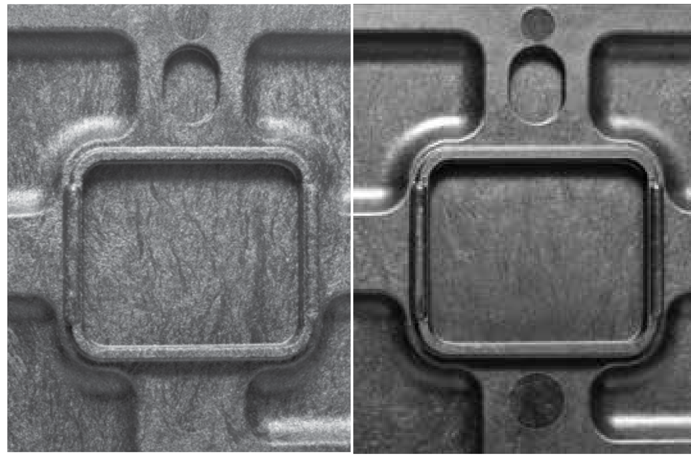
Product Showcase

» RESIN ADDITIVES

Polymer-modified carbon nanotubes

Zyvex Technologies (Columbus, OH, US) has launched a new product family called ZNT (Zyvex nanotube technology), a polymer-modified carbon nanotube additive for a range of host matrices that includes epoxies, elastomers, thermoplastics and aqueous-based solutions. The company argues that carbon nanotubes have been touted as performance-enhancing additives but have seen limited success due to poor nanotube dispersion and lack of adhesion to the matrix material. The ZNT family of products, however, is said to enable easy, cost-effective dispersion of carbon nanotubes, resulting in measurable

performance increases at affordable prices. Zyvex notes that many CNT suppliers, itself included, have been hesitant in the past to provide their fundamental technologies to other organizations without complex licensing models. With ZNT, however, Zyvex is taking a more open-source approach, which it hopes will lead to greater and faster adoption. ZNT is available in four formulations: ZNT-C for thermoset composites, epoxies and vinyl/poly esters, ZNT-W for aqueous-based applications, ZNT-Ep for peroxide-cured elastomers, and ZNT-Es for sulfur-cured elastomers.
www.zyvextech.com



» MOLDING COMPOUNDS

Class A-rated long fiber-reinforced polyamides

Standard LFT materials with fiber loadings of 50% or more exhibit high-viscosity characteristics, such as fiber print-through, that can make them problematic to mold, especially in thin wall sections. **PlastiComp Inc.** (Winona, MN, US) says it has enhanced the aesthetic capabilities of its Velocity-brand high-flow nylon (polyamide 6 and 6/6) long fiber-reinforced thermoplastic (LFT) composites. PlastiComp says Velocity simplifies the injection molding of high-fiber content LFT components by more easily producing the smooth, fiber-free surface necessary in a Class A finish. PlastiComp developed its Velocity series of high-flow LFTs to facilitate easier and quicker molding of high glass fiber or carbon fiber content materials. Although standard high-fiber content materials require higher molding temperatures to obtain a resin-rich surface, which results in slower cycle times and increased operating costs, PlastiComp reports that Velocity's fiber-free surfaces are obtainable at processing temperatures 17-22°C lower than a molder might expect. This minimizes, says PlastiComp, the need for secondary finishing operations to achieve a Class A finish.
www.plasticomp.com

» PROCESSING EQUIPMENT

Resin mixing/dispensing system

» **Isojet Equipements** (Corbas, France) and **JR Technology Ltd.** (Shepreth, UK) have developed a two-component resin mixing and dispensing machine, called Isojet 2K, for resin transfer molding (RTM) processes. This new machine allows the operator to regulate the temperature and pressure throughout the degassing, mixing and dispensing process, including heating and degassing of the resin prior to injection. One of the components is crystalline prior to processing and won't flow until it reaches 80°C. Thus, every part of the machine is heated, including the volumetric flowmeters. It can operate over a range of pressures (0-25 bar injection pressure) and flow rates (0-0.5 kg/min injection flow). The machine also has a data logging feature. A 19-inch, full-color touch-screen monitor displays temperatures and pressures of all parts of the process. The unit is self-contained and fully mobile.
www.isojet.com | www.jrtech.co.uk

» MOLDING COMPOUNDS

High-performance polyketone compounds

Lehvoss North America (Pawcatuck, CT, US) has relaunched its LUVOCOM 70 series of high-performance molding compounds based on polyketone (PK). Designed to fill the gap between those based on technical thermoplastics, such as PA6, PA66 and acetal, and high-performance thermoplastics, such as polyphenylene sulfide (PPS), polyetherimide (PEI) and polyaryletherketone (PAEK), various LUVOCOM 70 products had been available prior to 2000, but were cancelled when Shell Chemical discontinued Carilon PK polymer production. PK is a multi-use material that, Lehvoss says, offers inherently good tribological performance, as well as good hydrolytic stability, low permeability, good weld line strength and good processability, with shorter cycle times compared to other technical polymers, such as PA 66 and acetal. The polymer is now available again, and Lehvoss, therefore, redeveloped the compounds. The renewed LUVOCOM 70 line consists of three grades: 70-9045, reinforced with carbon fiber; 70-9046, lubricated with PTFE; and 70-9113/BK, formulated for low wear and friction.

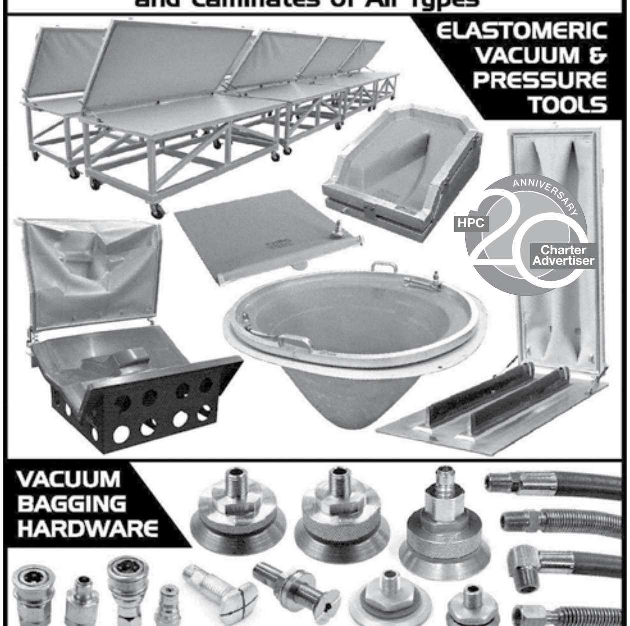
www.luvatol.com

» CORE MATERIALS

Pre-compressed, stitch-bonded core

Carbon-Core Corp. (Ruckersville, VA, US) has introduced Sphere Core SBC IP, a pre-compressed, stitchbonded glass fiber material that is volumized by means of embedded thermoplastic microspheres. It also features an additional polypropylene core, which functions as a flow medium. Sphere Core is said to be suitable for the production of dimensionally stable and lightweight homogeneous laminates, including sandwich constructions. It's available in thicknesses of 6, 8 and 10 mm and is combined with glass layers (fabric, textile or glass mats) on the outside.

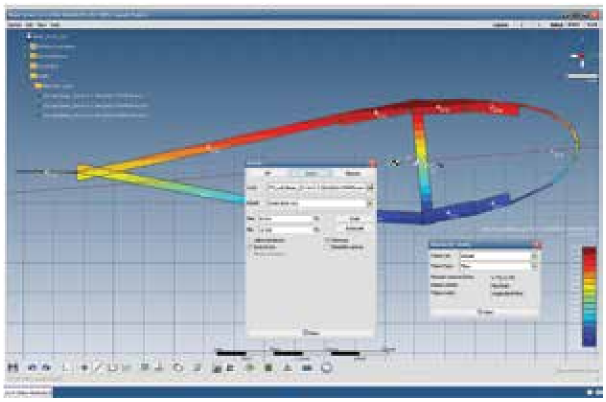
www.carbon-core.com



» DESIGN SOFTWARE

Web-based composites engineering solution

CompoSIDE (Cowes, UK) reports that it has commercialized its Internet-based composites design engineering solution. The software features several composites-specific modules, including PROJECTSpace, LAMINASpace, SECTIONSpace and FESpace, all of which will be available in the trial versions. The commercial release includes the dedicated design engineering module YACHTScant. It also enables integration with third-party tools to perform finite element analysis (FEA) and CAD. CompoSIDE features several analytical and numerical methods tools that enable users to create a range of strength and feasibility predictions for composites industry design challenges. Additional modules include BoMGen for bill-of-material and weight estimation, and REPORTSpace for integrated reporting. The commercial version of CompoSIDE is available in a range of subscription models.
www.composide.com



» NONDESTRUCTIVE INSPECTION

Ultrasound camera system

DolphiTech (Raufoss, Norway) has added a new model to its range of ultrasound cameras for nondestructive inspection applications. The CF16 camera is able to inspect carbon fiber composites up to 16 mm thick, with high-resolution 2D and 3D images. DolphiTech notes that inspecting thicker materials with ultrasound is a balance between depth and image resolution, however, the CF16 is said to provide uncommonly high-quality images. The camera is available in two versions: Expert and Operator. The Expert model is described as a "full-feature" set, designed specifically for nondestructive testing (NDT) experts. It is supported by the same software used in earlier versions. The Operator version has been created for DolphiTech TeamCenter, a software solution that integrates DolphiCam technology with inspection procedures, team-based NDT and remote expert support.
www.dolphitech.com

» CUTTING TOOLS

Specialized cutting tools

LMT Onsrud LP (Waukegan, IL, US) has introduced two new cutting tool series for trimming and shaping composites. The first is the 54-200 series, three- and four-flute cutting tools designed to machine glass-reinforced composites. The 54-200-series flute forms enable a "carving cut" as opposed to the typical "grinding" approach. The combination of optimal high rake (16°) and clearance angles creates a sharp cutting edge, which shears the fibers. These design features reduce heat build up. The open, deep, polished flute shape helps evacuate the cut material. A heavier core stabilizes the tool, enabling a chatter-free finish in the application. Further, the nanosphere-coated 54-200 tools have a useful life approximately double that of an uncoated tool. Available in either upcut or downcut configuration, the tools are reportedly equally adaptable to low and high spindle speed applications in any CNC machining environment.

Also on offer is the Progressive Chipbreaker 67-220 series. These three-flute, 3° up-shear tools are designed to promote efficient chip evacuation, while a staggered cutting edge pattern is engineered to generate very low cutting forces. This reduces the temperature in the cutting area, prolonging tool life. These tools feature polycrystalline diamond (PCD) cutting edges that support a range of feed rates and depth-of-cut combinations. The tool's Hi-Low asymmetrical chipbreaker profile helps reduce vibration and chatter caused by harmonic imbalance, resulting in improved surface finishes, while reducing both noise levels and tool wear.

www.onsrud.com

» MACHINING EQUIPMENT

Micron-level waterjet system

OMAX (Kent, WA, US) has launched its MicroMAX JetMachining Center, which provides micron-level cutting and machining of advanced composites, thermoplastics, advanced metals and glass. Designed for both prototype development and production runs, the MicroMAX is said to be a highly rigid machine with a table size of 0.7 by 0.7 m and an X-Y cutting travel of 0.66 by 0.66m. It uses advanced high-precision linear encoders, vibration isolation and software control systems to achieve a position repeatability of less than 3 microns and a positioning accuracy of approximately 15 microns. It comes with a high-precision 7/15 Mini MAXJET5i nozzle that features a 0.18-mm orifice and 0.4-mm mixing tube combination to quickly and accurately cut delicate, complex patterns. Because it forms a jet stream carrying an extremely fine abrasive, the nozzle can produce a kerf as small as 0.4 mm. The machine also has advanced pressure controls for piercing delicate materials. The MicroMAX includes the company's new Tilt-A-Jet accessory, which is said to nearly quadruple the position accuracy of the nozzle, enabling the machine to achieve virtually zero taper with most materials up to 76 mm in thickness.

www.omax.com

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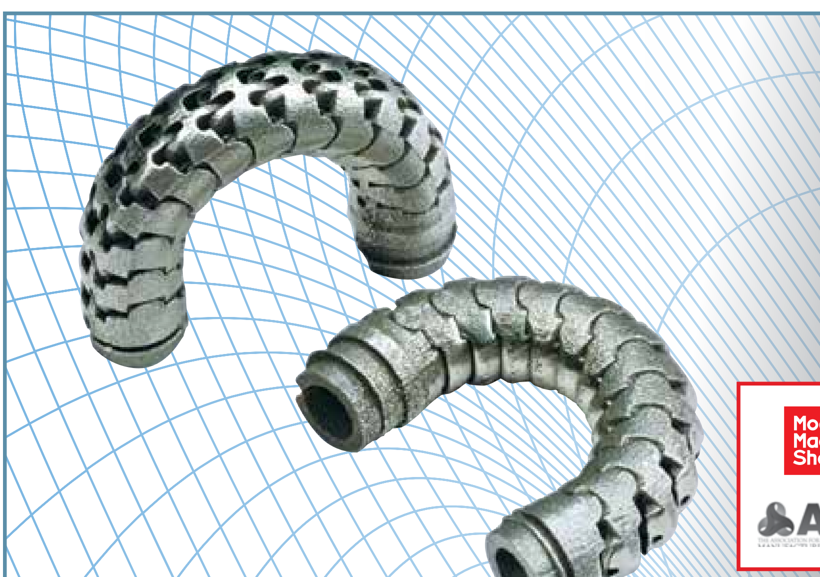


SkyPath: Scenic bikeway/walkway a winner with composites

E-glass/carbon/epoxy provides the means for this long-sought addition to a 1.1-km harbor bridge in New Zealand's capital city.

By Michael R. LeGault / Contributing Writer

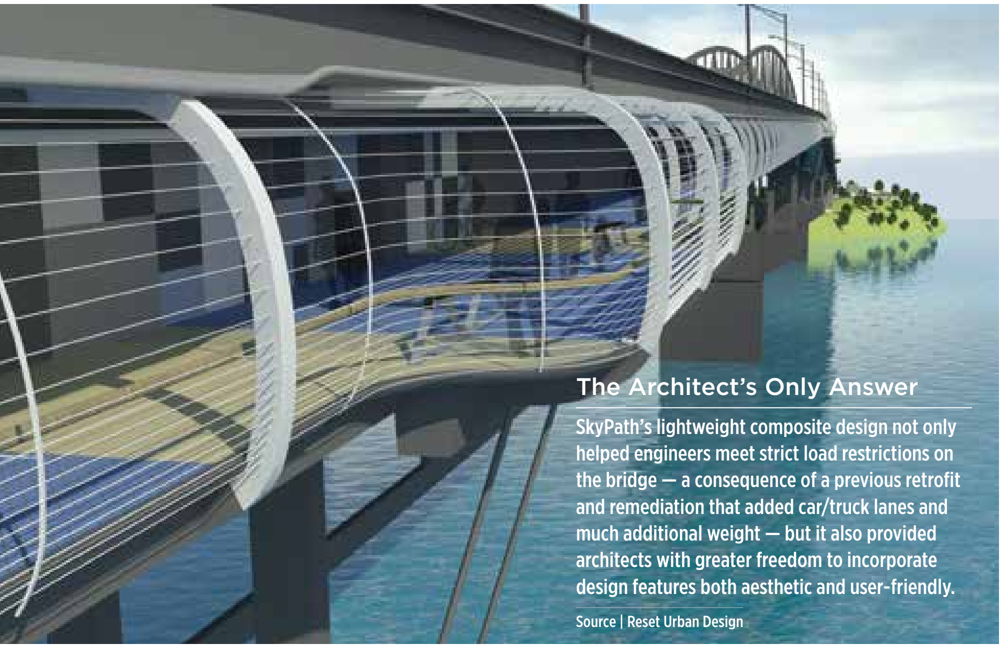
» The 1,020m Auckland Harbour Bridge is one of only two bridges that span Waitemata Harbour, connecting the city of Auckland, New Zealand, to populous suburban areas on the waterway's North Shore. Since its inception in 1946, the bridge has been a work in progress. Although a Royal Commission originally recommended a five- or six-lane bridge with footpaths on either side, the New Zealand government opted for the more affordable four-lane, no-footpath design that opened to traffic in 1959. On the occasion of the bridge project's 50th anniversary in 1996, a *New Zealand Herald* editorial called that decision "a ringing testament to … the peril of short-term thinking and penny-pinching."

In 1969, remedial action took the form of "clip-on" two-lane box girder sections attached to each side of the bridge, doubling the number of lanes. Attached only at the main piers, the section load is transferred via pier brackets — the box girders are independent of the bridge's structural truss and are connected to each other by transverse steel cross-braces. Although this solution was projected to have a 50-year lifespan, unanticipated wear and fatigue spawned several repair and structural-reinforcement projects. In 2007, trucks weighing 13 MT or more were banned from the clip-ons' outermost lanes to reduce structural stress until 2010, when the most recent fix added more than 900 MT of steel to the bridge.

Despite a groundswell of public support for the original footpath concept, there was little to show for it until that same year, when the SkyPath Trust (skypath.org.nz) was formed to work with the Auckland Council, serving as a conduit for public input, coordinating resources, and assembling engineers and public officials to assess the feasibility, cost and potential design solutions for a pedestrian/bicycling pathway dubbed SkyPath. "Forming the Trust allowed us to focus on what the issues were, because, for years, many experts had told us it was simply not possible to provide walking and cycling on the bridge," says Bevan Woodward, SkyPath project director and trustee. The negative rationale, of course, centered on the box girders and the additional loads the lane expansions had already placed on the original bridge structure.

Recruited to head a team that would assess design concepts, Garth Falconer, director at Auckland-based architectural firm Reset Urban Design Ltd., admits that composites were considered *only* after designs based on steel and aluminum raised concerns about weight and corrosion in the saltwater environment.

"We had assumed that composites would be far too expensive for what we were trying to do," Woodward admits, but reports that team members were pleasantly surprised to learn that the upfront cost premium for composites would be more than offset by maintenance and repair cost savings during SkyPath's much longer useful life. More significantly, it was clear that composites would not only mitigate the additional load on the bridge structure, but also offer greater freedom to explore design aesthetics.



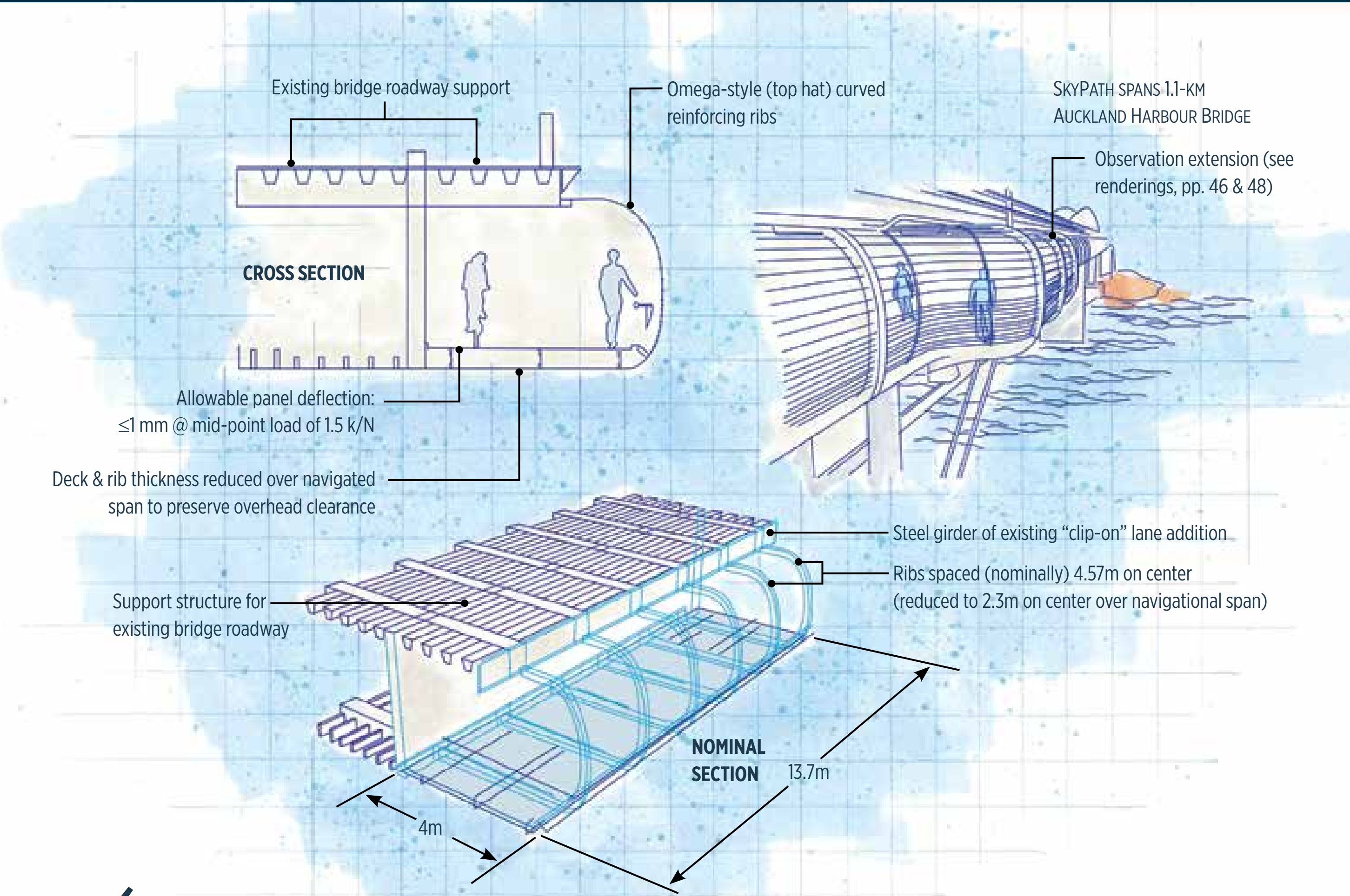
The Architect's Only Answer

SkyPath's lightweight composite design not only helped engineers meet strict load restrictions on the bridge — a consequence of a previous retrofit and remediation that added car/truck lanes and much additional weight — but it also provided architects with greater freedom to incorporate design features both aesthetic and user-friendly.

Source | Reset Urban Design

Tight design window

Composites fabricator Core Builders Composites (Warkworth, New Zealand) and the Composites Engineering Team of Auckland-based Gurit (Asia Pacific) Ltd.



DESIGN RESULTS | **SkyPath Trust Pedestrian Walkway/Bikeway**

- Lightweight sandwich construction, comprising PET foam core between faceskins of quadraxial E-glass fabric and unidirectional carbon in an epoxy matrix.
- Attachment and support of the structure with a series of 10m-long E-glass/carbon fiber, Omega-profile reinforcing ribs, spaced 4.5m on center across the bridge.
- Manufacture of modular 13.7m-long sections offsite to match existing "clip-on" box girder bridge additions so installation crews can easily slot them into place.

Illustration / Karl Reque

collaborated on the composite design. Airey Consultants (Auckland) signed on for civil engineering. When the preliminary design was presented in August 2014, the Council liked what it saw and SkyPath was advanced to a detailed engineering review, carried out by the bridge administrator and the New Zealand Transport Agency (NZTA).

As envisioned, SkyPath is 1.1 km in length, approximately 4m wide and about 5m in exterior height. The box girders for the 1969 lane additions were modular sections, each 13.7m in length. SkyPath's design involves complementary sections of the same length, which will be manufactured off site and slotted into place by construction crews working on the existing bridge deck. SkyPath's proposed composite deck is a modular sandwich panel comprising a Gurit GPET 100 FR foam core between faceskins of quadraxial E-glass fabric and unidirectional carbon fiber in an epoxy matrix. The foam core accounts for ~40% of the deck's weight, while the epoxy, E-glass fabric and unidirectional carbon fiber account, respectively, for roughly 30%, 24% and 2% of its mass.

In addition to the deck panels, SkyPath will require 257 curved,10m-long E-glass/carbon (5-10% carbon in composition) Omega-style (top hat) reinforcing ribs, which will attach approximately every 4.5m, at the top (to the transverse deck girders) and the bottom, to the transverse beams of the box girders, providing SkyPath's primary structural support.

Developed with Core Builders Composites' input, the modular sandwich design and repetitive geometry would reduce tooling cost, produce SkyPath's distinctive curved profile cost-effectively and ensure a high level of dimensional precision that would speed installation. Additionally, the carbon/glass hybrid helped solve a difficult cost/design equation: "Weight savings were critical to make this feasible," says Tony Stanton, Gurit (Asia Pacific) Ltd.'s engineering manager, "but the commercial numbers also needed to make sense. Optimizing the design around predominantly E-glass and GPET foam-cored construction with limited carbon offered the best balance between weight savings and cost." »

Walkway/Bikepath with a View

The SkyPath interior features a composite deck wide enough to permit separate bike and foot traffic lanes. The deck, here, is wider still to undergird one of five observation extensions on SkyPath which will enable path users to step out of traffic to enjoy a panoramic view.

Source | Reset Urban Design

Stanton says that because the retrofit box girders are independent of the bridge structure, they presented a unique design challenge in terms of minimizing dead weight, especially with respect to the bridge's center — and at 243.8m, its longest — free span. It is also the most highly loaded section of the box girder in terms of load-to-capacity ratio.

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"While weight savings [for SkyPath] is relevant to the entire bridge, it is most important over this region," Stanton says, noting that to support the weight of the structure and the live load (pedestrians using SkyPath) over this span, the box girders themselves, in *any* design scenario, would need reinforcement. The use of composites, however, minimized the quantity of steel that would be required.

Load and space limits

The SkyPath addition subjects the box girders and bridge piers to two primary loads: a dead (static) load, resulting from the structure's material weight, and a live (applied) load from pedestrian/bike traffic. Because the structure had to be designed for a fixed live load, weight/cost savings could be realized only by reducing the dead load. Accordingly, engineers assessed the local stiffness of the structural ribs during the design phase with a goal of optimizing the attachment details to direct loads into the areas of the primary box girder that had the highest reserve load capacity. Using this combination of composite material optimization and bridge loading optimization, Gurit and Aireys' engineers sought to minimize the reinforcement work required on the box girders.

The bridge's center span also presented engineers another challenge. It's the *navigation* span under which marine traffic passes. Rising 43m above the water, its "air draft" must be maintained. That is, no part of SkyPath could extend below the lowest point of the box girder. As the box girder reaches the apex of the span's gentle arch, it narrows from top to bottom, and the available vertical space for SkyPath is at its minimum. For an enclosed walking/cycling path, the local code requires minimum headroom of 2,400 mm. SkyPath's preliminary design, however, called for a more spacious 2,600 mm between the deck and the underside of the beams that support the roadway overhead. Designers considered reducing the clearance to 2,400 mm to negotiate the navigation span's height limitation, but in the end, preserved the headroom and prevented a "closed in" feeling by decreasing the thickness of the deck and subframe. To compensate for thinner ribs in this area, unidirectional carbon fiber capping (principally axial, but also off-axis fibers for shear connection to the rib's web) was added to the flanges of the rib's Omega profile. Additionally, rib spacing was decreased from the standard of 4.57m to 2.3m. This, in turn, allowed engineers to keep additional carbon in the capping to a minimum.

One additional design challenge was posed by *deflection and vibration*. Even more so than buildings, bridges are *active* structures. Loads imposed by traffic and environmental conditions already cause the Auckland Harbour Bridge to deflect by as much as 300 mm. To prevent SkyPath from increasing that distance, engineers imposed stringent deflection limits on the sandwich composite floor panels. Practically, that meant a high degree of stiffness: Panels should deflect 1 mm or less when subjected to a mid-point load of 1.5 k/N. Engineers also analyzed the bridge's natural vibration frequency to ensure that pedestrian traffic on SkyPath would not create frequencies at or near that value. SkyPath's low weight, shallow beam sections and relatively low modulus materials (E-glass) offered the potential for a "lively" structure where natural frequencies could occur in the same range as that created by groups of walkers or runners. To prevent this potential design flaw, designers hoped to maintain a first natural mode of vertical vibration for SkyPath greater than 5Hz. The closer spacing of the ribs across the navigation span made that target easier to hit.

Just one "yes" away

Assuming all goes according to plan, project approval is expected by May of this year. Reset's Falconer says engineers then can knuckle down to final, detailed design work. A projected build window of six to eight months, made feasible by the modular design and construction, means SkyPath could be complete in 2016. The composites — aesthetically pleasing, inherently fatigue resistant and nearly impervious to environmental assault — ensure that SkyPath will be a durable, low-maintenance and popular piece of infrastructure. CW

ABOUT THE AUTHOR

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