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## The Carbon Fiber Wheel: SEEKING A LESS EXCLUSIVE MARKET


MARCH 2018





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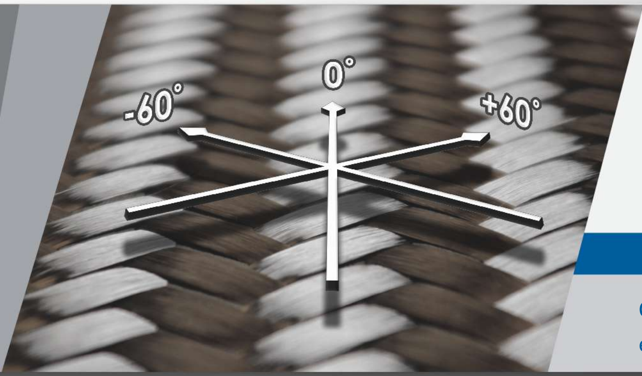


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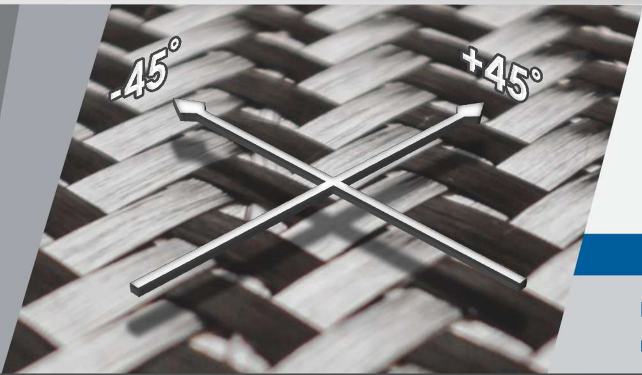


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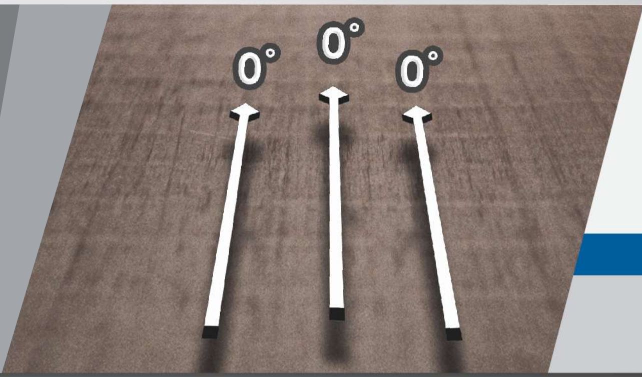


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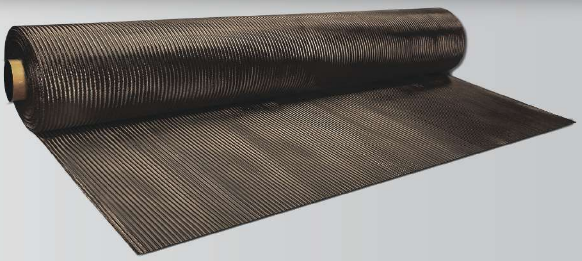
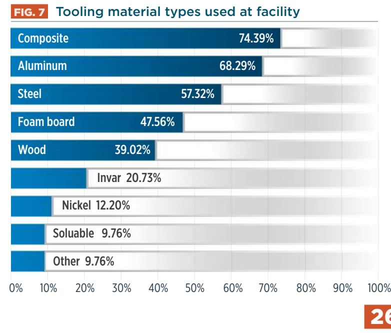


MARCH 2018 / Vol: 4 Nº: 3

## COLUMNS




FIG. 7 Tooling material types used at facility





## FEATURES



## DEPARTMENTS



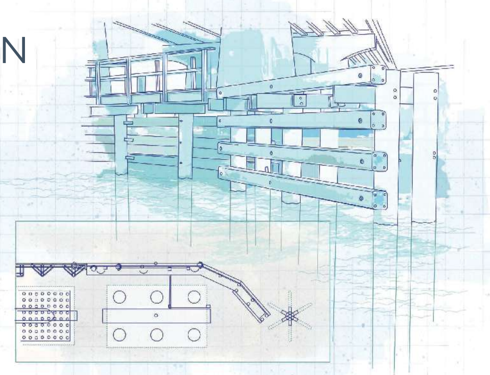
## ON THE COVER

A set of four all-carbon fiber or hybrid carbon fiber/aluminum wheels range in price from US$10,000-US$15,000. That makes them, for now, best suited for high-end vehicles like this high-end Jaguar *F-Type*. British wheel manufacturer Dymag (Chippenham, Wiltshire, UK) is searching out ways to make them affordable for series-production cars. Get the inside story on p. 30.

Source / Dymag

## FOCUS ON DESIGN





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I visited Spirit AeroSystems (Wichita, KS, US) in mid-February. It was my first visit to Spirit, and I was given a thorough and insightful tour of the company's composites manufacturing and R&D facilities. You will be able to read, soon, a full report of what I saw, with details about the manufacture of the Boeing 787 *Dreamliner's* forward fuselage section.

Gambling carefully on the Next Great Aircraft Program.

It is not difficult to come away from a visit to Spirit AeroSystems impressed by the size, scope and depth of the company's involvement in aerospace manufacturing. The Wichita facility alone employs almost 11,000 people and provides composite and metallic structures for almost every major commercial aircraft in operation today, along with a handful of military aircraft. The buildings in which I spent most of my time would, anywhere else, stand as massive manufacturing monuments in their own right, but they represent just a sliver of the total capacity on Spirit's aeromanufacturing campus.

I was struck in particular, however, by something I was told very early in my visit: Spirit AeroSystems has more than doubled its composites research and development investment in the past two years. That a company like Spirit does R&D is not a surprise. Nor is it a surprise that a company like Spirit might increase its R&D spending. What piqued my interest was the reason behind the investment: Spirit wants to be *more* than a Tier 1 aerospace supplier; it wants to be an integrated solutions provider, at the table with its customers to help optimize designs and to develop next-generation composite products and structures. What kinds of solutions? All, was the reply. In other words, Spirit wants to be ready for whatever the aerocomposites industry demands of it. The position that Spirit has taken is, I believe, emblematic of a broader truth about the aerocomposites industry today: We are in the middle of a sort of between-aircraft programs purgatory the likes of which we have never experienced before.

Consider this: The decision by Boeing, and then Airbus, about 15 years ago, to pivot to composites for the 787 and the A350, respectively, marked the start of the modern aerocomposites era, drawing very much on technologies developed in the 1990s. Now, with those programs in series production, aerospace manufacturers everywhere are looking to the future more furtively than ever. What will be the Next Great Aircraft Program, and how will it use composites? Will it be a redesign of the 737 or A320? A 757 replacement? What will be that program's expectations and requirements? What will be the composites opportunities on those craft?

It's clear that Spirit AeroSystems (and its competitors) has looked at the technologies employed today to make the 787 fuselage — automated fiber and tape placement with autoclave cure — and reasonably questioned whether those same technologies in their current forms represent the future of aerocomposites. And if they do not, what is? Out-of-autoclave? Dry fiber placement? Thermoplastics? In-situ consolidation? Infusion? Resin transfer molding? Bonded structures?

The answer, of course, as my hosts in Wichita said, is potentially all. Because of this, companies like Spirit AeroSystems are using this in-between time to take initiative on new technologies that might soon become solutions for aircraft OEMs. They are taking a calculated risk that *they* can develop the expertise, materials, tools and equipment to meet that evolving aerocomposites need, and in the process earn a piece of the Next Great Aircraft Program.

This can be unnerving. Gambling in this environment, even carefully, puts resources and people's jobs at risk — there will be materials, technologies and companies *not* chosen for the Next Great Aircraft Program. On the other hand, we are living through and guiding technological evolution like never before. Those who place their bets now by working proactively and thoughtfully to anticipate what is needed and expected for the future's commercial aircraft will be in the best positions to claim their share of the prize.

Spirit has almost 100 years of aerospace manufacturing history, and has accrued materials and manufacturing knowledge that has few rivals in the world. Its gamble on the future is probably a pretty good one, and one to which we should pay attention.

JEFF SLOAN — Editor-In-Chief

# Delivering the potential of thermoplastic composites

» Whilst many have been discussing and championing the benefits of thermoplastic composites (TPCs) as the next breakthrough, high-volume, lightweighting technology for more than a decade, their market penetration has not yet met these expectations. Why has this adoption of TPCs been slower than expected, and who is best placed to accelerate it?

The TPC market has been forecast to grow to nearly US$42 billion by 2022[1], with leading material market players, including Celanese, BASF, Solvay, Lanxess, DSM, PolyOne and RTP, offering a massive range of resin options and product formats, for a wide range of applications.

The list of benefits of TPCs certainly makes a compelling case for their consideration as a material replacement in both metallic and thermoset composite parts and assemblies. Massive processing speed gains vs. thermoset composites, plus recyclability and toughness make a very strong argument for engineers.

Raw material and intermediate cost comparisons are complex, given the large price variances between commodity TP resins, (e.g., polyamide, polypropylene) and the higher performing engineered matrices (polyarlketones, such as PEEK, PEKK and PAEK) as well as varying stages of maturity in the TPC intermediate supply chain. Therefore, some of the clearer cost advantages of TPCs relate to the option to re-design previously metallic parts to simplify later steps in manufacturing or assembly.

***So, what is holding them back?*** Taking a top-level view, the principal barriers to increased use of thermoplastics include a less widely accepted set of design data and less familiarity with material properties and the overall technology compared to that of their thermoset cousins. In some high-performance TPC applications, we do not yet have raw materials that are fully stable and consistent enough to maintain tolerances and match void content percentages seen with thermosets. Thermoplastics typically need melt temperatures of 160-300˚C and high pressures to impregnate reinforcement fibers or injection mold parts. The complex and often expensive tooling and machinery required is very different from that for conventional thermoset composite molding.

In our opinion, over the past 20 years, the investment in technology development has favored thermosets. But this is now being reassessed as the aerostructure and automotive markets look to thermoplastics to reduce cycle times and produce more readily recyclable composite parts out of the autoclave. We have hypothesized that the still-nascent TPC industry could overcome these barriers and realize its forecast potential with the help of two different industry sectors, coming at the problem from two very different approaches.

***Approach #1: TPCs bring industrial scale to composites.*** The first sector is dominated by large industrial chemical solutions providers, those with thermoplastic capability that typically operate on a scale at least an order of magnitude greater than their counterparts in thermoset composites that supply thermosets to the composites industry. We see these chemical heavyweights, with their deep-rooted resin and polymer expertise, and the maturity of the thermoplastic materials sector, as being both well placed and motivated to drive the transformation of the TPC sector.

To large players, such as Celanese and Solvay, the attraction of composites is the opportunity to improve margins and capitalize on large-volume applications, such as metal replacement in automotive. Development of new composite materials and applications also provides scope to further differentiate their product offering.

The thermoplastics transformation approach we expect to see deployed in this case would involve targeted product cost reduction via the integration of large-scale manufacturing technologies, further consolidation of the supply chain by bringing compounding and composite material production in-house, and the leveraging of existing strong relationships with OEMs. Significant M&A activity also would occur. We've already seen evidence of this trend in recent transactions: Solvay acquired Cytec, expanded its product portfolio and a boosted its activities in the aerospace and automotive markets. Celanese also added additional compounding capacity and materials technology to the portfolio with its 2017 purchases of compounders Omni Plastics and Nilit Plastics.

***Approach #2: Extending the reach of composites with TPCs.*** The thermoset composites molding sector presents a more fragmented structure than that for industrial TPCs, with numerous smaller specialists and less integration than is seen in the TPC sector as a whole. With an impressive growth rate (5-year CAGR estimated at 6-7%[2]) forecast to continue as lightweighting technologies become more established, margins are also higher for these applications that remain smaller in scale than their thermoplastic counterparts.

A differentiator between those who market thermoplastics and thermosets is that the latter have more experience with fiber reinforcement and use more complex, multi-component resin systems.

For suppliers of thermoset composites, the draw to expand into TPCs is the opportunity for step-change increases in volume and the potential to enter markets where thermoset composites are less well-established because their cycle times are too slow, costs are too high or recyclability is a prerequisite. Consider, for example, Teijin and TenCate. Both have a strong textile heritage, have certainly picked up the pace of TPC development and shown key aspects of our previously noted TPC approaches in their recent actions.

TenCate's range of thermoplastic products now almost mirrors its thermoset offering in scope: UD tapes and prepregs, reinforced laminates and bulk molding compounds are available with a range of mainly higher performance thermoplastic matrices. It's this focus on material performance in small- to medium-sized series, with examples such as aerospace leading edges, floors, brackets and cover plates, that we expect to see from this approach. TenCate also has formalized its industry and research collaboration, supplementing internal competencies and development with partnerships, such as its Tier 1 membership in the Thermoplastic Composites Research Center (TPRC) and other European consortiums and clusters, such as Thermoplastic Affordable Primary Aircraft Structure (TAPAS) and European Thermoplastic Automotive Composites consortium (eTAC)[3].

Teijin has developed TPC materials reinforced with its own carbon fibers and offers high-rate processing techniques for sub-60 second automotive parts. It also has added part production capacity and expertise, with its acquisition of molder Continental Structural Plastics, and has launched a recycled carbon fiber-reinforced thermoplastic material in Europe[4]. These downstream movements and transactions provide momentum to kick-start use of Teijin's new materials at component level.

Ultimately, we predict that aspects of both approaches will be evident over the next five-year period, with a solid understanding of the entire value chain being the key to success in this complex tapestry. The largest thermoplastics players are well placed, and evidently very keen to deploy their developmental and financial firepower now. Recent thermoplastic automotive projects, such as the Bentley *Bentayga* and Audi *Q7* SUV underbody engine shields, fuel tank and center tunnel covers, produced with trademarked LANXESS Tepex TPCs, are examples of thermoplastic technology leaders' involvement in truly industrial-scale composite applications that would be hard to match with thermoset composites. Therefore, we see the chemical materials giants as most likely to be able to execute in the largest scale applications.

Composites manufacturing specialists that focus on high-performance TP materials and employ downstream acquisition strategies to facilitate rapid adoption of their technology and promote their knowledge are especially suited to growth in more niche applications, such as aerospace or medical. We also expect to see M&A activity here because these technology leaders are attractive targets for major thermoplastics players that wish to integrate thermoset and thermoplastic composite expertise into their operations. CW

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[4] Teijin press releases (2017).

## ABOUT THE AUTHOR

Dr. Myriam Yagoubi is a consultant at Future Materials Group (FMG, Cambridge, UK). Her primary role is to support FMG's clients in developing their business growth strategies, creating benchmarking analyses, forecasting models and market entry approaches. She is also responsible for carrying out due diligence assignments for buy-side M&A and assisting in sell-side transactions. Previously a researcher and project manager for Infineum UK Ltd. (Abingdon, UK), she developed and commercialized novel products for the lubricant market. Yagoubi holds a Ph.D in organic chemistry from the University of Oxford and an MS in chemistry from the Ecole Nationale de Chimie of Montpellier, France.

# Advancing technology in a multinational world

» The month of March brings the annual migration of composites researchers, manufacturers, specifiers and end-users from points near and far, to Paris for the JEC World exhibition. The largest of its kind, JEC World offers attendees and exhibitors alike the opportunity to assess the health of the composites marketplace and see the latest in machinery, processing, materials and applications. One comes away from JEC with an appreciation for the industry's breadth and reach.

Markets served by those who offer composites technologies are, indeed, global in scope. In the automotive industry, BMW assembles vehicles in seven countries, Mercedes in 11, Ford in 16, and both Volkswagen and Toyota in more than 20 countries worldwide. Although some models are designed for local markets, each OEM is seeking lighter, more durable, more sustainable solutions for future production.

What collaborative scenarios can we create that leverage assets in *multiple* countries and get to solutions faster?

In aerospace, Airbus assembles commercial aircraft in four countries, including China and the US, and sources components and assemblies from numerous countries outside of Europe. The recent Airbus and Bombardier *C Series* alliance extends that reach to Canada as well. Although all Boeing aircraft are assembled in the US, Boeing facilities in Canada and Australia engineer and deliver key subsystems, and major components, including carbon fiber wings, are sourced from suppliers in Japan, Europe and elsewhere. Boeing's proposed acquisition or joint venture with Embraer aims to include assembly in South America. Even Lockheed Martin's F-35 *Lightning II* has subassemblies shipped to Fort Worth, TX, US, from Australia, Canada, Denmark, Italy, The Netherlands, Norway, Turkey and the UK.

The largest user of composites by volume, the wind energy industry, is also highly globalized. Ever-increasing blade size has made fabrication nearer wind farm locations a practical necessity. With the acquisition of LM Wind Power, General Electric now builds turbine blades in at least 13 countries. Siemens Gamesa has blade facilities in nine, and Vestas in seven. Even independent blade fabricator TPI Composites builds blades in four countries. All of these maintain blade factories in China, the fastest-growing market.

Although most composites-based sporting goods and electronics are built in Asia, both are *sold* into global markets. Pressure vessels and products designed for the oil and gas, infrastructure and construction industries are made and sold globally. It's hard to find a segment in the composites universe that *isn't* worldwide.

Each of these market segments is served by a host of multinational suppliers at the Tier 1 and materials levels. This is especially true within the automotive segment, where, at the request of their OEM customers, Tier 1 suppliers establish facilities close to the final assembly points.

*In contrast to the above*, the university systems tasked with educating future generations of composites scientists and engineers, together with the host of research institutes and consortia are, with very few exceptions, *single nation-based*. This industry/academia mismatch creates some systemic friction: The composites industry must address increasingly global technical issues. But its OEMs and their suppliers feel pressure to work with local or national universities and institutes to take advantage of government matching funds when an international coalition might approach the topic most effectively. Although recent advances are quickly disseminated though conference proceedings, refereed journal submissions and in trade publications, such as *CompositesWorld*, global issues are, at best, incrementally addressed.

I first drew attention to this issue in March 2016, less than year after the start of operations of the Institute for Advanced Composites Manufacturing Innovation (IACMI) in the US. I noted that governments, which provide base funding for research institutes and universities, have a vested interest in promoting the relative competitiveness of their in-country manufacturing bases. Yet, as many have noted before, major topics — modeling/simulation, composites recycling, reduced energy consumption, speed/efficiency, and workforce development/education — are *global needs* for multinational OEMs and their suppliers.

What can we do to address these topics from a research perspective, and make composites as ubiquitous as competing materials? What sort of collaborative scenarios can we create that leverage assets in *multiple* countries and get to solutions faster? At IACMI, we are in discussions with one European consortium regarding jointly funded research projects, student exchanges and other topics. Along this line, I am working with the JEC Group to organize an initial gathering of many national composites institutes and clusters at JEC World to, at the very least, get acquainted and agree on the most important research and education needs of our industry members. In time, we can explore how we might establish international projects to address those needs. How far can we get? Who knows? I'm excited to find out. CW


**ABOUT THE AUTHOR**

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

# Application of video extensometry to ASTM D 5656

Adhesive bonding is a critical part of the structural designer's toolkit, whether components are metallic or composite. The availability of high-quality, reliable and reproducible data is central to the ability to design and deliver cost-effective bonded assemblies. Although standard test methods are available, those methods typically specify the use of data acquisition tools that were considered state-of-the-art at the time the method was established. It can be useful to consider the opportunities made available by re-envisioning established test methodologies, using more recently developed measurement technologies.

This column examines how the application of a video metrology technology can offer more effective measurements than conventional means within ASTM standards and extend the range of data available without any changes to the test specification. ASTM D 5656 is used here as an example of the advantages of the new technology, which can be applied across a range of both standard and novel test procedures.

Reliable, reproducible data is central to the design and delivery of cost-effective bonded assemblies.

## Extensometry update

In the ASTM D 5656 test method, thick adherend lap shear samples are adhesively bonded, and a tensile load is applied to place the adhesive in shear. The use of thick, rigid adherends minimizes peel forces, ensuring that the test will obtain data on the shear stress/strain properties in the adhesive — the data useful when designing or analyzing adhesively bonded joints.

The current solution used to measure extensions on this specimen is the KGR extensometer, and it has been adopted as the standard by ASTM. The extensometer uses the conventional strain-gauged beam approach and is attached to the sample using either three or four pins, depending on the specific implementation.

The relative movement between the two plates of the thick adherend shear test fixture is then tracked during the test. Extensometers are attached to both edges of the specimen and the readings are averaged to give the reported strain. Problems have been reported with these extensometers in terms of slippage at the pin connections, the impact of any rotation on the reported strains, damage to the extensometers when samples fail with the extensometers attached, and the common issues of reliability and the potential for baseline drift with strain gauge systems.

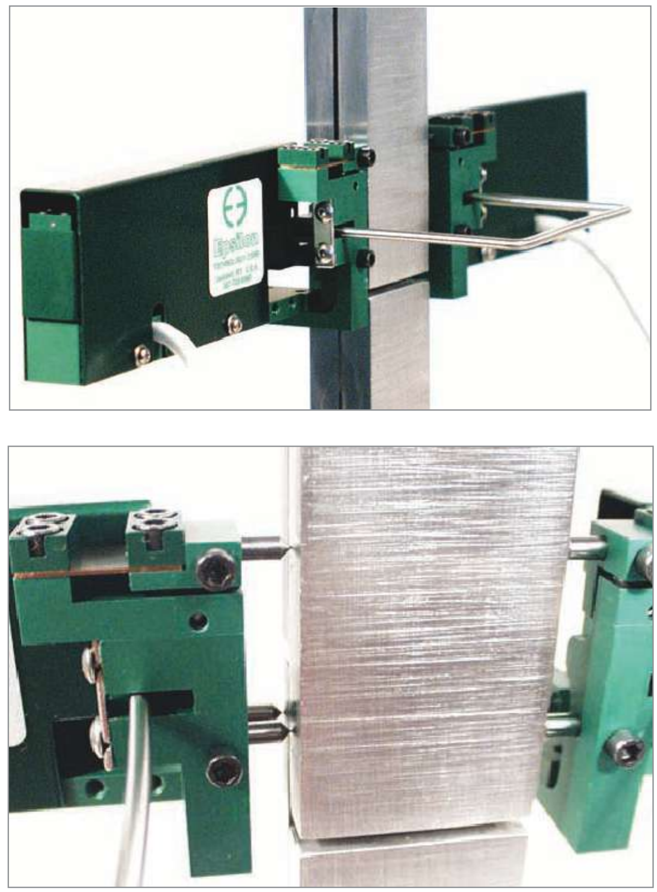


**FIG. 1** An electro-mechanical KGR extensometer, the current ASTM standard test device, is shown in overview (top) with a close-up of the contact pin detail (bottom). Source | Imetrum

## The video metrology alternative

In place of the standard extensometer (Fig. 1, above), during a demonstration ASTM D 5656 test, a video metrology-equipped extensometer developed by Imetrum (Flax Bourton, UK) was used. Imetrum's systems are designed to yield traceable data across most testing and monitoring requirements for materials, components, assemblies and structures. The system is fully commercial and routinely used to determine material properties, quality control, model verification, and to perform structural testing and in-service assessments. The system's trademarked Video Gauge technology ensures that the system meets the most demanding requirements for strain, elongation, modulus and other measurements in tensile, compression, flex, shear and peel tests. The Universal Video Extensometer (UVX) can deliver resolutions to better than 3 microstrain and calibrate to unparalleled accuracies, with ISO 9513 class 0.5/ASTM E83 B-1, even at low strains and gauge lengths.

Under controlled laboratory conditions, the UVX system will track the x and y coordinates of a target box used to define the position of a feature in the video stream to a resolution of 1/200$^{th}$ of a pixel or better. This level of resolution makes the system effective in situations where conventional extensometric measurements are difficult because they are carried out

- on a very small scale.
- at very high temperature.
- on very delicate specimens.
- in high-speed testing.
- in complex loading regimes (such as those tested in ASTM D 5656).
- in remote sensing of large civil engineering structures.

In this demonstration, two 5-megapixel cameras and suitable lenses were selected to maximize the adhesive bond line in camera view. The large number of pixels representing this bond line ensured a high measurement resolution. In this case, 0.1µm displacement resolution was achieved.

The cameras were positioned front and back and synchronized to replicate the setup of the KGR extensometer (Fig. 2, top right). A measurement plane was calibrated, using the known dimension of the overlapping bondline for scale. This enabled extension measurements to be made in millimeters, in accordance with the standard. Measurement points were applied according to the positions defined in the ASTM standard.

### Comparing test results

Test results were compared with data collected using a conventional extensometer (Fig. 3, bottom right). The mean value of shear modulus (81.6 ksi) was found to be within 1% of KGR-determined data (82.2 ksi). Shear modulus determined using the KGR data had a standard deviation of 27.8%, but the shear modulus determined using the UVX data had a standard deviation of only 14.0%. Additional testing suggested that using six measurement points, rather than three, could potentially more than halve this uncertainty to 6%.

In addition to providing KGR equivalent point displacement data for manual calculation of the shear stress/shear strain curve (Fig. 4, p. 14, top), the video extensometer can measure shear strain directly, using groups of targets. The shear strain gauge is shown in Fig. 4, bottom). The gauge can be extended to cover the entire bond length and aligned with the bond line for precise measurement. A sufficiently small field of view would allow the shear strain to be measured directly in the adhesive layer, avoiding uncertainty that comes from measuring on the adherends.

**FIG. 2** This photo of the experimental setup shows the UVX video metrology system's two cameras positioned in front and in back of the test coupon, which is mounted in the test frame. Source | Imetrum

Although the current method, using a KGR, provides average shear strain between the adherends, it does not provide *all* the information that would be of benefit in a research environment. UVX can provide additional data, including changes in the thickness of the adhesive layer, relative rotations of the adherends, point-to-point differences in the shear strain in the adhesive layer, shear and tensile strains in the adherends and tracking of the development of cracks within the adhesive. The UVX technology enables a simpler, more robust and reliable approach to the capture of the basic shear strain, as required by ASTM D 5656. »

| IMETRUM DATA | | | | |
|---|---|---|---|---|
| ksi | | Front | Back | Ave |
| Sample 1 | original | 83.4 | 90.9 | 87.2 |
| | rotated | 113.4 | 71.3 | 92.4 |
| Sample 2 | original | 59.9 | 68.9 | 64.4 |
| | rotated | 79.5 | 47 | 63.3 |
| Sample 3 | original | 84.8 | 90.5 | 87.7 |
| | rotated | 109.5 | 79.8 | 94.7 |
| Mean | 81.6 | | | |
| StDev | 14.0 | | | |
| %COV | 17.2 | | | |

| CUSTOMER DATA | |
|---|---|
| ksi | |
| Sample 1 | 47.7 |
| Sample 2 | 78.3 |
| Sample 3 | 114.3 |
| Sample 4 | 105.9 |
| Sample 5 | 64.8 |
| Mean | 82.2 |
| StDev | 27.8 |
| %COV | 33.9 |

**FIG. 3** A comparison of the test results obtained using the UVX video metrology-equipped extensometer and a conventional KGR extensometer. Source | Imetrum

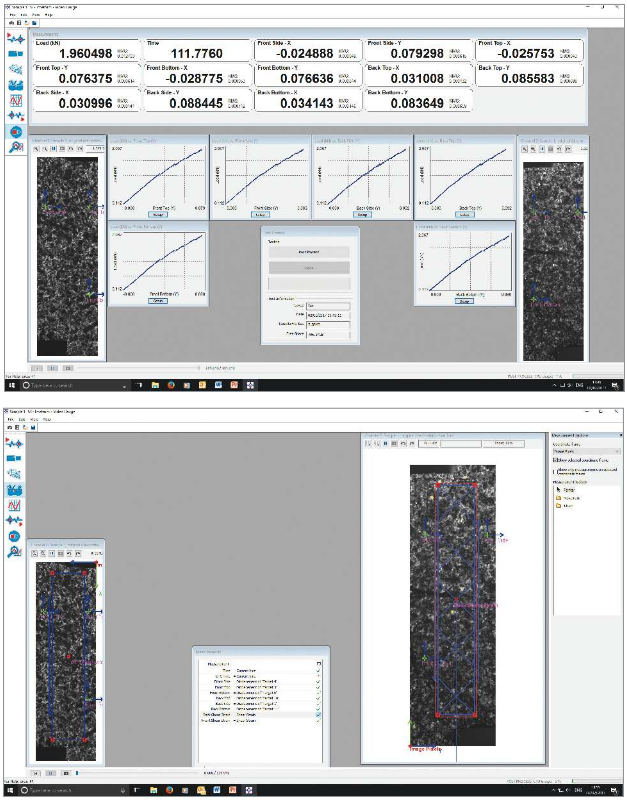



**FIG. 4** Screen shots taken from the video gauge images identify KGR equivalent measurement points (top) compared to those gathered by the conventional shear gauge (bottom).

Source | Imetrum

In addition, it allows all the rich data currently not captured to be recorded for in-depth analysis (Fig. 4, at left).

A total of 18 points were identified and measured (Fig. 5, p. 15) yielding the following data:

- Shear strains between points 16 and 17 provide the basic functionality of the KGR extensometer.
- Tracking points 2 and 16 and points 3 and 17 allow rotation of the sample to be determined.
- Tracking points 3; 11 and 17; and 4, 12 and 17 allow the shear and tensile strains in the arms of the test fixture to be captured.
- Tracking points 5 and 6; 9 and 10; and 13 and 14 allows the strain in the adhesive to be measured directly.
- Tracking the displacements of points 2 and 3 or 16 and 17 allows any change in adhesive thickness to be captured.

The various relationships between these points can be tracked in real-time during the test and/or stored for post-process analysis.

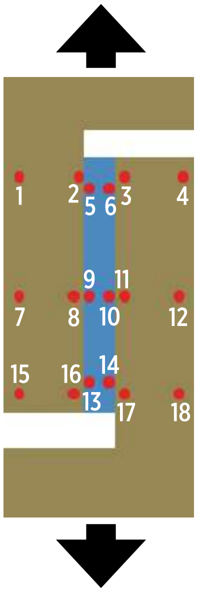



**FIG. 5** The various relationships between 18 points on the critical central section of the test specimen (depicted here) can be tracked via video metrology both in real-time during the test or analyzed later in post process. Source | Imetrum

## More repeatable, reliable, applicable

In this demonstration, video-derived measurements were shown to give more repeatable results than a conventional KGR extensometer, while still following the rules outlined in the ASTM D 5656 standard. Potentially, this could allow for smaller specimen batches, leading to time and cost savings.

Subsequent testing demonstrated that even greater consistency could be achieved by using the UVX multi-point capabilities to track strain at multiple points along the bond line. Multiple measurements also can even out the variations in stiffness seen along the bond line, further improving repeatability.

A noncontact extensometry solution offers other benefits, such as removing the potential for device slippage on the specimen or device damage at failure. Furthermore, although the KGR extensometer was developed specifically for the ASTM D 5656 test, video metrology-equipped extensometers are more test-method agnostic. The UVX configuration used here can be employed to make measurements on other specimens and for other test method standards. UVX Flexi video extensometers, for example, are highly configurable with a wide choice of user-interchangeable camera and lens options, enabling a single system camera to be used for almost all material testing requirements. The UVX is designed for ease of use and fast throughput speeds and is ideal for batch testing. CW

### ABOUT THE AUTHOR

Simon Jenkins is a chartered mechanical engineer, providing technical leadership and project management in manufacturing research to GKN Aerospace (Filton, UK). Previously an applications engineer for Imetrum (Flax Bourton, UK), he supported customers by performing dynamic measurements on test articles, ranging from sub-millimeter laboratory-scale coupons to bridges in service. Before coming to Imetrum, Jenkins spent 12 years at BAE Systems (Bristol, UK) working in materials research, with specialties in nonstandard mechanical testing, high-strain-rate testing and digital image correlation. He holds a Ph.D in mechanical engineering from Bristol University.

# The US Composites Industry in 2018: A strong start

## January 2018 – 58.4

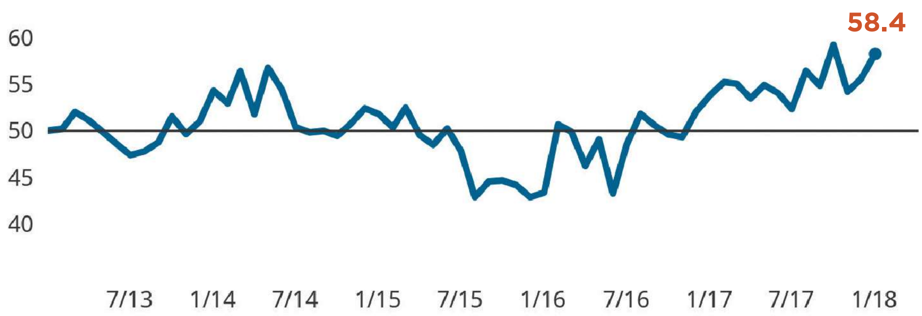
Registering 58.4 for January, the Gardner Business Index (GBI): Composites Fabricating started 2018 only slightly below the peak reading recorded in 2017. The January reading sustained strong fourth-quarter 2017 performance, which averaged 56.5, with the peak coming in October, surpassing 59.0. Compared to the same month one year earlier, the Index had increased approximately 8 points. The Gardner Intelligence review of the underlying data for the month indicates that Production and Supplier Deliveries lifted the Index higher while Backlogs and Exports held the Index down. That said, no Index component showed contraction (<50.0) during the month.

As January closed out, GBI survey respondents indicated that Production and New Orders had been, in recent months, the most significant drivers of the overall Index, followed by Employment and Supplier Deliveries. During that same period, New Orders growth had exceeded Production growth. In such instances, Gardner Intelligence has commonly found a near immediate upswing in either Backlogs or Exports or both. The data from third-quarter 2017 and January 2018 indicate that both Backlogs and Exports are increasing, suggesting that a growing portion of New Orders may be coming from foreign consumers. A 9% decrease in the value of the US dollar during 2017 also might explain some of the increase in demand from customers based outside the US during that four-month period. CW


**ABOUT THE AUTHOR**

Michael Guckes is the chief economist for Gardner Intelligence, a division of Gardner Business Media (Cincinnati, OH US). He has performed economic analysis, modeling and forecasting work for nearly 20 years in a wide range of industries. Guckes received his BA in political science and economics from Kenyon College and his MBA from Ohio State University. **mguckes@gardnerweb.com**

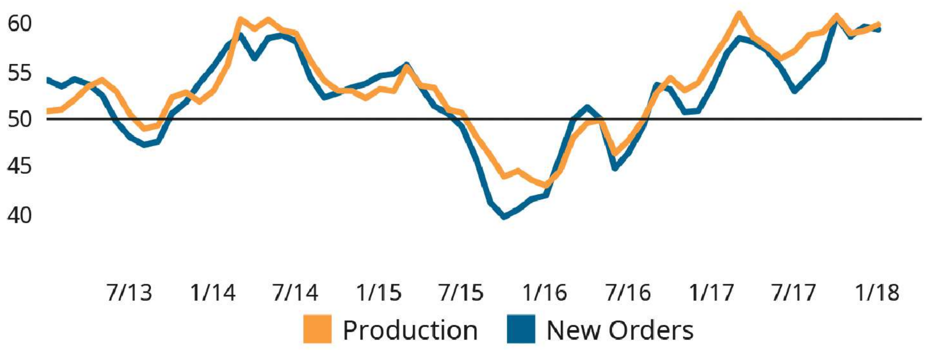

GBI: Composites Fabricating




### Composites in 2018 begin near 2017 high

The Composites Fabricating Index ended January within 1 point of the high reading from 2017. The strong growth in Production and New Orders suggests that the industry is starting 2018 well-positioned for continued growth.

GBI: Composites Fabrication - New Orders and Production
(3-month moving average)




### Healthy growth and trend toward Exports

Strong expansionary readings in the New Orders and Production subindices suggest that the industry is growing at a very healthy rate. Expansion in Exports suggests that a growing portion of New Orders are from customers outside the US.

**An excerpt from the *CW Talks* interview with Chuck Miller about the genesis of polyurethane tooling board, a rewarding Industry 4.0 intro in the boatbuilding world, and an effort to break the aerocomposites inspection bottleneck.**

# Q&A: Chuck Miller, founder and president, Coastal Enterprises

*Editor's note: Tooling board has become a nearly ubiquitous material in composites manufacturing, particularly useful for the quick and efficient fabrication of plugs and molds. Chuck Miller helped bring tooling board to the industry decades ago and, in a recent* CW Talks: The Composites Podcast *episode, explained how he went from building rocket launch vehicles in the 1960s to developing polyurethane foam for composites. Excerpts of that discussion follow. To listen to the entire conversation, search for* CW Talks *on iTunes or Google play, or visit* www.compositesworld.com/podcast.

Source | Coastal Enterprises

***CW*: Tell me about your work on the *Saturn V* moon-launch program.**

**CM:** That was in the mid-1960s. .... I was a senior manufacturing engineer for the *Saturn S-2* vehicle, which was the second stage of the *Saturn V*. .... My job initially was involved in the tooling, because we were building the tooling to build the *Saturn*. ... We built 15 of them, and the first two of them were built just to try out the tooling. And so, once that happened, we morphed into other things that were manufacturing-related, and that's when my first exposure was to tooling board and something other than just iron and aluminum, etc.

***CW*: Tell me about the type of tooling you were making for the *Saturn V*.**

**CM:** The whole entire *Saturn V* was just a gigantic fuel tank. The first stage was powered by kerosene or liquid oxygen, and the second stage — the one I was involved with — was powered with liquid hydrogen and liquid oxygen. And the third stage, which was made by McDonnell-Douglas, also was powered by liquid hydrogen and liquid oxygen. The overall *Saturn V* was 370 ft tall, weighed six-and-a-half million pounds at launch, and it was completely made by Boeing and by North American Aviation, who I worked for, and McDonnell-Douglas. .... But nothing had existed before because no one had launched someone into space, and certainly not to try and go to the moon. So, everything we did was state of the art because there was no art, and it was the state of a bunch of pretty young people at that time that were creating this *Saturn V* from nothing that had never been done in the past.

***CW*: How did you start using composites?**

**CM:** I got into the composites because of the fuel lines that went from the liquid hydrogen tank and over and down past the liquid oxygen tank below it to each of the five engines. They [the lines] had to be covered with a fairing, a high-temperature fairing, that kept the launch heat from turning the liquid hydrogen into a gas. So, they were very important structures, and we had to build them out of composites because we couldn't find a metal light enough to be attached and hanging out in the breeze during launch. These fuel lines were about 20 inches in diameter and 40 ft long. They weren't tiny things. They had to be completely covered and insulated from the launch shear of the air rushing over the top of them.

***CW*: As I understand it, the tools for these fairings were made with Micarta. What was it like working with Micarta?**

**CM:** Micarta was about the only thing around that could be used. Micarta was a very strong, very heavy, laminated epoxy and we used that as the actual layup tool. And then the high-temp glass and polyimides. At that point, we had a 40-ft diameter autoclave, because of all of the things that had to be bonded together. .... None of us had seen Micarta or had even tried to make a resin.

***CW*: One of the things the Saturn S-2 required was insulation. Why was that, and what was used?**

**CM:** Liquid hydrogen operates to stay liquid at -423°F and it couldn't change temperature very much before it went from a liquid to a gas, so the insulation was on there to keep it cool enough. .... The first insulation package was a phenolic honeycomb that had a skin of Mylar over the top of it. And that phenolic honeycomb assembly was bonded with gaseous nitrogen, and the nitrogen kept the temperature down, but we couldn't keep the seal, and the gaseous nitrogen was leaking all over the place. …. When they finally gave up on it, fortunately this guy named Wernher von Braun, the rocket scientist that came from Germany, knew about this polyurethane stuff, and so we tried to see if it could work under cryogenic conditions, because nobody knew that either. …. It took us about two years to figure out how to get this stuff to stay on, and we finally did that for launch vehicle five.

**_CW_: With the _S-2_ program complete, you were looking for work?**

**CM:** I was out with all this experience, and nowhere to go. One of the men I was working with was transferred to the Los Angeles office of North American Aviation, and they were building *XB-70*, the first supersonic fighter, a huge, huge plane. He called me one day and said, "We just got delivery of a 50-ft CNC" — which was one of the earliest ones built — "and I was thinking about the foam we used on the side of the *Saturn*. We need something to do the tool proofing on this thing to make sure it's working right. Can you make this foam in a higher density, as a board, something we can machine? Because right now we are using railroad ties, and we are tying those together and machining those." I said, "Yes, we certainly can," without a clue of what that really meant. So, that was my first exposure to tooling board. …. The first board we made was 4 inches thick, 4-ft by 4-ft, and they tried it out and liked it a lot. They went from just tool proofing the landing gear to tool proofing the whole, entire wing section, so they said, "Hey, can you guys do this in a 40-ft piece?" … And again, the answer was, "Of course." … I still say the same thing. I always say, "Yes," and we get together and figure out how to do it. That will never change.

## BIZ BRIEF

**RTP Company** (Winona, MN, US), a compounder of custom-engineered thermoplastics, announced its expansion into Poland with an 7,990m$^2$ facility located at Prologis Park V in Nowa Wieś Wrocławska. Its newest manufacturing location will support regional demand, provide a consistent supply of RTP Company's product to European customers, and provide RTP Company with the ability to expand operations in the future. The new facility will have a wide dock area, office space and a laboratory with controlled temperature and humidity. The production area will be equipped with additional ventilation and drainage, and will accommodate up to six production lines.

AEROSPACE

## Zero-defect manufacturing of composite parts

ZAero – Demonstrators

Inline Quality control for ADMF

Inline Quality control for AFP

Sensor for curing monitoring

Integrated demonstration with manufacturing database and decision support tools

Despite the advent of automated fiber placement (AFP) and tape laying (ATL) equipment, the promise of high-rate production of flight-critical aircraft components is still frustrated by the need to meet air safety inspection requirements manually. Currently, an inspector must regularly stop the AFP or ATL machine used to fabricate composite wing and fuselage structures, etc., and visually inspect the layup before proceeding. Profactor (Steyr, Austria), a non-university R&D center, conceived of and now coordinates ZAero, a European Commission (EC) funded project, which aims to increase composite parts production efficiency by 30-50%. Profactor manager for machine vision Dr. Christian Eitzinger says that the ZAero effort, which began in 2016 and ends in 2019, will replace existing manual inspection processes during fiber placement that currently create a production bottleneck. "The solution," he explains, "is an automatic inspection system that will detect gaps, overlaps, fuzzballs and foreign object debris (FOD)." For that to happen reliably, the inspection system must have a "learning component" that enables it to distinguish a normal part surface from one with these defects and also must differentiate between the defects. Profactor's learning component also will be distinguished from those used elsewhere. Instead of training the system offline and then placing it into production as a "frozen design," the ZAero machine learning component's decision support tools will be trained online, using the data stream from the production line. "The challenge," Eitzinger explains, "is that the system's machine learning will be changing all the time and perhaps not always in the right direction. Thus, one of the issues is how to assess and manage this online machine learning in order to keep the process chain stable." Ideally, the more the process operates and the more data it generates, the more intelligent these decision support tools will become.

The sensors ZAero is using for layup have been developed in-house. It is also pursuing sensors developed and recently qualified by InFactory Solutions for MTorres AFP equipment. "Our experiments are currently based on dry fiber placement with MTorres and FIDAMC," Eitzinger adds. DANOBAT's Automated Dry Material Placement (ADMP) process will also be used, because it enables placing a large amount of material in a short time.

Simulation work, led by Dassault Systémes, is currently focusing on the layup process. Eitzinger explains, "If there are defects, what do you do? Instead of using the current set of complex rules, their approach is to acquire data from how the part is actually manufactured and use this in FEA models to predict the part's performance. You simulate the defect using real data and predict what impact it will have. Can it stay or does it need to be removed/addressed?"

The automated inspection system is projected to generate savings of €150 million/year if implemented as planned in the series production of Airbus (Toulouse, France) A320neo carbon fiber-reinforced plastic (CFRP) wing covers. They will also resolve the inability of current quality control systems to keep up with Airbus' increased aircraft production rates (60 aircraft/month).

Discussion of the ZAero project expands online in the *CW Blog* | **short.gardnerweb.com/ZAero** and its follow-up on the resin infusion flow front sensors being developed for resin state monitoring during cure.

Also read *CW's* February cover story "Improving composites processing with automated inspection" | **short.compositesworld.com/AutoInspEI**, and this CW Blog | **short.compositesworld.com/MaassBlog.**

## BIZ BRIEF

**Element Materials Technology** (London, UK) completed its acquisition of **Exova PLC** (Edinburgh, UK). The new Element Group will consist of 200 laboratories located in more than 30 countries. This latest acquisition follows a period of significant growth and is expected to result in excess of US$700 million in annual revenues and serve more than 40,000 customers worldwide. To support the acquisition, Element has fully refinanced its existing banking facilities and raised US$1.4 billion of first and second lien term debt, alongside US$150 million of committed ancillary facilities. Element will continue under the leadership of CEO and president Charles Noall, alongside an executive team formed from the senior management groups of both companies.


Source | Sea Ray Boats

MARINE

## Industry 4.0 comes to boatbuilding

When structural engineer Sean Minogue was charged with updating shop floor processes at Sea Ray Boats' (Knoxville, TN, US) multiple facilities, he was asked to focus on saving weight and cost, yet achieve higher tolerances during builds. Minogue began by replacing the old ways Sea Ray tracked fiberglass consumption (monitoring the revolutions of a wheel around which the fiberglass filaments were wound) and resin consumption (basing calculations on a stroke counter linked to a pneumatic pump). He wanted a system, instead, that could track resin, chop, and other material usage by part, and monitor usage in real time to enable comparison to requirements. In addition, the system would record labor hours, cure cycle data, takt time (average time between the start of production of one unit and the start of production of the next), historical weight data, and most of all, provide real time data to the operators.

To accomplish this, Minogue and Sea Ray developed a material monitoring system (MMS) with the help of HBM (Darmstadt, Germany), known for its sensors, instruments and software for data acquisition and process control. The PMX signal conditioning system from HBM, a data acquisition system intended for the Internet of Things (IoT), measures and monitors myriad tasks and machines via industrial Ethernet interfaces, and collects and stores the data for quality control.

During a recently concluded, year-long beta test on the Sea Ray yacht production line in Merritt Island, FL, US, the PMX system was linked to load cells and a high-accuracy scale, to measure the weights of pallets that hold the fiberglass spools, and to a flow transmitter connected to a flow meter that controls the amount of resin going to each of two chopper guns. The MMS then provided the data: A lamination monitor, a custom-built Power over Ethernet system with connected Honeywell barcode scanners, provides constant progress updates on computer screens to chop spray operators. Each operator scans a barcode associated with each section of the hull, and as the chopper gun operates, the lamination monitor displays material usage and compares it to the design in real time. The lamination monitoring system software, developed by DragonPoint Software Inc. (Rockledge, FL, US), provides status updates on job progress to managers, updates inventory, etc., and reports results to the facility's engineering and quality database.

Although Minogue originally considered using individual signal conditioners to read signals from the old, analog equipment, because of availability and low cost, he chose instead a system that offered the flexibility to add more signal channels to accommodate additional equipment (e.g., to record gel coat usage during spraying operations) and other factors such as temperature and humidity: "We've used HBM's equipment in our testing lab for years. The PMX was advanced and had a built-in Application Programming Interface (API) that would let me build a database to read signals from all this equipment." Over the course of the beta test, the new MMS system has helped operators reduce material costs, work more efficiently by enhancing process control and has kept finished parts compliant with company weight specs.

Was it worth the investment? For the *Sea Ray 590* hull (see photo), the use of this technology already has resulted in a 1,000-lb savings in chopped glass and resin per hull alone. Currently, the MMS is slated to roll out on production lines for *Bayliner*, *Boston Whaler* and other Sea Ray models in other Brunswick production facilities over the next two years.

## BIZ BRIEF

**McLaren Automotive** (Woking, UK) is opening in Yorkshire the £50 million (US$61.3 million) McLaren Composites Technology Centre (MCTC) which will be home to McLaren's second production facility and the first-ever outside of Woking. More than 40 McLaren employees are already based in Sheffield, housed at the University of Sheffield's Advanced Manufacturing Research Centre, where they are advancing the process for creating the lightweight carbon fiber Monocage tub structures at the heart of McLaren cars. When fully operational, the MCTC will employ around 200 people, and will supply its tubs to the McLaren Production Centre in Surrey where the company's sportscars and supercars are hand-assembled.

## CW MONTH IN REVIEW

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

**METYX Composites secures HIPA funding for Hungarian expansion**
The Hungarian Investment Promotion Agency announces support for an investment project to expand METYX Hungary's production facilities.
02/13/18 | short.compositesworld.com/METYXHngry

**SGL, Fraunhofer launch fiber placement tech center**
The Fiber Placement Center, in SGL's Meitingen, Germany, facility, is also supported by Compositence GmbH and BA Composites GmbH.
02/13/18 | short.compositesworld.com/SGLFraAFP

**Daher opens third Moroccan facility**
The France-based manufacturer's new facility — its third in Morocco — will offer metals and composites production services.
02/12/18 | short.compositesworld.com/Daher3Mor

**Vestas anti-icing solution boosts cold-climate wind energy**
Based on electro-thermal heating elements, it is embedded in the turbine blade's laminate directly below the blade skin's surface.
02/12/15 | short.compositesworld.com/VestasIce

**Kaneka Aerospace acquires Henkel's composites portfolio**
Kaneka will take over all of Henkel's commercial rights, technologies and patents.
02/12/18 | short.compositesworld.com/KanekaHenk

**New consortium launches energy storage market and technology study**
In Aachen, Germany, participants include AZL Aachen GmbH, RWTH Aachen University, RWTH spinoff CONBILITY GmbH and 19 international companies.
02/12/18 | short.compositesworld.com/EnergyCons

**PAL-V flying car to debut at Geneva Motor Show**
The two-seat, composites-intensive PAL-V *Liberty* is expected to be certified soon, with deliveries to follow in 2019.
02/05/18 | short.compositesworld.com/PAL-Vdebut

**World's largest offshore wind farm begins construction**
Orsted's Hornsea Project One, in waters east of the UK, will feature 174 turbines and provide 1.2-GW of energy — power for more than 1 million UK homes.
02/05/18 | short.compositesworld.com/Hornsea

**FACC to supply engine fan cases for Pratt & Whitney**
The fan cases, which FACC will manufacture in hybrid metal/composite construction, will be used on various business jets.
02/05/18 | short.compositesworld.com/FACCPW

**US wind power industry releases fourth quarter 2017 market report**
There are now 89,077 megawatts (MW) of wind-generated electric power available from turbines in wind farms installed across 41 US states.
03/17/15 | short.compositesworld.com/Exel-BMW

# *CompositesWorld* 2018 Operations Report

*CW*'s inaugural Operations Report aims to shed some light on the state of composites manufacturing today, and how it might evolve.

**By Jeff Sloan** / Editor-in-Chief

» To help its audience better understand how the composites industry is evolving, and how manufacturing technologies are currently evaluated and deployed, *CompositesWorld* recently conducted its first Operations Survey. The results are in, and the data are presented here.

Conducted in late 2017, the Operations Survey was sent to a variety of *CompositesWorld* readers in a host of manufacturing environments, ranging from aerospace to automotive to marine. The goal was to learn as much as possible about the markets served, the materials and processes used, the emerging technologies and the outlook for growth.

Respondents were based mostly in the United States and work primarily in management, manufacturing, factory automation, engineering and product design and R&D. Survey questions asked for information based on the respondent's primary facility/location only.

Responses were, not surprisingly, dominated by people who fabricate composite parts for the aerospace end-market (Fig. 2, at right), followed by defense, industrial, automotive and marine. Further, a little more than 50% of respondents work in facilities that generate US$10 million or less in annual revenue (Fig. 3, bottom right). Of all composites fabrication processes, the most common in the survey were prepreg layup, compression molding, infusion, resin transfer molding (RTM) and 3D printing. And, in addition to composites fabrication, more than 60% of survey respondents work in facilities that provide design engineering, assembly, machining/finishing, prototyping and research and development services (Fig. 4, p. 27, top left).

The good news is that respondents were, on the whole, highly optimistic about composites use at their facility and by their customers. Over the coming 12 months, 50% of respondents expect their facility's volume of composites manufacturing, and revenue from composites, to increase. Another 49% expect those two values to remain unchanged.

Similarly, 46% expect the volume of composites used by customers to increase, while 53% expect it will stay unchanged. And 52% expect to spend more money on composites manufacturing equipment in the next 12 months, while another 44% »

**FIG. 1** Number of people employed at facility

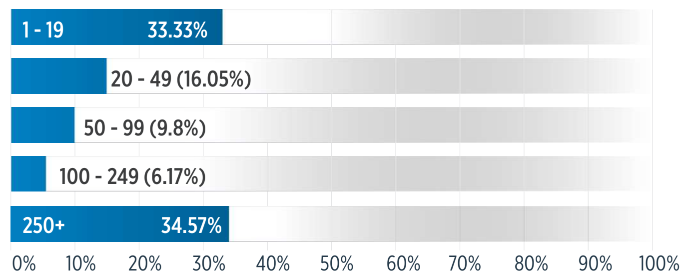



**FIG. 2** End markets served by facility

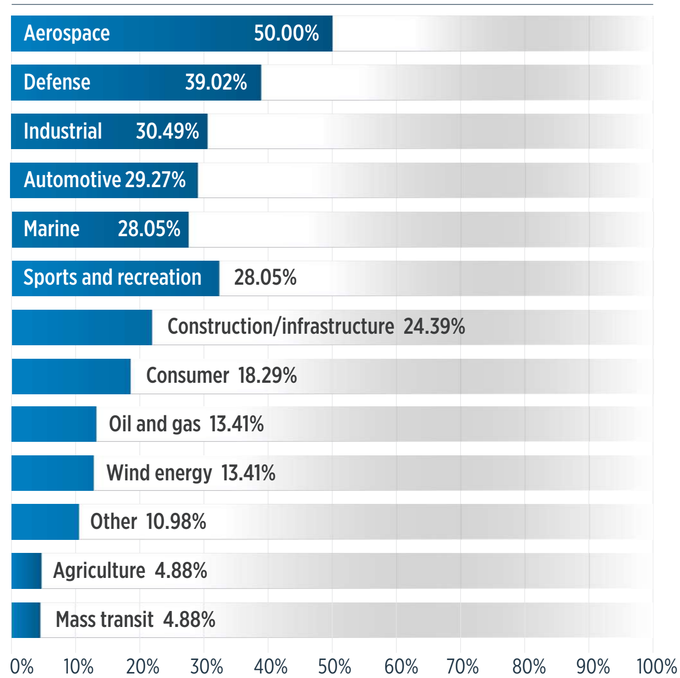



**FIG. 3** Facility revenue

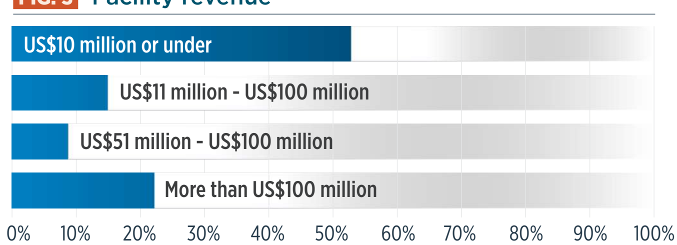


**FIG. 4** Services performed at facility

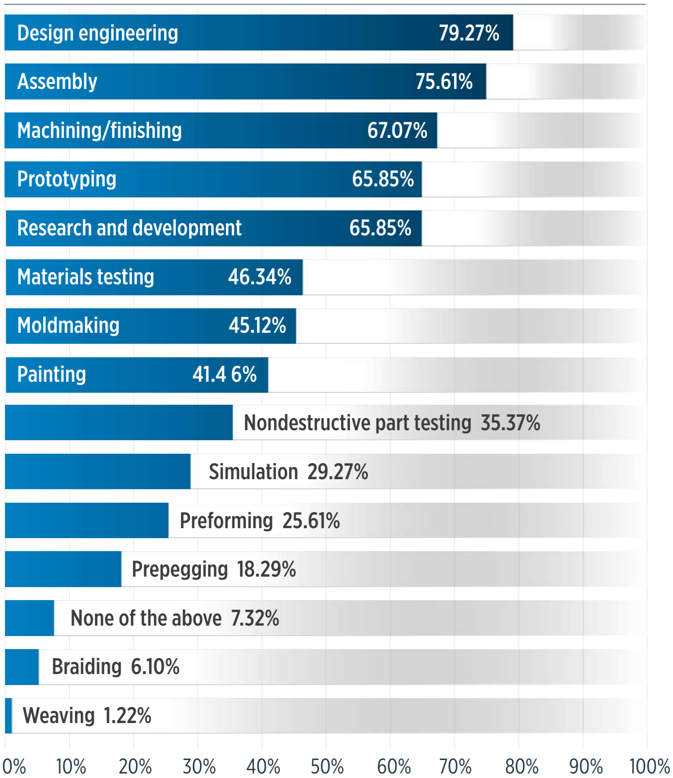



**FIG. 5** Manufacturing processes performed at facility

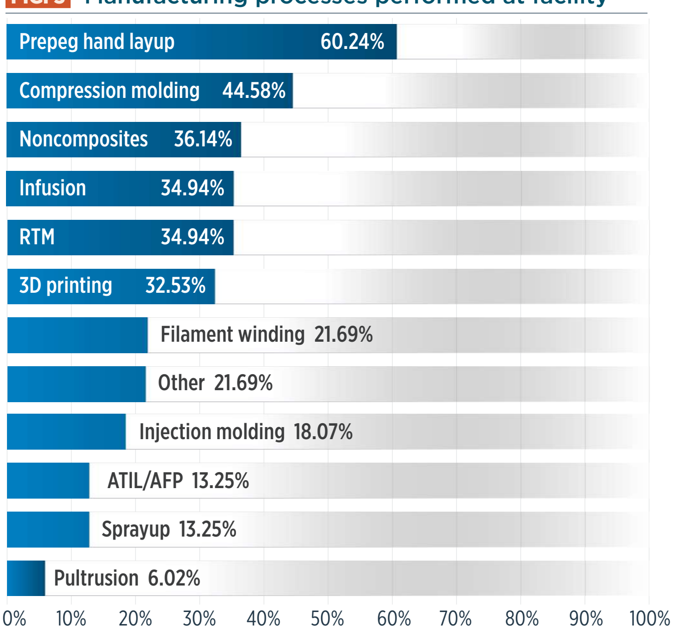



**FIG. 6** Resin and fiber types used at facility

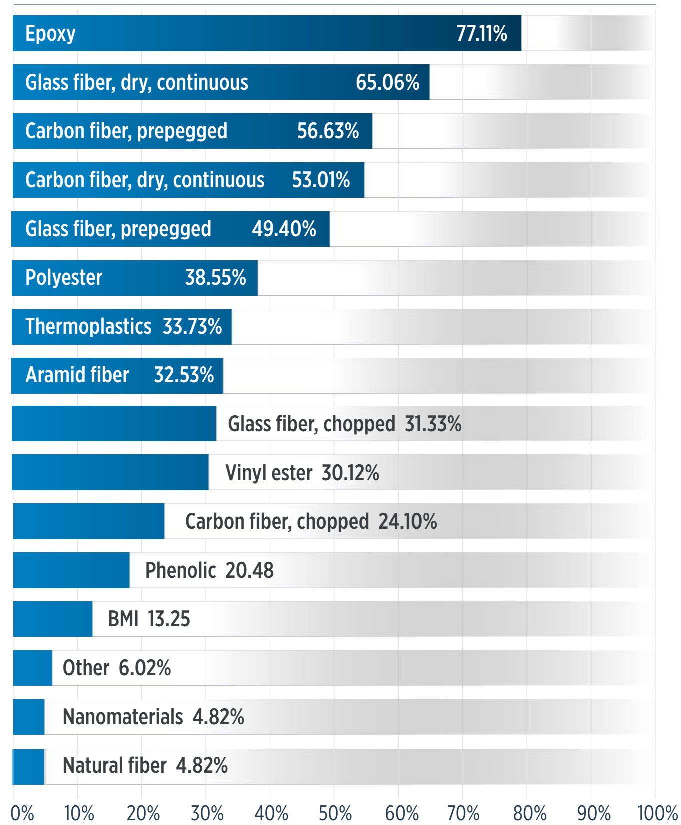



**FIG. 7** Tooling material types used at facility

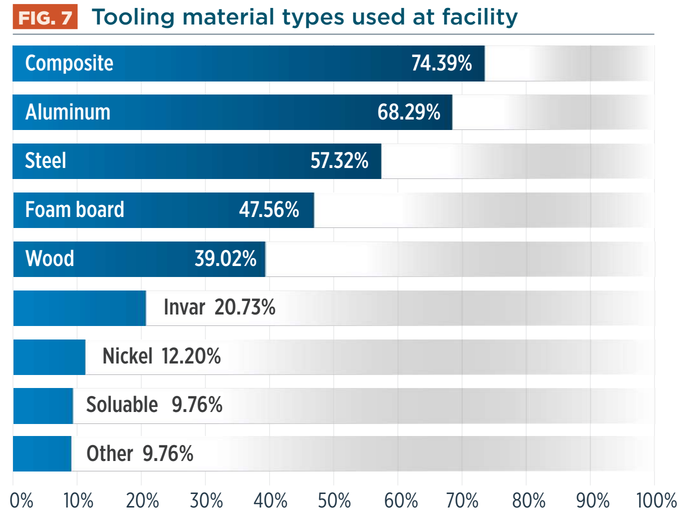
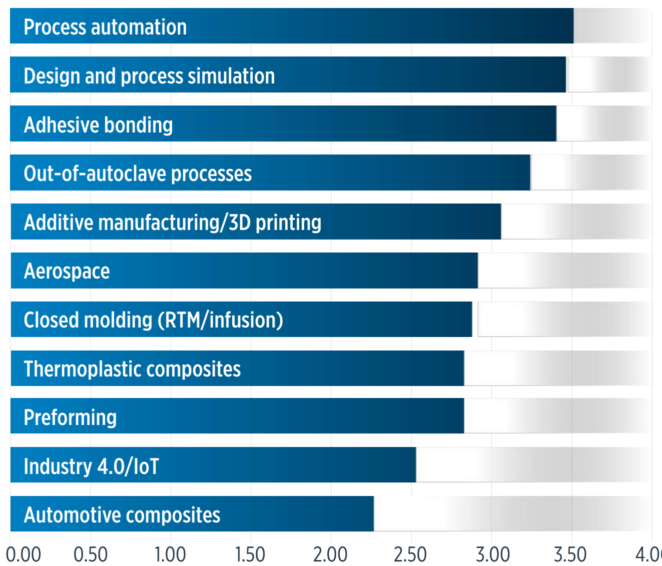


**FIG. 8** In the next 2 years, your facility will do more with ...




expect equipment investment to remain unchanged. In fact, respondents indicated that about 10% of gross sales revenue was spent on new manufacturing equipment in 2017.

We also asked respondents to look at emerging technologies and agree or disagree that use of them at their facility will increase over the next two years — 1 = strongly disagree, 5 = strongly agree. The graph in Fig. 8, above, shows the average rating (characterized as "intent") for each technology category. Not surprisingly, process automation, design/process simulation and adhesive bonding top the "agree" list, followed by out-of-autoclave, 3D printing, aerospace composites, closed molding, thermoplastics, preforming, Industry 4.0 and automotive composites.

There is, however, a story within this data. Responses to our query about aerospace composites intent were highly polarized, with 29% each strongly agreeing and disagreeing that use would increase at their facilities, which might reflect the fact that aerocomposites manufacturing can be highly lucrative, but also very challenging. Responses regarding automotive composites intent, however, were more clear: 62% either disagreed or strongly disagreed. This might be symptomatic of widespread uncertainty regarding the potential of composites use in high-volume vehicles. Responses regarding 3D printing intent, on the other hand, were more evenly distributed, with 20% each rating it 1, 3, 4 or 5.

*CW* will conduct this Operations Survey again in late 2018, with data reported in 2019. If you have suggestions for other types of information the survey might seek, please contact *CW* editor Jeff Sloan at **jeff@compositesworld.com**. CW

ABOUT THE AUTHOR

Jeff Sloan is editor-in-chief of *CompositesWorld*, and has been engaged in plastics- and composites-industry journalism for 23 years. **jeff@compositesworld.com**

# Carbon fiber has designs on production wheels

## A high-performance CFRP wheel manufacturer for nearly 20 years, Dymag is now part of a broader effort to reduce their cost and migrate them into volume vehicles.

**By Jeff Sloan** / Editor-in-Chief


■ **The market: Betting heavily on volume viability**

Dymag has developed the BOXSTROM X and BOXSTROM Y wheels, featuring a carbon fiber composite rim or barrel and aluminum spokes targeted to both the automotive aftermarket and auto OEMs. The goal is to increase manufacturing efficiency and thereby decrease cost, making the wheels viable for higher-volume manufacturing. Source (all images) | Dymag

» Composite materials have earned their way into cars and trucks, performing a variety of structural and semi-structural functions. Unit volumes, once limited to hundreds per model year, now increasingly number in the thousands. One application, however, has remained difficult to rein in from a composites perspective: the *wheel*.

It's not that all-composite or hybrid composite wheels cannot be made. They can, and their benefits are substantial: up to 50% reduction in unsprung rotating mass vs. aluminum wheels, increased acceleration, more rapid braking, improved handling and reduced noise. But at the current *minimum* price of US$10,000 for a set of four, they are likely to be found only on the highest of high-end vehicles. Lamborghini. McLaren. And the like.

So, the ultimate goal — as it is with almost everything automotive-related — is to provide these benefits cost-effectively enough to find their way onto a broader range of vehicles. And if you are a manufacturer of composite wheels, cost-effectiveness comes neither easily nor overnight. It is achieved, instead, through innovation, creativity and hard work. And that only after you establish a place in the market with a quality product — quality measured not merely by mechanical performance but aesthetic appeal as well.

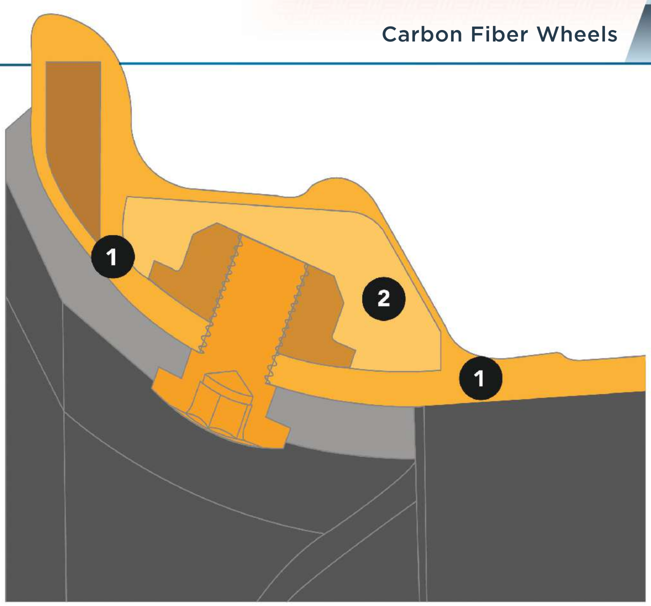
### Great *and* great looking

British wheel manufacturer Dymag (Chippenham, Wiltshire, UK) knows well that how a wheel *looks* is as important as what it *does*. In 1995, the company developed what it says was the world's first one-piece, carbon composite motorcycle wheel. This was followed in 2004 by a hybrid carbon fiber/aluminum wheel, sold primarily into the automotive aftermarket. In 2009, Dymag hit on hard times and was liquidated. Current CEO Chris Shelley acquired the Dymag name and was able to bring the senior engineering and production team back together, focused on returning to aftermarket composite and forged-aluminum motorcycle wheels. By 2015, Dymag had secured funding from the UK government to develop a new, patented product design and mass-production process for the next generation of durable, lightweight carbon composite automotive and motorcycle wheels.

Dymag now has on the market two carbon fiber/aluminum wheels, the BOXSTROM 7X and the recently launched BOXSTROM

7Y. Both feature a woven carbon fiber rim with bolted-in aluminum spokes. The wheels were both launched into the aftermarket, but Shelley says Dymag also has secured several OEM contracts, all for relatively high-end performance cars, including the Fisker *EMotion* all-electric sportscar.

Shelley notes the BOXSTROM wheels' price point starts at £10,000 (~US$13,550) per set, "but that will come down as the technology matures and costs fall." To reach the next level of volume (10,000-25,000+ wheels per year), he says, the price point needs to drop into the £5,000-£10,000 range (as low as ~US $6,775), with an even split between aftermarket and OEM sales.




■ **Patented wheel flange and fastener system**

Much of Dymag's design innovation and expertise has gone into the Boxstrom wheel's resin transfer molded barrel and how it intersects with the spokes. This cross-section shows the fastener from the aluminum spoke engaging with the barrel's flange. Section 1 is the primary load path of the barrel. Section 2 is a biaxial layer that supports the primary load path and supports the fastening system, which carries 90% of the radial load.

## Carbon fiber outside, aluminum inside

Most of the know-how in Dymag's patented BOXSTROM is in the composite rim, which is made with preformed biaxial and triaxial carbon fiber fabrics (standard-modulus 12K and 50K tow) wrapped around a mandrel and then resin transfer molded (RTM). The epoxy resin system, Araldite XB 3292/Aradur 2954, is provided by Huntsman Advanced Materials (Switzerland) GmbH (Basel, Switzerland) and was initially chosen because it offered both high-temperature durability and high mechanicals, and met the processing requirements. This resin system, says Olivier de Verclos, Huntsman Advanced Materials' technical support manager, also has been on the market for several years and, therefore, offers a level of reliability important to Dymag.

Much of the rim's (or barrel's) intellectual property rests in the BOXSTROM's patented wheel flange and fastening system, which Shelley would not discuss in detail except to say that they incorporate a structural foam core and convey physical and mechanical performance not found in other composite or aluminum rims (see the graphic at top right). Overall, he argues, the design gives Dymag a technical edge on its competitors. "This is not just black aluminum," he points out, "but a structure optimized for composites to reduce weight, while improving durability and safety."

Wheels are every vehicle's touchpoints with the road, and as such, must perform flawlessly.

"Dymag wheels are designed and tested to the highest OEM specifications," he adds, "as opposed to some other companies that aim to meet the minimum recommended aftermarket standards, but may fall well short — especially for high-performance tuned cars and tire packages that significantly exceed these aftermarket specifications in terms of load conditions."

The question is often begged of carbon fiber/aluminum wheels, why use aluminum at all? Indeed, there are monobloc carbon wheels on the market that use carbon fiber in the rim and the spokes, thus there is no technological barrier to be cleared.

Shelley says it is simple: Carbon fiber limits design options in the spokes. Aluminum can be more easily adapted to a variety of spoke shapes, styles and designs, allowing aftermarket and OEM customers to meet a variety of end-user preferences and tastes. Indeed, spoke design has become a significant differentiator in the marketplace, so the material that best facilitates spoke design variation wins out. Where the wheels are tested to full OEM specifications, the weight differences between hybrid vs. monobloc is minimal compared to the large weight savings both offer vs. all-aluminum wheels. Shelley also notes that use of carbon fiber in spokes in high-performance applications may necessitate the design of larger cross-sections or additional carbon material to achieve the lateral spoke stiffness, because vehicle brake packages often limit the physical space available for a deep spoke design.

With Dymag's BOXSTROM wheels, a typical 20-by-9.0-inch wheel designed and tested by an OEM checks in at about 9 kg, and Shelley says this will likely drop closer to 8 kg as spoke design is optimized. This compares to a traditional OEM cast-aluminum wheel, at 15 kg, or an OEM forged-aluminum wheel, at 12 kg. Such weight saving, Shelley notes, is very difficult for OEMs to ignore. "OEMs wouldn't touch a carbon fiber wheel five years ago," he argues. "But now they are all working on it for a combination of performance benefits and the drive for lower weight to reduce carbon emissions."

## Room for improvement

Increased OEM interest in carbon fiber wheels, although good for companies like Dymag, also brings with it more scrutiny and more pressure to improve materials and manufacturing processes, and reduce costs. Still, once developed, this wheel now capable of higher-volume manufacture also must meet safety and performance standards. Wheels are every vehicle's touchpoints with the road, and as such, must perform flawlessly. "Wheels, tires »


## The price: Under five-figures would be nice

A set of four all-carbon fiber or hybrid carbon fiber/aluminum wheels range in price from US$10,000-US$15,000, which makes them, for now, best suited for high-end vehicles like this Jaguar *F-Type.* Dymag believes that if the cost can come down to US$6,000-US$13,000 per set, then higher volumes (10,000-25,000 wheels/year) will be within reach.

and brakes are safety critical," Shelley notes. "Taking weight out reduces margins of safety, which you don't want to do without careful consideration."

As part of this careful consideration, OEMs and companies like Dymag are developing standards for carbon fiber wheels, including radial cornering fatigue performance, impact performance, durability and more. Shelley believes that as OEMs develop a better understanding of composite materials, they will fine-tune and optimize these standards. "Our wheels still must perform as well as aluminum wheels in terms of durability, but taking the weight out of any wheel can reduce safety margins and compromise performance due to the lack of stiffness. This is a constant challenge for us," Shelley says.

All of this has forced Dymag and other carbon fiber wheel manufacturers to seek opportunities to improve their products, and the processes that produce them. For example, although Huntsman's epoxy is well-established, "Dymag is already looking at next-generation resins for future wheels," Shelley reports. "We are committed to continue providing our partners with relevant data and we have already invested in, and have access to, state-of-art testing equipment. This enables us to simulate real-wheel service conditions to prove the reliability of the offered solutions and minimize the risks. With Huntsman Advanced Materials, we are working to achieve things like thermal stability, higher impact properties, less UV sensitivity, increased productivity and better aesthetics."

Huntsman's de Verclos acknowledges the push to reduce manufacturing costs, which is imperative if all-, partially or hybrid composite wheels are to become an option for high-volume vehicles. The company, he says, is working on material chemistry and manufacturing process optimization to achieve this. Shelley says, "Materials can be a little more expensive if you are reducing the amount of material being applied and creating production efficiencies."

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Aesthetically, OEMs are putting pressure on Dymag to improve surface quality. "The level of scrutiny that some of our customers put on the surface quality of our carbon fiber is going up," Shelley says. "There can be absolutely no pinholes, no defects. This is really a major, major challenge." Further, OEMs and their customers like to have the carbon fiber weave in wheel components exposed. Because of this, Dymag and its customers have developed an ABC hierarchy to characterize wheel material visibility: A=always visible; B=sometimes visible; C=never visible. A and B surfaces, as would be expected, receive the most attention to make sure they meet appearance requirements. "Aesthetics are paramount in the luxury and performance markets," Shelley says.

To achieve this aesthetic, the choice of the resin system is crucial. Its selection has an impact on wheel color. "When it comes to color," de Verclos explains, "using the right chemistry to increase productivity and performance is quite often playing against us. We have been able to design systems with good initial color, as well as color stability during service, without compromising on technical and process performance."

## Driving toward higher volumes

It is clear that composite materials, design tools and manufacturing processes are evolving in directions that will make carbon fiber wheels safer *and* more affordable. But when can the world expect to see them on high-volume vehicles? "The move towards lightweight vehicles is only set to intensify as OEMs look to a future without the combustion engine," says Shelley. "For an electric vehicle, lightweight wheels will also extend range. However you look at it, the growing demand from OEM and aftermarket audiences for this kind of technology in the coming years can only help the transition to mass-market manufacturing and bring carbon composite wheels and their unparalleled benefits within the grasp of every driver." CW

**ABOUT THE AUTHOR**

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# Consolidating thermoplastic composite aerostructures in place, Part 1

## After more than 30 years of development, could in-situ consolidation finally fulfill its promise to eliminate fasteners and the autoclave, and enable an integrated, multifunctional airframe?

**By Ginger Gardiner** / Senior Editor

» For more than six decades, composites have earned their way onto commercial aircraft, literally step by step. At each stage, they've proven themselves capable of forming increasingly flight-critical parts with the required strength, stiffness and near absence of flaws — surface porosity and unseen internal voids — that could be the source of future damage as aircraft age. Until comparatively recently, that near void-free standard (<1% porosity) was maintained by a combination of vacuum bag consolidation and, typically, many hours of exposure to high heat and pressure in an autoclave during the curing process. In recent years, development of oven-curable resins (systems that can be consolidated to acceptable void contents *without* an autoclave) have helped to shorten cure cycles and, because ovens cost less to operate than autoclaves, to reduce both the time and expense required to produce parts. In parallel, automated filament winding, automated tape laying (ATL) and automated fiber placement (AFP) equipment have replaced hand layup in many applications, radically increasing the speed at which parts can be laminated.

**Pioneers of in-situ consolidated structures**

Automated Dynamics developed the full-size, integrally stiffened, in-situ consolidated thermoplastic helicopter fuselage pictured at top in 2012, after many sub-scale demonstrators in the prior decade. Accudyne achieved autoclave-level properties in CF/PEEK cylinders, the largest (shown here) at 152 cm in diameter.

Source (top) | Automated Dynamics

Source (immediately above) | Accudyne Systems Inc.

Although these systems are equipped with rollers that compress the material immediately after placement to ensure adhesion and avoid formation of air pockets that would create voids, consolidation of the laminate still typically occurs in the second step of what remains a two-step process, under a vacuum bag, in an autoclave, oven or other heating device, such as a heated tool. This state of the art persists, at least in part, because today's certified aerocomposite materials are predominately thermoset-based.

There is an alternative. In fact, there has been one for decades. Known as *in-situ consolidation*, it means, consolidation *in place*. The key is the use of thermoplastic rather than thermoset matrices. Thermoplastic materials are liquid when heated to melt temperature and solidify when cooled, but do not need to crosslink like thermosets. Consolidation of a thermoplastic composite (TPC), then, can be accomplished by quickly heating the impregnated reinforcement to the melt temperature of the thermoplastic polymer matrix and then applying pressure *as the tape or tows are placed* onto a tool and/or a previously placed laminate. True in-situ consolidation (ISC) is a *one-step* process — no further heating or pressure steps are required after fiber placement or tape laying is completed.

The implications of eliminating an entire and expensive step in the manufacturing process are so significant and obvious that one might ask, why isn't everyone already doing it? For one (there are other reasons, to be discussed), the aerospace industry pays a very steep price for change. Materials substitutions inevitably require extensive and costly testing and recertification.

That said, two-step consolidated TPCs are already in use in select aircraft applications. Although their processing temperatures are much higher than thermosets — closer to 400°C vs. 180°C/350°F for primary structures — their cycle times are much shorter because TPCs require only cooling rather than cross-linking. Thermoplastics also are inherently tough, and need no special formulation to provide the fatigue-resistance necessary for aircraft applications. Further, because thermoplastics can be reheated and reformed, they can be welded (a cost-saving, fastener-free assembly option). As the aircraft industry pursues materials and processing options that will enable production rates of at least 60 aircraft/month and support the envisioned digital manufacturing, multifunctional structures and sustainability that are deemed necessary for next-generation aircraft, TPCs have emerged as frontrunners. In an impressive percentage of recently completed, large-scale aircraft demonstration projects, TPCs have been the material of choice.

In this first of a two-part series, *CW* explores the history of ISC TPC structures, memorializing the almost four decades of development that has laid the foundation for this one-step technology.

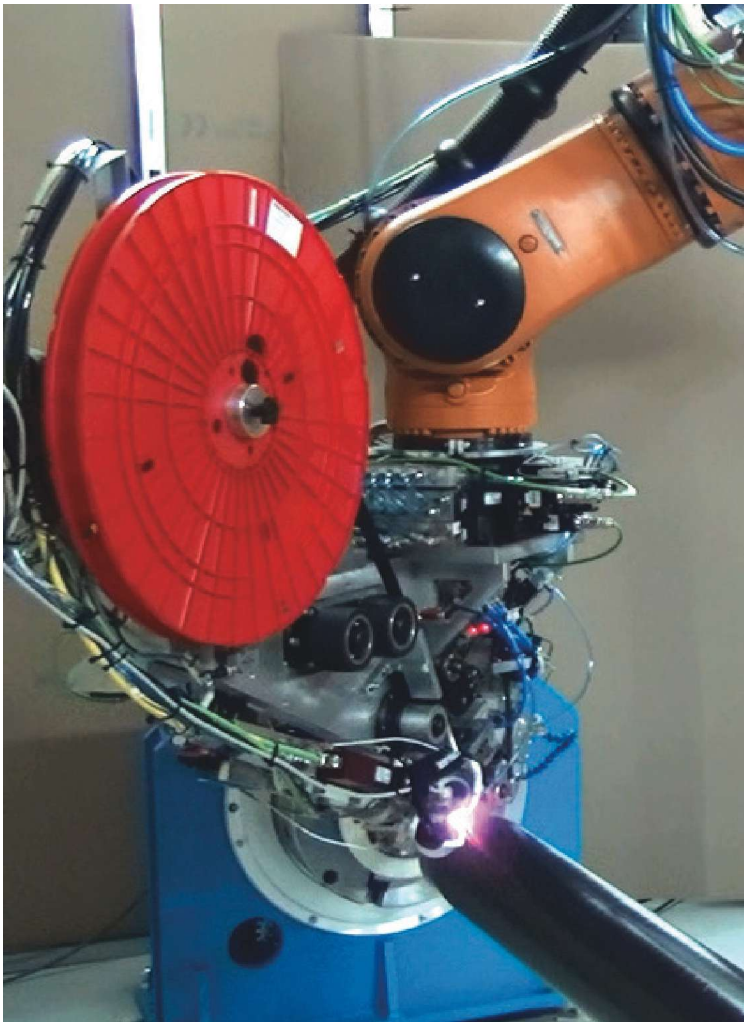
### In-situ early on

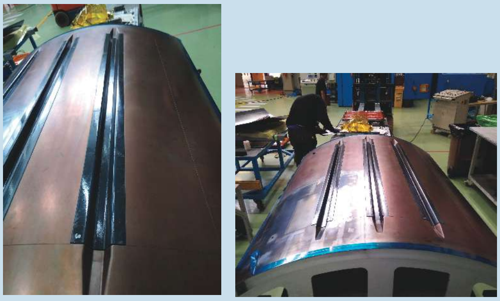
Development of TPC aerostructures began in the 1980s in The Netherlands. Fokker Aerostructures (Hoogeveen) and Fokker Technologies (Papendrecht) — both now part of GKN Aerospace (Redditch, UK) — started work with materials supplier TenCate (Almelo) that "resulted in the J-nose for the A330/A340 and then the A380," recalls Henri de Vries, senior scientist, composites, in the Structures Technology Department at the Netherlands Aerospace Centre (NLR, Amsterdam). A research institute that supports the Dutch aerospace industry, the NLR began working with Fokker and TenCate, and is now touted as one of the aviation industry's great reservoirs of TPC knowledge.

"In 1986, we had a high-temp autoclave, Fokker had facilities for press forming and resistance welding, and TenCate had the ability to make flat panels," de Vries continues. Glass fiber/PPS J-nose technology was developed using press-molded ribs and an autoclave-cured skin. Though these were not ISC structures, they were the first TPC structures to fly and pioneered the use of resistance welding, a process that de Vries says, "was unique at the time." (See Learn More, p. 38). »

**FIG. 1** ISC via AFP

In-situ consolidated thermoplastic composites are typically made using automated fiber placement. This machine by MIKROSAM can process thermoset, dry fiber or in-situ consolidated thermoplastic composite materials, the latter most commonly built using laser heating. Source | MIKROSAM





AFP layup flat panels, cut and stamp into stringers, place stringers into integrated fuselage panel tooling.

AFP skin onto stringers, achieving in-situ consolidation.

Completed, consolidated TPC demonstration part.

**FIG. 2 FIDAMC ISC TPC curved panel**

**Pictured here are the manufacturing steps developed for FIDAMC's in-situ consolidated curved panel with integrated stiffeners.** Source | FIDAMC

**ALTERNATIVE, TWO-STEP APPROACH**
- Frames and stringers are stamped from AFP flat panels
- Loaded into tools
- Mated with pre-layed AFP skin
- Assembly is vacuum-bagged and autoclave-cured.

Across the Atlantic, Automated Dynamics (Niskayuna, NY, US, now part of Trelleborg Group, Trelleborg, Sweden), began its first TPC project in 1985-86. "It was an SBIR [small business innovation research grant] funded by the US Army for development of a helicopter main rotor blade spar," says Automated Dynamics president Robert Langone. "In-situ consolidation was a focus from the beginning." A hot nitrogen gas torch was used to heat the thermoplastic to its melt temperature. A few years later, the company developed a heated roller for compaction. Quality further advanced when it acquired personnel and technology from Imperial Chemical Industries (ICI) Composites, the original developer of Victrex polyetheretherketone (PEEK), also known as APC-2 in its unidirectional (UD) tape prepreg form, a material still in use today.

"We were founded to sell machinery, but by the early 1990s we were producing in-situ consolidated cylindrical parts every day," notes Langone. Automated Dynamics sold its first articulated arm-based ISC workcell to NASA Langley Research Center (Hampton, VA, US) in 1994, and by the late 1990s was fully immersed in industrial production of ISC parts for the oil and gas industry. These included antenna shields, logging sleeves, plugs, pipes, pressure vessels and more, made from glass, aramid and/or carbon fiber (CF) and a range of matrix materials, including PEEK, polyethylene (PE), polypropylene (PP) and others.

> It is difficult to achieve <1% void content in ISC TPC parts when incoming tapes have up to 20% void content.

De Vries notes that Accudyne Systems Inc. (Newark, DE, US) also was an ISC pioneer, "the first to characterize the process window and develop a flexible compression head to keep pressure on the material as it cools." That was important because PEEK, polyetherketoneketone (PEKK) and PPS, as semi-crystalline polymers, develop the crystalline lattice structure, which imparts their notable mechanical properties and chemical resistance, *as they cool*. Like Automated Dynamics, Accudyne's first work relied on hot gas torches and heated shoes.

"One could almost say that Accudyne's work around in-situ consolidated TP parts began with DuPont," says Mike Smoot, VP sales and marketing at Accudyne Systems. Several Accudyne employees were part of DuPont's Advanced Materials Group in the 1980s and '90s. "During that time," he continues, "we developed a thermoplastic head and placed it on a standard filament winder. Infrared [IR] lamps heated the incoming tow, hot shoes guided the material onto the part, hot gas torches heated the laydown area and chilled pressure rollers cooled the molten polymer. Noncontact IR sensors measured the temperature of the incoming tow and laydown area, adjusting the thermal devices accordingly to stay within the required PEEK or PEKK process specifications."

DuPont's work led to its participation in an early 1990s Defense Advanced Research Projects Agency (DARPA) program to build a 610-mm (24-inch) diameter, 16-mm (0.629-inch) thick ring-stiffened cylinder, using IM7 carbon fiber/APC-2 UD tape. Smoot says the ISC cylinder achieved <1% porosity and failed within 3% of its design load when tested underwater at 5,500 psi. This success opened other development opportunities for a variety of parts including rings and bearings for chemical processing, sonar shells, handheld rocket launch tubes, helicopter pitch links, and containment rings for high-speed permanent magnet rotors.

From 1998 to 2012, Accudyne did extensive work in developing an in-situ *laminator* that could process either 76-mm (3-inch) wide tape or 12 ends of 6.35-mm (0.25-inch) tow. Initial effort focused on

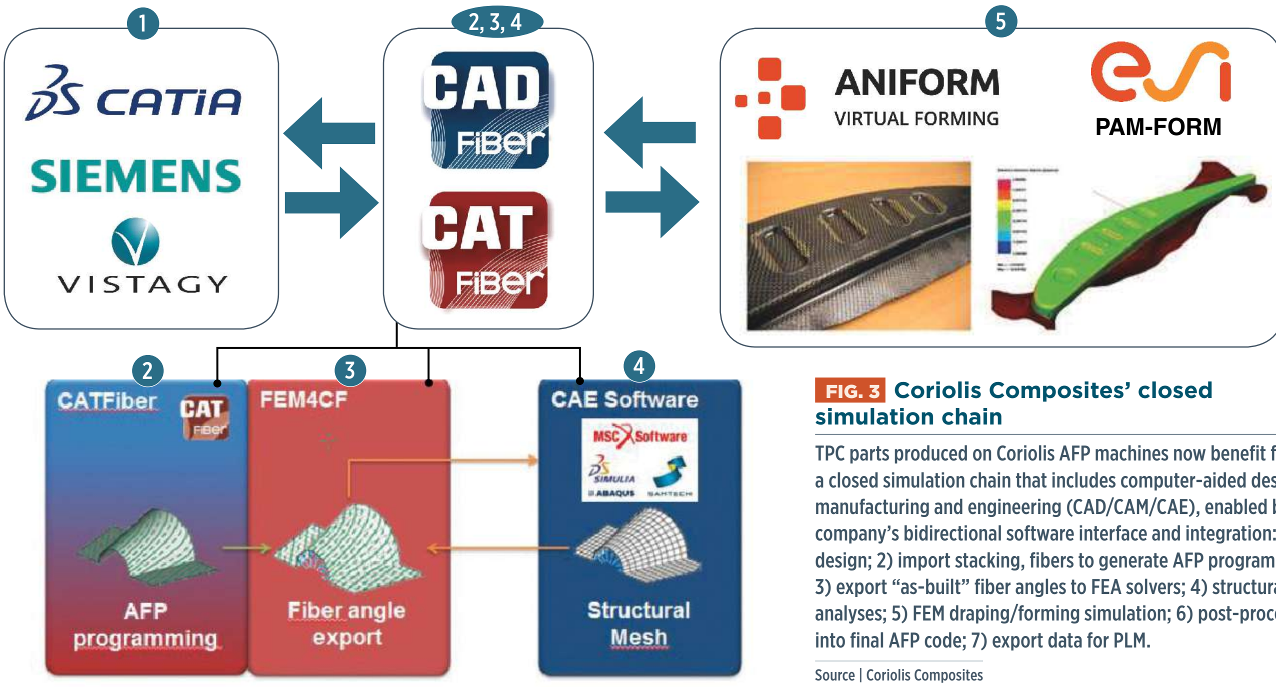



**FIG. 3** **Coriolis Composites' closed simulation chain**

TPC parts produced on Coriolis AFP machines now benefit from a closed simulation chain that includes computer-aided design, manufacturing and engineering (CAD/CAM/CAE), enabled by the company's bidirectional software interface and integration: 1) design; 2) import stacking, fibers to generate AFP programming; 3) export "as-built" fiber angles to FEA solvers; 4) structural analyses; 5) FEM draping/forming simulation; 6) post-processor into final AFP code; 7) export data for PLM.

Source | Coriolis Composites

simple flat panels but ultimately resulted in a conformable head capable of producing panels with mild curvature, pad-ups, drop offs, titanium honeycomb core and TPC stiffeners.

"These were gantry-based systems that used hot shoes, hot rollers, IR lamps, gas torches and chilled rollers to process the thermoplastic tapes with automated placement onto a 1m-by-1m rotary table," says Smoot. "Accudyne produced a similar rotatory table for Fiberforge's first RELAY machine, placing tape at whatever angle was necessary." Now-defunct Fiberforge (Glenwood Springs, CO, US) sold its RELAY technology to Dieffenbacher (Eppingen, Germany). Accudyne used the in-situ laminator to make hundreds of panels and characterized the laminates via open hole compression (OHC), short beam shear (SBS) and many other tests, achieving 89-95% of autoclaved composite properties. "The head could in-situ laminate CF/PEEK panels at 3.05 m/min with voids less than 2%," notes Smoot, "but it was difficult to get below 1% voids, partly due to the incoming materials having void contents as high as 20% and a rough surface, which limited the intimate contact of the mating plies."

### Advancing consolidation for aerostructures

By the early 2000s, Fokker, TenCate and NLR had amassed significant experience with thermoplastic structures fabrication and KVE Composites Group (Den Haag, The Netherlands) had pioneered induction and resistance welding. NLR not only had characterized a wide range of thermoplastics, from polyamide (PA) to polyetherimide (PEI), PPS, PEEK and PEKK, but also had researched the effect of crystallinity on mechanical properties and focused on automated processing, including welding and ISC technology.

"We began with an Automated Dynamics gas torch-heated machine but later replaced that with a Coriolis system because we saw the benefits of laser heating and also the potential to use infrared heating in a single machine," de Vries explains. Coriolis Composites (Quéven, France) began producing AFP systems in 2000. "From the beginning, all of our machines have been developed to handle thermoplastic, thermoset or dry fiber materials," says Coriolis chief technology officer and director Alexandre Hamlyn.

NLR's more in-depth work on ISC included how to compress the material, "and how to do this on doubly curved surfaces, which is quite complicated," he adds. "We also looked at laser optics. We developed a computer model to look at the laser heating process starting from the creel up to full consolidation of the laid material. We worked with Coriolis to refine this process and the equipment." The heating cycle is complex, notes de Vries, "because you must process fast without burning the material."

"Airbus has really been the major force developing in-situ consolidated thermoplastics technology," Hamlyn points out. "It has many competitive projects in France, Spain, Germany and the UK, and is also working with the NLR in The Netherlands." However, Airbus R&D in automated laying of TPC materials began in France, led by the company's chief technology office (CTO) in Suresnes. "We worked with Coriolis to develop robotic AFP into an industrial solution with the FlashTP machine," recalls Cyrille Collart, Airbus head of (HO) Innovation & Development, Manufacturing Technologies Composites (Nantes, France). He notes the Flash TP machine is still used in Airbus TPC developments, installed at the Technocampus EMC2, a research and technology transfer center located adjacent to Cetim (see Learn More) and the Airbus production facility in Nantes.

### Pursuing large, primary structures

There is a TPC development roadmap in Europe, supported by Airbus and a variety of national aerospace consortia — e.g., » TAPAS1, TAPAS2 in The Netherlands and the Civil Aviation Research Council (CORAC) "Investing in the Future" program in France — plus programs in Germany, Austria and Spain (find more on these programs in this article's online version and elsewhere in Learn More). These programs are coordinated with, and feed into, much larger pan-European collaborations, notably Clean Sky (2008-2016) and Clean Sky 2 (2017-2021), which are part of the European Commission's Horizon 2020 program (2014-2021). Note these are public/private partnership (PPP) programs deliberately organized to achieve technology readiness level (TRL) 6 for multiple composites and metals technologies and eventual downselection for future aircraft production. They also involve almost every major aerostructures supplier in Europe.

Having demonstrated co-consolidated TPC skin-stringer structures in increasingly larger sizes and complexity, these programs are now ramping to full-scale fuselage demonstrators in Clean Sky 2. The Multifunctional Fuselage Demonstrator is particularly interesting, featuring an asymmetrical, half-barrel fuselage design that will be manufactured by 2020 using thermoplastic composites. The goal is to integrate cabin, cargo and aircraft systems with the airframe to reduce weight and manufacturing cost while enhancing space for passengers and cargo.

In general, TPC development in France and The Netherlands has pursued a two-step approach while one-step ISC has been favored in Spain. Full details about these programs, program particpants and outcomes can be read in the online Side Story "Thermoplastic composite demonstrators — EU roadmap for future airframes" (Learn More).

INSCAPE — In-situ manufactured carbon/thermoplastic curved stiffened panel — continues development by Airbus DS (Defense and Space, Madrid, Spain) with FIDAMC from Clean Sky 1, and will feed into the Clean Sky 2 Airframe Integrated Technology Demonstrator (ITD). "The curved structure that was proposed by Airbus DS tries to demonstrate manufacturing capabilities dealing with curvature and tapering on stiffened panels," explains Rene Adam, R&D director at program partner and composite aerostructures supplier FACC (Ried im Innkreis, Austria). He notes that INSCAPE's approach is similar to FIDAMC's in terms of stringer-skin installation and a one-step AFP in-situ consolidation process with laser heating (Fig. 2, p. 36). "It complements FIDAMC's gantry-installed AFP for semi-flat wing panels in the OUTCOME project," says Adam. "INSCAPE addresses higher curvatures and tapering with a more flexible Kuka robot arm and a different manufacturing process for stringers, as well as different material suppliers and faster layup speeds." He adds that this type of structure may be used in engine nacelles, fuselage doors or the tail cone section of the fuselage, and also in higher curvature structures, such as leading edges, pylons, flaps or other movables.

STELIA Aerospace (Toulouse, France) exhibited a TPC fuselage demonstrator at the 2017 Paris Air Show that features welded stringers and frames as well as lightning strike protection (LSP) integrated into the skin during AFP (see Learn More). Automated Dynamics also has patented LSP integrated during AFP, but the full-size, integrally stiffened CF/PEEK fuselage it produced in 2012 for a helicopter customer used one-step ISC vs. STELIA's two-step press-and-weld approach. Langone notes that Automated Dynamics completed *sub-scale* stiffened fuselage demonstrators 10 years earlier. "In-situ consolidated aerospace parts have long been a focus of ours, and we have many at the demonstration level," he says. "These include driveshafts, floor panels, fuselage structures and control surfaces, all produced in-situ. We have parts in various stages of being verified and qualified as we work towards regular production."

## AFP machine development and digital design

Langone says Automated Dynamics developed laser heating for ISC and began selling laser-based commercial AFP systems in 2015. "Today, our hot-gas system can process roughly 18 times faster than it could in 1990 in terms of pounds per hour," he notes, "And our laser heating is three times faster beyond that."

About this same time, FIDAMC switched to an MTorres eight-tow-head AFP machine with a new optic laser. The 6-kW laser is the same but the optic — which converts the circular light beam into a rectangular profile to match the tape being placed — enables a wider profile to provide heat across the 50-mm width of eight tows vs. the 6-mm-wide unitow of its previous machine.

MIKROSAM (Prilep, Macedonia) has developed a machine that can process thermoset *or* TPC structures, including in-situ consolidation. "We can achieve 98% consolidation and more than 30% crystallinity, depending on the materials," says MIKROSAM sales

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Read more online about Fokker's production of thermoplastic J-nose structures in *CW's* Plant Tour titled, "Fokker Aerostructures: Hoogeveen, The Netherlands" |short.compositesworld.com/TourFokker

Read more online about the RELAY acquisition in "Dieffenbacher acquires Fiberforge tape layup technology" | short.compositesworld.com/RELAY-DB

Read more online about Cetim's TPC technologies in the *CW Blog* titled, "Automated Preforming — Quilted Stratum Process (QSP)" | short.compositesworld.com/AP-QSP

Read more online about the TAPAS programs "Thermoplastic composites: Primary structure?" | short.compositesworld.com/PrimaryTPC

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Get more details online about FIDAMC's development of ISC wing panels in "Thermoplastic composite wings on the horizon?" | short.compositesworld.com/WingsTPC

Read the online sidebar to this feature article, titled, "Thermoplastic composite demonstrators — EU roadmap for future airframes" | short.compositesworld.com/TPCmapEU

Learn more about STELIA's Arches Box TP demonstrator:

"STELIA Aerospace develops induction welding technology" | short.compositesworld.com/SteliaWeld

"Porcher works with Stelia Aerospace on thermoplastic fuselage" | short.compositesworld.com/TPfuselage

Also watch the video | www.youtube.com/watch?v=JAGM6mY-8d4 director Dimitar Bogdanoski. "We have processed multiple TPC tape products, including those from Barrday, TenCate, Toho Tenax and Suprem."

The machine can lay four or eight tapes/tows. "Any of the tows/tapes can be cut if you don't need all of them placed," says Bogdanoski, who claims an automated head change, from ATL to AFP (or *vice versa*) can be completed in 5 minutes. "AFP has a lower scrap rate vs. ATL due to the narrower material, so it is increasingly preferred. It's useful to have this change capability to define which process is better for your part or project."

Changing from thermoset to TPC takes about an hour, swapping the infrared (IR) heater used with thermoset materials to a 3-, 4- or 6-kW laser used with TPC — depending on the width of material that will be placed. "We can even use a 12-kW laser, but it requires a special license," Bogdanoski notes. "The machine speed is between 5 m/min and 30 m/min for ISC parts, regardless if the material is PPS, PEEK or PEKK. We use an IR camera and an in-house developed thermal model, which forms a closed loop to control temperature of the laminate. It also incorporates video monitoring, which we developed in-house for quality assurance." MIKROSAM sold one of these systems in 2016 and three in 2017.

TPC parts produced on Coriolis machines now benefit from what the company calls a "closed simulation chain," which integrates computer aided design, manufacturing and engineering (CAD-CAM-CAE) enabled by the company's bidirectional software interface and integration (Fig. 3, p. 37). "The part begins with design by the OEM in CATIA [Dassault Systèmes, Velizy-Villacoublay, France]," says Hamlyn. "Our CAT/CADFiber software imports the composite stacking from CATIA and gives the user the tools needed to model all of the fibers. It then generates and optimizes the AFP tape/tow courses."

After a test part is placed for validation, the software then exports true "as-built" fiber angles — including singularities such as tow drops and gaps due to use of narrow tapes, etc. — to commercial FEA solvers (e.g., NASTRAN, ABAQUS, SAMCEF) and enables mesh mapping between the AFP surface and the structural FEM mesh. Hamlyn says this reduces errors and facilitates data transfer as well as modeling of forming simulations. "This is the first step towards automating design optimization," he asserts. "So now designers can perform structural analyses and crash simulations, interfacing with ANSYS [Canonsburg, PA, US]." The latter uses solid modeling instead of FEA shell elements for simulation of multi-ply composite laminates.

Next, physics-based FEM draping/forming simulations are performed, using programs like AniForm (Enschede, Netherlands) or ESI Group's (Paris, France) PAM-FORM. "This includes intra-ply shear and fiber loading during forming, compaction and ply-ply slip," notes Hamlyn. Thus, issues with wrinkles, gaps and fiber orientation during the transformation from 2D layup to 3D preform or part can be addressed and the preform contour can be optimized. He continues: "You then compare simulation results to real part trials to validate what is really happening. Once the design is frozen, our software interfaces with Dassault Systèmes' DELMIA for machine simulation to check laying metrics and robot movements, ensuring that the AFP head can produce the part without collisions, etc. Once this is okay, our post-processor will transform the digital design into robot code, so the AFP machine will do exactly what you have simulated."

### "Factory of the Future"

This digital design and manufacturing chain and the automation already proven in large TPC aerostructure demonstrators align well with the Clean Sky 2 vision for future aircraft manufacturing, which is described as highly automated, flexible and based on functional integrated design. Thermoplastics also offer a means for attaining a multifunctional airframe, especially as the line between AFP and 3D printing dissolves. Clean Sky 2's Platform 2 "Innovative Physical Integration Cabin – System – Structure" program includes large, integrated fuselage demonstrators. The Clean Sky 2 Joint Proposal Platform 2 key drivers are cost and weight:

> "Without considering the engines, more than 50% of the recurring cost of manufacturing an aircraft is determined by the fuselage, the cabin and cargo equipment and the integration effort performed in the assembly of these components. .... considering a short-range commercial aircraft operating over 15 years, the reduction of just 100 kg of its original weight leads to more than 4 tons of fuel saving. Therefore, the potential of lighter and more efficient structures and systems for contributing to the ACARE vision 2020 [50% cut in $CO_2$ emissions, which means 50% cut in fuel consumption for new aircraft in 2020], is enormous."

By combining multiple airframe components into a much smaller number of integrated, TPC-based modules equipped with distributed power and systems, myriad parts, fasteners and holes are eliminated with a corresponding cut in machining and assembly operations. Clean Sky 2 proposes that potential weight savings could provide up to a double-digit reduction in fuel burn and a sustainable path to meeting future aircraft demand. Although there is still much to be developed and validated, thermoplastic composites seem destined to play a part in the aircraft factory of the future.

*In Part 2,* CW *will explore issues with PEEK and PEKK materials and quality of tapes as well as the debate over a one-step vs. two-step process, all of which will impact how in-situ consolidation and thermoplastic composites play a part in future aircraft.* CW

**ABOUT THE AUTHOR**

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# Composites Events

**March 1-2, 2018 — Vienna, Austria**
14th World Pultrusion Conference
pultruders.org/pdf_news/1_WPC_Save%20the%20date.pdf

**March 6-8, 2018 — Paris-Nord Villepinte, France**
JEC World 2018
jeccomposites.com

**March 6-8, 2018 — Osaka, Japan**
4th Annual World Congress of Smart Materials
bitcongress.com

**March 12-14, 2018 — Beverly Hills, CA, US**
*SpeedNews* 32nd Annual Commercial Aviation Industry Suppliers Conference
speednews.com/commercial-aviation-industry-suppliers-conference

**April 10-12, 2018 — Detroit, MI, US**
SAE 2018 World Congress Experience
wcx18.org

**April 10-12, 2018 — Knoxville, TN, US**
Composites Recycling Conference
s1.goeshow.com/acma/RecyclingConf/ereg346937.cfm?clear

**April 23- 26, 2018 — Ft. Worth, TX, US**
Rapid + TCT 2018
rapid3devent.com

**May 7-10, 2018 — Chicago, IL, US**
WINDPOWER 2018 Conference and Exhibition
windpowerexpo.org

**May 14-17, 2018 — Stockholm, Sweden**
Int'l Conference on Epoxy and Resins Technology (ICERT 2018)
vbripress.com/bcs18s/pages/epoxy-and-resins-conference

**May 16-18, 2018 — Shanghai, China**
SAMPE China 2018
sampechina.org

**May 21-24, 2018 — Long Beach, CA, US**
SAMPE 2018 Long Beach
nasampe.org/events/EventDetails.aspx?id=699309&group=

**CW June 13-14, 2018 — Novi, MI, US**
ameri*mold* 2018
amerimoldexpo.com

**CW June 13-14, 2018 — Novi, MI, US**
Composites Overmolding: A 1-minute cycle time initiative
compositesovermolding.com

**June 20-21, 2018 — Nottingham, UK**
Composites Innovation
compositesinnovation.com

**June 21-23, 2018 — New York City, NY, US**
Composites Pavilion – American Institute of Architects Convention 2018
conferenceonarchitecture.com

**June 27-28, 2018 — Chicago, IL, US**
The Future of Composites in Transportation
jeccomposites.com/knowledge/international-composites-agenda/future-composites-transportation-jec

**July 15-21, 2018 — Paris, France**
ICCE-26, 26th Annual Int'l Conference on Composites/Nano Engineering
ice-nano.org

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

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

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

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

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

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## SHOWCASE

# Composite fendering piles fit the bill

## Composites replace wood in New Jersey marine fender project.

By **Sara Black** / Senior Editor

» Wood is a great material for many applications, including marine pilings and fenders — after all, the Italian city of Venice is supported on a forest of wooden pilings, some nearly a thousand years old. Yet, there are times when wood can't make the grade. Marine borers, such as *Limnoria,* are a serious threat. Further, there is a trend among environmental regulators to prohibit the use of creosote, the material used to water-proof wood for use in marine environments.

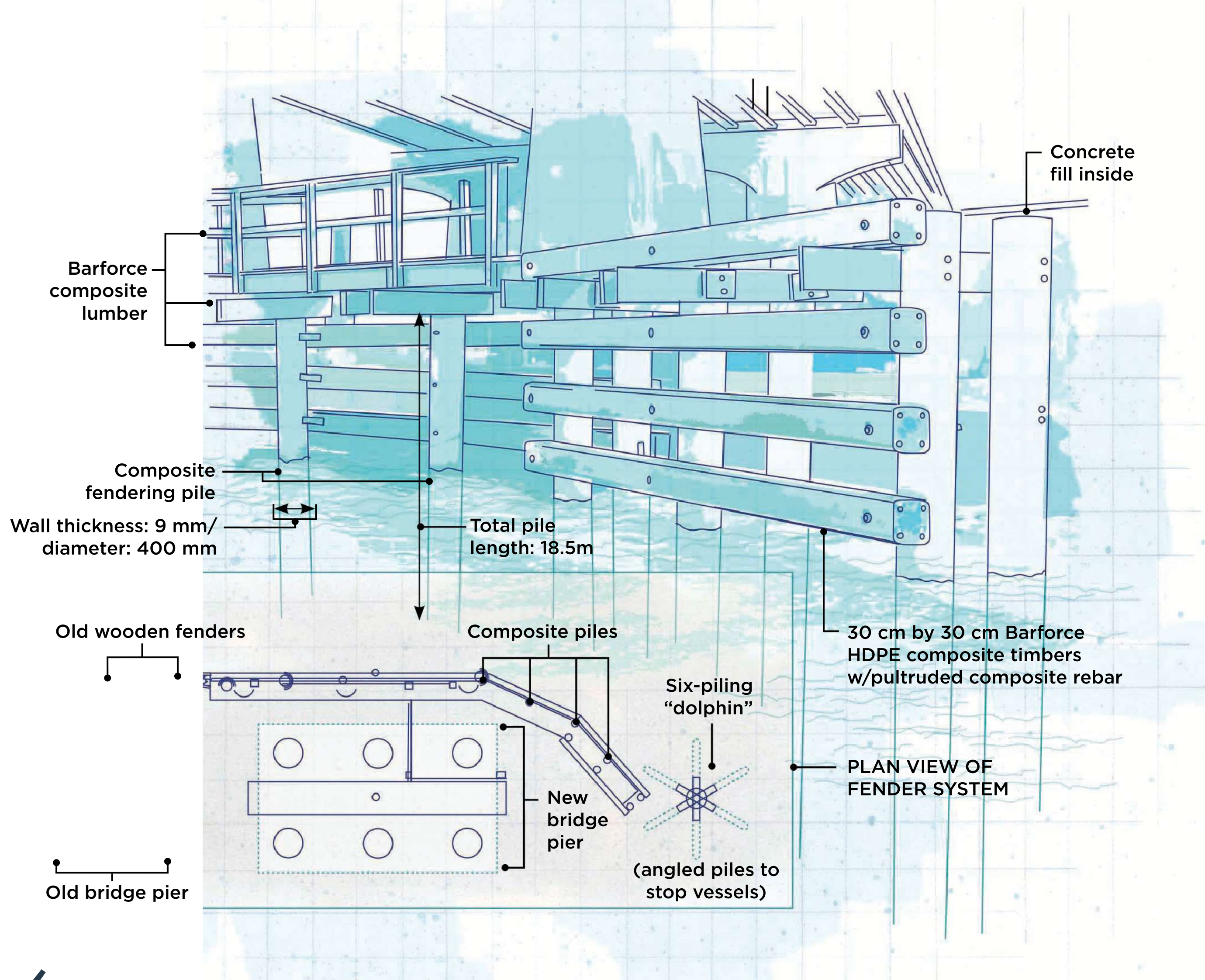
That trend had already moved through New Jersey when work began more than five years ago on the new Manahawkin Bay Bridge span, alongside the existing 50-year old — and structurally deficient — truss span that links mainland New Jersey to popular Long Beach Island. "The State of New Jersey outlawed all creosote-treated wood 10 years ago, the material often used along with concrete for marine pilings," says Erik Grimnes, business development manager at Kenway Composites (Augusta, ME, US). As a result, composites were chosen for the fender system that protects the new bridge's concrete piers. "New Jersey's Department of Transportation had good previous experience with composites, and specified composite pilings in the fender design documents."

Such pilings have been a specialty of Augusta-based Harbor Technologies, and remain so under Kenway's ownership, says Kenway president Ian Kopp. Kenway acquired the assets of Harbor Technologies in 2015, and was, in turn, acquired in March 2017 by Creative Pultrusions (Alum Bank,

### Showcase for composite marine fender/pile systems

The Manahawken Bay Bridge that connects mainland New Jersey to Long Beach Island was recently upgraded to create a second span for better access for residents. The new span, built by WSP USA (New York, NY, US), received a National Recognition Award for exemplary engineering achievement in 2017. The new span's bridge piers are protected by composite fenders.

Source | InfrastructureUSA.org




**DESIGN RESULTS** — **Manahawken Bay Bridge Marine Fender Project**

- Composite pilings allow greater design freedom and easier installation where treated wood has been banned.
- Custom design optimizes performance with less material, for lower cost.
- Fendering performance is enhanced with concrete fill, which increases allowable piling deflection.

Illustration / **Karl Reque**

PA, US). Trademarked HarborPile, the pilings' design, described by Grimnes and project engineer Nate House, is an interesting example of how composites can be customized for specific project conditions.

### Optimizing a piling for best material use

"Fenders are essentially fence posts that support guard rails, in simple terms," explains Grimnes. New Jersey Department of Transportation (NJDOT) authorities wanted to surround the bridge's deepest structural piers with energy-absorbing structures that would prevent damage to them from a large, out-of-control vessel. In this case, NJDOT specified (in US customary, non-metric units) an impact load or force of 40.76 kip-ft, which it calculated would be produced by a 200-ton hopper barge, the largest vessel that NJDOT knew would ply the waters beneath the bridge, says House. Unlike a wharf or pier, where pilings must withstand significant axial loads to support the overhead structure, the Manahawkin piles would be *fendering piles*, which would need to resist lateral loads, explains House. The hollow tubes would be driven down into the sea bed far enough so that the soil friction provides fixity, to hold them in place: "The main purpose of the piles is to absorb energy, so they must deflect if hit by a vessel."

NJDOT engineers provided Kenway with design factors for the piles: 1) a maximum allowable deflection of 18.6 inches (from »


■ **Transition from old to new**

The new bridge span piers with composite fender system are on the left; the older truss span piers, protected by wooden fenders, are on the right.

Source | Schiavone Construction


■ **Cascading savings based on materials selection**

The comparatively low weight of the composite piles made it possible to drive them into the sea bed with a relatively small excavator, which clamped to the top of each pile — a source of cost savings on the project. Source | Schiavone Construction

vertical), 2) a minimum bending moment of 3,276 kip-inches, and 3) a minimum bending stiffness of 2.76 x $10^9$ lbs-$in^2$. Given these parameters, and the 40.76-kip-ft impact load force, House was able to design the strength and stiffness of the pilings, using Kenway's in-house design spreadsheet.

The extensive spreadsheet, developed over many years by Harbor Technologies, is based on "lots of historical test data," says House: "We've worked with the University of Maine's Advanced Structures and Composites Center [ASCC, Orono, ME, US] to do full-scale failure testing of our parts, using ASCC's large press, to test a variety of laminates and wall thicknesses." Each project is customized, using the design spreadsheet. There are no off-the-shelf pilings. For the Manahawkin project, the NJDOT specified a 16-inch (400-mm) outside diameter, but, says House, "we were able to optimize the piling wall thickness with our spreadsheet calculations."

**LEARN MORE**

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

Read *CW's* previous story on composite pilings, including those made by Harbor Technologies, online | short.compositesworld.com/OtWFPiles

House explains that a pile that is, for example, 300 mm in diameter with a wall thickness of 25 mm (1 inch) has the same strength and stiffness as a 400-mm-diameter pile with a wall thickness of 12.5 mm (0.5 inch). This is because of the geometric properties of the tubular pile; the larger diameter translates to a stiffer part: "It depends on the distance between the centroid, or neutral, axis, to the wall — the larger that distance is, the stiffer the pile becomes," he states. Translated to the composite design, the 300-mm pile might use 45 kg of material, whereas the 400-mm pile requires only 32 kg of material because of the thinner wall, yet it achieves the same strength and stiffness properties. "So, I've used less material, for less cost and achieved a larger, more useful shape," adds House. He stresses, however, that this principle can be extended only so far. A 750-mm diameter pile with a wall thickness of 1.5 mm might appear on paper to be stiff enough, but "that very thin wall obviously wouldn't withstand the driving loads and would buckle."

House's spreadsheet calculations indicated that, given the water depth and soil conditions, a 400-mm-diameter pile with a wall thickness of 9 mm (0.375 inch) and a length of 18.5m (~60 ft) would meet the NJDOT requirements. And, says House, the driving, or installation, loads actually proved pivotal to the design: "Piles are typically driven with a vibratory hammer or impact hammer, both of which generate significant axial loads on the pile. A thinner wall could have met the structural requirements of the fender, but we needed the 9-mm wall to stand up to the driving." Heavy knitted quadraxial fabrics, ranging from 3,390-6,800 g/$m^2$, used to fabricate the piles (more on that below) ensured axial strength was adequate to stand up to the driving forces.

NJDOT also specified that when in place, the pilings would be filled with concrete, which works to composites' advantage in this application. When a hollow tube fails, it buckles and collapses, but concrete performs well in compression, to prevent buckling, explains House: "We have extensive test data that show that concrete-filled piles actually exhibit greater deflection, essentially two times more than a hollow pile, before failure." Adds

## Piles primed for installation

The composite piles arrived at the job site on this trailer, with steel driving tips already installed.

Source | Harbor Technologies/Kenway

Grimes, "The two materials actually work *compositively* to give better performance. The composite shell acts as an external rebar cage to improve the performance, and protects the concrete from corrosion." For the Manahawkin project, a total of 38 piles were required.

Finally, the fender system would combine the driven pilings with sturdy, molded fiber-reinforced polymer (FRP) Barforce composite lumber manufactured by Bedford Technology (Worthington, MN, US). Supplied as solid timbers and planks in a variety of sizes, they are made of 100% recycled high-density polyethylene (HDPE), with embedded pultruded continuous fiberglass composite reinforcing rods, or rebar. For the Manahawkin project, 30-by-30-cm (12-by-12-inch) timbers were specified for the horizontal fender elements, as shown on the drawing (p. 45). Bedford also supplied 7.5-by-30-cm planks, also reinforced with the composite rebar, to support the walkway and railings, as well as the necessary composite elements for the walkway surface and railings at each bridge pier. While Bedford typically supplies its Barforce materials in black or yellow, NJDOT specified that the composite lumber be brown in color, for a more natural, wood-like look.

### Heavy-duty materials

To make the piles, says Grimnes, heavy quadraxial fabrics supplied by VectorPly Corp. (Phenix City, AL, US) are combined with polyester or vinyl ester resin, supplied by Polynt-Reichhold (Carpentersville, IL, US) or other suppliers, in a proprietary manufacturing process. "It's a vacuum infusion process, combined with centrifugal casting. The closed mold is spun to help compact the fibers during the infusion process," he explains. The quadraxial fabrics ensure that at least 50% of the fibers run axially along the pile length, and about 25% of the fibers end up as hoop direction reinforcement. The remainder are oriented at 45°.

Resin choice depends on the project conditions, and all piles are gel coated, with product supplied by Polynt-Reichhold or Ashland LLC (Columbus, OH, US) for added durability and appearance. For this project, because of the concrete fill, each pile was equipped with a conical steel driving tip to increase the pile's bearing resistance during driving, while keeping mud and debris out of the pile interior. The 27 kg/m piles were shippable on a standard, over-the-road tractor trailer, but Grimnes points out, "We're able to ship much longer piles, under special permit conditions for over-length loads."

The Manahawkin Bridge's height, he explains, prevented use of a bridge-mounted crane to drive piles from above. Instead, a small excavator was situated at water level, on a floating work platform, to do the driving: "The excavator clamped onto a bolted-on steel collar to drive the piles. It's important to note that if the piles had *not* been composite, this floating platform and excavator method wouldn't have been possible — heavier steel or concrete piles would have required much heavier driving equipment." The horizontal composite timbers were attached to the pilings with long stainless-steel bolts, and similar metallic hardware connects the composite walkway and railing elements to the timbers.

"Our client sees the benefits of using composites for this application, since they are essentially maintenance-free and will last for at least 50 years," concludes Grimnes. NJDOT is likely to replace the existing timber fenders associated with the old bridge span with composites as well, over the next several years. It is, apparently, an ideal application for customizable composites tailored for site-specific conditions. CW

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