CW

CompositesWorld

2020 *Corvette*:

ENGINEERING, BEAUTY, SPEED

AUGUST 2020

The industrialization of thermoplastic epoxy / 26

Composites fill the gaps in dinosaur skeletons / 32

Potential in Formula 1 composite manufacture / 36

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Source / General Motors Co.

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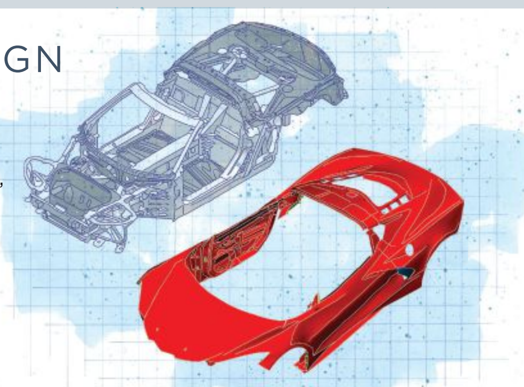
52 Part 2: Beauty, speed, luxury: 2020 *Corvette*

Innovative composite materials trim mass, costs and noise on the high-volume mid-engine Chevrolet *Corvette Stingray* sports car. Peggy Malnati continues her coverage in this second installment.

By Peggy Malnati



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» My father-in-law, in 1966, prior to the birth of his two children, purchased a new *Corvette Stingray*. I've never seen the car, but I've seen photos. It was Nassau blue with a removable hardtop and much beloved by my father-in-law. After the birth of their first child — the person who would eventually become my wife — my father- and mother-in-law faced a dilemma: The *Corvette* was not designed to accommodate an infant in a car seat and thus was not a practical vehicle for a young family.

The *Corvette* is the exception in autocomposites.

For this reason, my father-in-law made the difficult decision to sell the *Corvette*. However, as soon as the buyer of his *Corvette* drove away, my father-in-law regretted the decision to sell. In fact, he tried to buy the car back, to no avail. To this day, my father-in-law still gets sentimental any time the subject of conversation turns to his 1966 Nassau blue *Corvette Stingray*. It was the one that got away.

It's been more than 50 years since my father-in-law made that purchase, and of course the *Corvette*, which debuted in 1953, has been through several iterations since. At 67 years old, the *Corvette* is one of the longest-living nameplates ever produced. Over that time, there have been eight generations of *Corvette* — designated C1-C8. The most recent generation is on the cover of this month's *CW*.

We split our coverage of the MY 2020 *Corvette Stingray* into two parts. Part 1 was published in July 2020 *CW* and Part 2 appears in this August 2020 issue, on p. 52. Both stories were written by *CW* contributing editor Peggy Malnati.

We had to divide our coverage over two issues because, frankly, the C8 generation is such a radical departure from the norm for the *Corvette*. If you are a *Corvette* aficionado, the most significant difference is that the engine in the C8 has been moved to the middle of the vehicle, which substantially changes the car's lines and aesthetic. Indeed, as Peggy notes in her story, between the C7 and C8 generations, there is only one duplicate part. All else is new.

The second departure from the norm for the 2020 *Corvette* is its prolific use of composite materials. This is not to suggest that previous *Corvette*s lacked composite materials — you will recall that the *Corvette* was made famous, in part, originally, by its use of fiberglass body panels. Indeed, throughout the *Corvette*'s life Chevrolet has proved most willing to apply glass and carbon fiber composite parts and structures to the vehicle. But even in light of this rich composites history, the C8 represents a step-change in composites use, ranging from the now famous curved composite rear bumper beam to the rear trunk and front trunk (frunk) to myriad underbody panels.

Possibly the most remarkable aspect of the MY 2020 *Corvette* is that it packs the new mid-engine concept into such a composites-intensive design to produce a vehicle that is — relatively speaking — so affordable. With a base price of $58,900, the *Corvette* is a veritable steal given its performance and engineering, and given the current market for high-end, high-performance, limited-production sports cars.

Despite all of this, and as appreciative as the composites industry is of the *Corvette* and its place in composites manufacturing history, I can't help feeling some disappointment as well — not in the car, but in the automotive industry. In the broader automotive universe, the *Corvette* continues to be the exception that proves the rule when it comes to composites use. I am reminded, every time I see a *Corvette*, that it is one of the few vehicles on the road that makes significant use of composite materials in major parts and structures, and remains affordable enough for most people to buy. Meanwhile, the rest of the mainstream automotive industry remains in the rearview mirror, making promising but definitely *incremental* use of composite materials.

Looking to the future, increased vehicle electrification does offer the composites industry a new opportunity to find applications well-suited for the materials. This is particularly true of applications, like battery covers, that don't have a long history of using aluminum or steel and thus can be designed with composite materials and manufacturing processes in mind. It is in such applications that we should focus our energies.

In the meantime, I will continue to appreciate the *Corvette* for what it was and what it has become. And I will see if I can't track down the person who bought that 1966 Nassau blue *Corvette* from my father-in-law. Maybe he's ready to sell.

JEFF SLOAN — Editor-In-Chief

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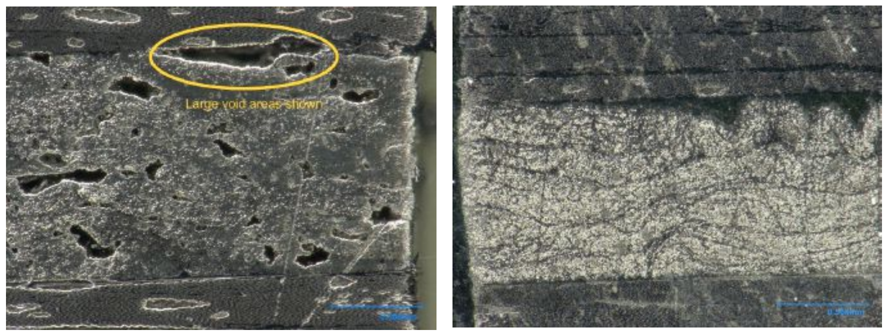
Why prepregged products beat their dry counterparts

A bead of sweat ran down the middle of my back. I had been in a conference room for nearly three hours concluding a high-stakes negotiation, with the future of a multi-billion dollar company's expansion resting squarely on the solution I was proposing. The product I was selling at the time was dry carbon fiber. I had invested years learning my customer's businesses, listening to what their pain points were, identifying problems they hadn't seen and recommending innovative solutions to their problems. Years later, I found myself using this knowledge to breathe life into a long-existing product — preimpregnated composite fibers — that would further transform my view of the composites industry forever, and potentially help that customer and others like them expand into the marketplace. In this article, I want to share what I learned during my career to summarize the winning attributes of preimpregnated products.



Laminate using wet winding with voids (left) compared to a near void-free laminate created with towpreg (right). Source | TCR

Preimpregnated fiber reinforcements enable a company to manufacture lower-cost products, increase throughput, enhance product performance and improve quality and worker safety, resulting in immediate payback. If your company is filament winding, using automated tape laying (ATL), laying up by hand, tube rolling or compression molding, chances are prepreg and towpreg products can improve the manufacturing process. The benefits are realized no matter if the company is consuming millions of pounds or even the smallest amount of material.

I will illustrate direct and useful comparisons for how fabricators can benefit from prepregs, assessing them against more traditional forms of composites production. I will focus on five key areas: efficiency, quality, performance, safety and profitability. In each area, I will present a high-altitude view of where prepreg products fit in the composites industry and explain their benefits across multiple manufacturing processes. In the end, I hope you will be able to appreciate that the value of prepreg materials greatly exceed their cost.

Efficiency

Years ago, as a carbon fiber salesperson, I sat in a room filled with automotive executives negotiating the price of carbon fiber. Their sole focus was to justify why a \$5-per-pound carbon fiber price would place the material in such high demand from the automotive industry that it would exhaust the world supply.

The automotive executives were so focused on carbon fiber price — in their minds, the largest raw material input — that they ignored the largest cost component that would ultimately determine whether using this material was viable: efficiency.

During that meeting, I stated something ironic: Even if carbon fiber were free, it was still unlikely that auto producers could afford it. Then I explained that metal-stamped hoods required seconds to manufacture, while molding carbon fiber hoods took, at best, minutes. With a bottleneck like that, it would be difficult to meet automotive production targets. To this day, that company has not used one single pound of carbon fiber for automotive body panels. In the meantime, the inflation-adjusted price of carbon fiber has fallen well below that \$5 per pound threshhold.

The point of this anecdote? Many companies focus on the price of prepreg, ignoring the efficiencies it enables. Further, although curing carbon fiber composites still remains a relatively long process for automotive hoods, it is critical to understand that *efficiency* plays a huge role in determining the *total* cost of a part.

For example, in filament winding, efficiency has a large impact on the output of a manufacturing line. In this process, in the use of wet winding, as winding speeds increase, air is driven into the resin bath, creating voids and reducing mechanical performance in the final part. Fully wetting out tow bundles, therefore, can only be achieved at relatively low speeds. As a result, stable wet filament winding can achieve speeds of about 1 meter per second.

Comparatively, prepregged tow, or towpreg, can run as fast as 5 meters per second in filament winding. Towpreg also reduces voids because it eliminates the need to wet out a fiber bundle.

We can look further into the supply chain to uncover more efficiency improvements. If a filament winder uses a wet process, during a normal production shift an operator mixes resins with a pot life of 6-8 hours, which are designed for a shift of use. At the end of the shift, cleanup is required, which includes washing out resin baths, cleaning resins off guide rollers, measuring resin levels, taking inventory and a host of other tedious but necessary actions. During these setup and tear-down periods, operators are not manufacturing products. If an operator spends one hour per shift doing this, it adds up to 250 hours of lost time, or six weeks of work time for one worker for one year.

With room-temperature towpreg, this setup is eliminated. Operators begin their day by placing the spools on the creel racks and immediately running product.

Similarly, with room temperature-stable prepregs, companies also enjoy switching off machinery when they want, and picking back up days later where they left off. There is no need to wait around until the prepreg thaws, record temperatures and refreeze material. Operators simply grab material and begin working. This time is recaptured in pure manufacturing output.

> I found myself using this knowledge to breathe life into an existing product — prepreg composite fibers.

Another path to prepreg efficiency is through the modification of tackiness. For example, a resin's tackiness can be moderated so that a braided prepreg can be easily maneuvered around difficult angles without sticking to a mandrel. In this way, fabricators manufacturing ducting or complex tube structures can gain enormous throughput efficiencies compared to use of woven fabrics.

Supply chain efficiency is streamlined even further when inventory calculations are finished in minutes, with fewer products — resins, catalyst, floor paper, mixing container and more — to count and monitor. Purchasing managers can ensure products are in stock, managing fewer vendors.

Further, the resin mixing, staging and inventory rooms necessary for wet molding processes are also not required for prepregs, which allows a company to decrease its operational footprint, or at the very least, use the existing footprint for further capacity expansion with partmaking equipment. Additionally, since machines are being used to produce products during the full shift, machinery utilization rates skyrocket, which drives down the requirement for new equipment and the potential for increasing CAPEX.

In real-world examples, we have witnessed a 20% increase in throughput from customers implementing prepreg products over their wet winding or wet layup alternatives. Since work time is reduced, there is also a direct correlation to labor, allowing more to be accomplished with fewer workers.

Focusing on use of prepreg, a fabricator can increase the output of its facility, decrease labor, make more efficient use of the operational footprint and drive down unit costs.

Quality

One of the most important manufacturing processes for many fabricators is quality control. Aerospace, defense, energy storage, oil and gas, healthcare and other end markets demand quality and traceability. The cost of measuring and managing quality is born by most fabricators using traditional in-house QA labs.

Even at my company, there are multiple QA procedures in place during the production of prepreg. These procedures use a number of technical methods to verify the resin is correctly mixed, with multiple personnel performing checks before resins are blended. Once accepted, a resin then must make three trips through the laboratory for quality checks. Many methods are in place to remove uncertainty and ensure accuracy and repeatability, including the use of FTIR (Fourier transform infrared) spectroscopy. This instrument uses light to scan and produce a "fingerprint" of the resin to ensure accuracy. This is done before any resins are placed on reinforcements.

Product is then manufactured on custom machinery, built in-house. This allows tight control over the application of the resin to the reinforcement. As the prepreg product is formed, it then proceeds to QA labs for final approval. Each lot contains a Certificate of Conformity, which outlines the resin content of every spool of prepreg and towpreg. Customers can trace the exact spools and resin content of those spools back through to each part that was produced.

To further maintain quality control and consistency, prepreg production is done in a temperature- and humidity-controlled environment. This diminishes aspects of variability usually present in other manufacturing environments.

Quality inherently finds its way into the production of parts. In typical wet winding and wet layup, the amount of resin applied to the fiber reinforcement varies far more than it does during the manufacture of towpreg and prepreg. In traditional wet winding and layup, measured resin variation can usually be controlled to ±5.0% COV (coefficient of variation). This large variation is usually accounted for with higher design allowables.

By comparison, prepreg products typically maintain resin content to ±2.0% COV. By monitoring these levels with tight tolerance, the desired fiber volume is assured. This allows for use of tighter design allowables, which leads to faster wind times, reduced material use, faster cures, reduced part weights, thinner parts and other benefits.

In conclusion, the quality and consistency of prepreg allows for the production of more consistent parts with higher repeatability and minimized part rejections.

In my next column, I will examine how prepreg achieves higher degrees of performance and ensures greater worker safety. CW

ABOUT THE AUTHOR

Before joining TCR Composites in 2019, Brian Bishop had the privilege of working with two of the top advanced composites companies in the world. He has been in the composites business for 20 years, traveling the world marketing and selling materials to some of the world's largest corporations. He excels at identifying industry problems and implementing solutions to overcome them. His life is wonderfully balanced with his wife and children in Austin, Texas.

Seeking inspiration in a virtual environment


Source | Getty Images

» We live in an increasingly virtual world. This was true well before February 2020, and the changes the coronavirus pandemic has brought only accelerated the trend. Raise your hand if you used the Zoom application in 2019. I sure didn't. We've had plenty of virtual meeting platforms for quite a while — I recall using Skype as early as 2005 or 2006 to connect with Australia and Europe, and to connect back to the U.S. from those same places. Successive platforms grew mainly as a way for companies to conduct internal meetings with far-flung colleagues, reducing the need for travel with the ability to share content, then video, with others. This evolved into applications for webinars and training, growing year by year. 2020 has been the year where entire conferences, including composites-focused events, have been put online, with new features being added for trade show content and networking options. No doubt these platforms are here to stay and will become part of the mix, especially for short, focused technical conferences, when in-person events return.

It begs the question: How far can the virtual environment take us?

This trend, however, does beg the question: How far can the virtual environment take us? Let's take aviation, for example. We can create a virtual composite airplane and simulate the manufacturing of the components, including resin flow, lamination, spring back, etc. We can simulate the factory floor and assembly process, as well as virtually test the components and airplane for stiffness and fatigue. And I know I'm *very* grateful that pilots train extensively in a flight simulator before hopping in a real cockpit! At some point, however, no matter how capable our digital tools are, the virtual world must be traded for the physical world with the certification and production of actual airplanes. None of us, I wager, would pay for a virtual seat on a virtual airplane to a virtual destination.

As important as the virtual world has become, growing the economy requires *making real things that people and companies will buy*. Developing confidence in these virtual tools requires validation that only comes from making and testing the coupons, components and assemblies that the virtual tools represent. And the sooner we all get back to doing that, the better. The same goes for returning to in-person events, I believe.

Over the years, people that read this column have asked me, "where do you get your ideas for what to write?" Historically, I get many topics from what I see, hear, touch and experience at in-person events — trade shows and conferences — walking the show floor, visiting exhibitors and engaging in side conversations with attendees, colleagues and friends.

Looking back at events I attended in 2019, I wrote columns inspired by the January Detroit auto show, JEC World in March, a small infrastructure event in April, SPE ANTEC and SAMPE in May, the SPE Automotive Composites Conference and Exhibition (ACCE) in early September, CAMX in late September and the *CW* Carbon Fiber conference in November. That's seven of 12 columns right there. Throw in some significant events like the cancellation of the A380, the merger of Raytheon and United Technologies, the 50th anniversary of *Apollo 11* and some insights from a collaboration mission trip to Germany, and we're up to 11. It's pretty easy to come up with one more idea with all that fodder.

So how hard is it for *this* writer to depend solely on "virtual inspiration" when traditional avenues are closed off? Pretty hard, I'll admit. Luckily, there are still some really great things going on in the industries we serve. My column from June 2016 focused on how manufacturing is in my blood, and how inspired I get visiting factories. Following the CAMX event last September, I was granted a tour of the SpaceX manufacturing site in Hawthorne, Calif., U.S. before catching my red-eye flight home. This facility produces the engines and the advanced composite components used for the various SpaceX launch platforms. Like many, I was enthralled with the May 30 launch of the SpaceX *Crew Dragon* atop a *Falcon 9* rocket, the first delivery of astronauts to the International Space Station from U.S. soil since the Space Shuttle was retired in 2011. Composite materials played a major role in the success of the mission, and no doubt a lot of virtual models and simulation did too. At the end of the day, though, it was the real, *physical* hardware that had to perform. CW

ABOUT THE AUTHOR

Dale Brosius is the chief commercialization officer for the Institute for Advanced Composites Manufacturing Innovation (IACMI), a DOE-sponsored public-private partnership targeting high-volume applications of composites in energy-related industries including vehicles and wind. He is also head of his own consulting company, which serves clients in the global composites industry. 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 served as chair of the Society of Plastics Engineers Composites and Thermoset Divisions. Brosius has a BS in chemical engineering from Texas A&M University and an MBA.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Composites Index reading remains unchanged from May

June 2020 — 42.3

» The Composites Index was unchanged in June, maintaining its May reading of 42.3. Survey respondents reported slowing contraction in new orders, production and export activity. An increasing proportion of respondents indicated that supplier deliveries quickened, sending the measure down nine points and putting downward pressure on the overall index. Employment and backlog activity readings fell further below a reading of 50 in June, indicating a quickening contraction in hiring and backlog levels.

Slowing supplier deliveries result in an elevated reading. The reason behind this has to do with the knowledge that during a period of strong economic growth, upstream suppliers experience lengthening backlogs which cause delays of the timely delivery of their products to composites fabricators. To correlate the slowing of deliveries with a growing economy, this index component rises as supplier deliveries slow, and fall when deliveries quicken.

As a result of the unprecedented disruption to the U.S. and world economies caused by COVID-19, supply chains worldwide have been forced to slow down production and deliveries, elevating the supplier delivery index, as it implies that upstream manufacturers are finding ways to move product more efficiently than just a few months ago. It also suggests that overall conditions improved in June despite no change in the overall Index's value. CW

ABOUT THE AUTHOR

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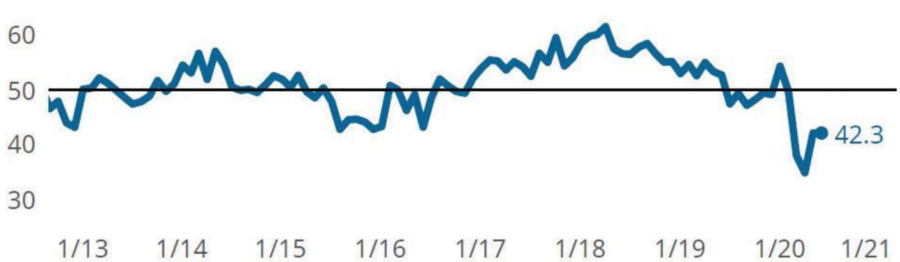
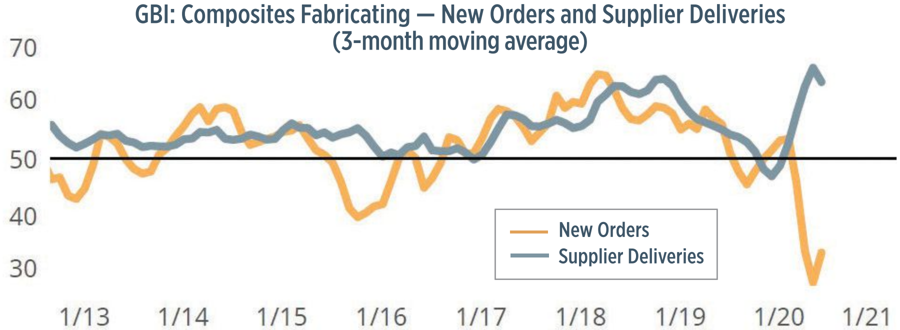
GBI: Composites Fabricating



Composites Fabricating Business Index:

The Composites Index was unchanged from May to June with the Index holding at 42.3.

GBI: Composites Fabricating — New Orders and Supplier Deliveries (3-month moving average)



Index registers higher new orders and production readings and quickening supplier deliveries:

Despite no change in the overall Index reading, new orders and production reported slowing declines; supplier delivery readings quickened. These changes should be considered welcome news for the industry.

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FASTIGUE: Empowering digital twins of large-scale composite structures

» As wind farms evolve into systems with soaring complexity, digital twins of the individual composite rotor blades will revolutionize the industry by providing real-time performance predictions coupled to a structural health monitoring feedback loop. This is especially important for high-growth *offshore* wind turbines, where maintenance is challenging and expensive.

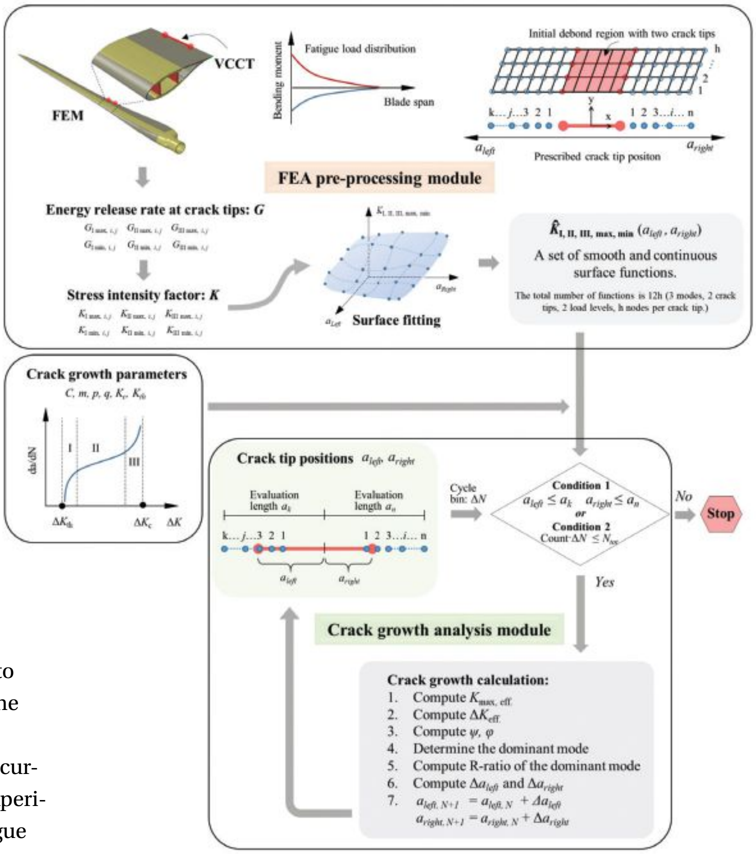


FIG. 1 Flow chart of the proposed FASTIGUE approach comprising an FEA pre-processing module (top) and a crack growth analysis module (bottom). Gray arrows indicate the computational flow, showing that feedback between the FEA pre-processing module and the crack growth analysis module is avoided, resolving heavy computational demands of fatigue crack simulation for large structures such as composite wind turbine blades. Source | Martin Eder, Xiao Chen, DTU Risø

Fatigue prediction makes digital twins computationally demanding

A prominent challenge for such digital twins, and their ability to improve the operation of large-scale composite structures, is the prediction of fatigue failure. Typically, this failure is caused by progressive material degradation induced by the millions of recurring mechanical and thermal load cycles a composite blade experiences during its 20- to 25-year life. The integration of such fatigue prediction capabilities into digital twins increases the computational load and, thus, the need for computational speed — preferably without compromising accuracy. However, the nemeses of real-time fatigue-life prediction methods for large structures are numerous, including highly dynamic (quasi-stochastic) loading conditions, intricate component geometries, anisotropic material behavior and structural nonlinearities. All of these increase complexity and decrease computational speed.

Appropriate consideration of these important effects and their interplay, then, compels the use of full-scale, 3D finite element models. The next hurdle is to bridge several orders of magnitude between characteristic length scales. At the macroscopic level, for such analysis to be efficient, it must discretize (break up into smaller elements) blades with a characteristic length of 100 (1×10^2) meters. And yet, the physical damage process must be resolved on a microscopic level with a characteristic length of $<1\times10^{-5}$ meters. Continuum damage-based fatigue models do bridge this gap by smearing over these scales using phenomenological considerations — in other words, where responses are prescribed by force and deformation relationships and related to geometry. In contrast, fracture-based fatigue models are renowned for providing both more information (e.g., discrete cracks comply better with damage inspection) and a higher degree of accuracy. Thus, they are often the preferred choice.

However, these fracture-based models require discrete crack modeling approaches, which necessitate high mesh discretization levels at the crack tip, resulting in models with high computational demand. Even sub-modeling (breaking up large structures into simultaneous modeling of substructures) hardly manages to tip the balance. Such highly discretized models are manageable for monotonic loading, where the load is applied in one direction and increased to determine yield and failure such as in tension and compression testing. But this falls short for analysis of high-cycle fatigue loading, where classic *"update-and-rerun"* approaches require that the crack tip be consecutively updated (e.g., adaptive re-meshing), followed by a re-run of the 3D model for a considerable number of load cycles, *N*. With N approaching several million, computation times become impractical. Thus, despite the availability of advanced discrete fatigue simulation models, their application to large composite structures is largely unfeasible.

FASTIGUE resolves heavy computational demands

This, then, is the problem: fatigue analysis of large structures presents a fidelity-versus-speed dilemma. In pursuit of a solution, Dr. Martin Eder and Dr. Xiao Chen, researchers at Technical University of Denmark (DTU, Risø Campus), have recently developed a super-efficient discrete fatigue crack growth simulation approach, coined FASTIGUE, for large-scale structures such as composite wind turbine blades. FASTIGUE is based within the classic realm of fracture-based fatigue analysis, but trades some general applicability for a significant gain in computational speed. The specialized approach puts forth a set of empirically corroborated assumptions that facilitate the decoupling of the finite element analysis from the crack-growth analysis procedure. In other words, the computationally demanding fracture analysis is outsourced into a pre-processing module while the crack-growth simulation is conducted subsequently and independently in a separate fatigue analysis module (Fig. 1, opposite page).

This approach pertains to specific situations in which (1) the crack propagation path is predefined and (2) the variation of the fracture parameters is quasi-uniform along the crack front. Cracks in the adhesive bondline along the trailing edge of composite wind blades provide a good example — indeed, they propagate along the bondline in a fairly uniform manner. This has been empirically corroborated by small-scale fracture tests as well as large-scale blade tests and is explained by the large bondline width-to-length aspect ratio of 1:500 (or larger).

Upon introducing an initial through-crack into an arbitrary location along the bondline of the structure, the fracture parameters (e.g., the stress intensity factor, *K*) can be computed in both crack tips for a number of user-defined crack lengths on both sides denoted as $_{a1}$ and $_{a2}$ (Fig. 2), allowing an entire possible solution domain to be constructed by surface fitting in a pre-processing step (Fig. 1).

Since the fracture parameters between the two crack tips influence each other, the fracture analysis in this pre-processing step ought to be conducted for all linear combinations of the number of auxiliary crack tip positions chosen. Still, the number of runs in this step is significantly smaller than the number of runs involved in the classic fatigue analysis scheme. Thus, this approach requires significantly less computation time. Also, it is straightforward to fit a smooth 3D interpolation surface through these auxiliary points, providing the fracture parameter as a continuous function of the crack tip positions denoted as $K_{a1,a2}$. It needs to be emphasized

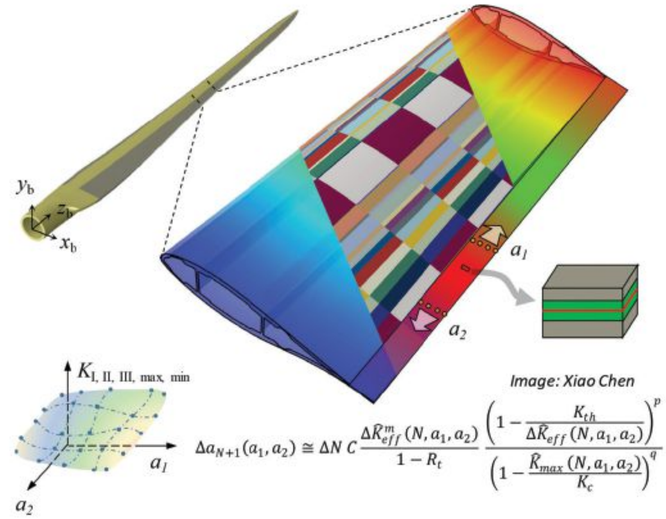


FIG. 2 In FASTIGUE, an initial through-crack is introduced at an arbitrary location along the bondline of a 3D finite element wind blade model. The crack proceeds away from this point in both directions along the bondline at the blade's trailing edge. The fracture parameters (e.g., the stress intensity factor, *K*) can be computed in both crack tips for a number of user-defined crack lengths on both sides denoted as $_{a1\ and\ a2}$. Source | Martin Eder, Xiao Chen, DTU Risø

that the spacing between these auxiliary crack tip positions is independent of the fatigue growth analysis. Any desired discrete crack growth within the possible solution domain defined by the fitted surface can be analyzed.

Once the surface-fitting functions of $K_{a1,a2}$ are established, the actual crack growth analysis is performed independently by adopting any suitable discrete crack growth law defining the crack growth speed as a function of the prevailing fracture parameter state in both crack tips. In essence, under the proviso of the assumptions posited, a per-se demanding 3D fracture problem is reduced into a pseudo 1D problem described by a set of two coupled first-order ordinary differential equations (ODEs) of the generic form $da_{1,2}/dN=CK(_{a1,a2})m$ where *C* and *m* are the well-known empirical growth parameters. These ODEs can be solved rather efficiently using any *Runge-Kutta* type time integration scheme.

Since the function $K_{a1,a2}$ is already established for the entire » growth domain, the fatigue growth analysis no longer involves finite element analysis and the computational effort boils down to solving a coupled initial value problem for an arbitrary initial crack length configuration. Owing to the computational efficiency of the adopted explicit time integration schemes, crack growth analyses can be conducted in a fraction of the computation time required for classic "update-and-re-run" schemes.

Flexibility and validation of FASTIGUE approach

FASTIGUE was validated against a crack-in-a-rod analytical solution with good agreement between its predictions compared to those obtained from a high-fidelity finite element analysis. It was demonstrated that FASTIGUE offers a robust and efficient tool for predicting the fatigue crack propagation in the trailing edge adhesive joint of a full 3D finite element wind turbine blade model.

FASTIGUE can be run in two different modes: it provides the crack extension of the crack tips for a given cycle number and, conversely, provides the cycle number for a given crack extension. It is noteworthy to mention that FASTIGUE can be endowed with any desired discrete crack growth law. Moreover, the growth of multiple cracks present in the structure can be considered.

This tool was specifically developed for its integration into digital twin systems and particularly lends itself for use in reliability-based inspection planning schemes and *Monte Carlo* simulations, which can be conducted for a large variation of growth parameters and initial flaw sizes. This shows just the beginning of its potential for application in large-scale structures such as composite wind turbine blades and beyond.

This research is published in the Digital Twin Special Issue of *Engineering Fracture Mechanics*, vol. 233, June 2020. It is supported by DARWIN: Drone Application for pioneering Reporting in Wind turbine blade Inspections, Innovation Fund Denmark (6151-00020B), and RELIABLADE: Improving Blade Reliability through Application of Digital Twins over Entire Life Cycle, EUDP (64018-0068). CW

ABOUT THE AUTHORS

Dr. Xiao Chen, associate professor at Technical University of Denmark, received his doctoral degree in structural engineering in 2011 from Nagoya University in Japan and worked as a postdoctoral research fellow in the National Wind Energy Center at the University of Houston, Texas, U.S. From 2013, he served as assistant professor and then associate professor at Chinese Academy of Sciences in Beijing before he joined DTU in 2017.

Dr. Martin Alexander Eder, senior research scientist at Technical University Denmark, earned his doctoral degree, after several years in international industy, in 2011 in earthquake engineering at Imperial College (London, U.K.). He continued there as a postdoctoral researcher before joining DTU Wind Energy in 2012. In 2018, he obtained another MSc degree in materials and manufacturing engineering at DTU.

A Tech Table details various suppliers' external mold release products, a German railway bridge is suspended on CFRP hangers, a series of eVTOL programs and aircraft take to the skies and BTG Labs studies surface treatment methods for thermoset and thermoplastic composites.

Tech Table: Mold release agents

Mold release agents — arguably the products most responsible for long tool life — provide a critical barrier between the mold surface and the molded part. No matter the market, a properly applied mold release encourages easy separation of part from mold. An improperly applied mold release, or a mold release not applied at all, causes well-documented problems in demolding high-quality parts. It is no surprise, then, that release agents are a vital part of quality control during the composites fabrication process, and help guarantee proper mold care, making them a cost-effective strategy for manufacturers.

As a result, mold preparation and maintenance is not just common, it's mandatory. Suppliers of mold releases offer a variety of products designed to cater to specific materials, processes and applications, with factors like operator preference, plant safety and environmental impact in mind.

CW has built a downloadable table of mold release agents with data provided either directly by the supplier, or from public sources. View the downloadable table as a PDF, accessible here: short.compositesworld.com/TechTblAug.

It should be noted that, due to the wide variety of mold release products available in the composites industry, the products in this table only represent external mold release products in each supplier's product line; internal release products, conditioners, cleaners, primers and sealers are not included. For more information on these and other composites industry products, use the *CW* SourceBook database to find and identify suppliers. You can find the *CW* SourceBook at www.compositesworld.com/suppliers.

This is the second in a series of Tech Tables *CW* is publishing in 2020, each designed to provide as comprehensive a list as possible of suppliers, their products and selected product qualities. *CW*'s first Tech Table, published in January 2020, covers aerospace structural adhesives.

CARBON FIBER

Toray reduces carbon fiber and prepreg production

As a direct result of the coronavirus pandemic, Toray Composite Materials America Inc. (TCMA, Tacoma, Wash., U.S.) announced its realignment of U.S. operations, and a corresponding reduction in employee headcount to better position the company for an extended downturn in its commercial business streams.

TCMA says it will immediately suspend operations at its Spartanburg, S.C., U.S., plant and significantly reduce capacity in its Tacoma prepreg facility. These actions will result in a reduction of roughly 25% of the workforce across CMA's facilities in the United States.

"Decisions that directly impact our associates and their livelihood are never ones that we take casually," says president and CEO, Dennis Frett. "But these actions are absolutely necessary to reduce our costs and position the company for the future."

Toray notes that COVID-19 and the corresponding collapse of global air travel has dramatically reduced demand for passenger aircraft. Furthermore, says the company, global macroeconomic conditions are reducing the demand for industrial products. "Considering industry analysts and recent actions by other aerospace companies, we see a three-to-five-year timeline until we return to a sales volume that resembles anything pre-pandemic," says Timothy Kirk, vice president of Aerospace Sales.

These actions will enable TCMA to reduce its costs to partially mitigate the immediate downturn in business. Additionally, TCMA will enhance its cooperation with business units in the United States to better meet customer expectations and adapt to a changing market.

Toray, headquartered in Tokyo, Japan, is the largest carbon fiber manufacturer in the world, with a global, nameplate carbon fiber capacity of about 57,000 metric tonnes. For a full list of carbon fiber suppliers and their manufacturing capacity, view news online short.compositesworld.com/TCMAnews.

INFRASTRUCTURE

German railway bridge suspended on CFRP hangers

Source | Teijin

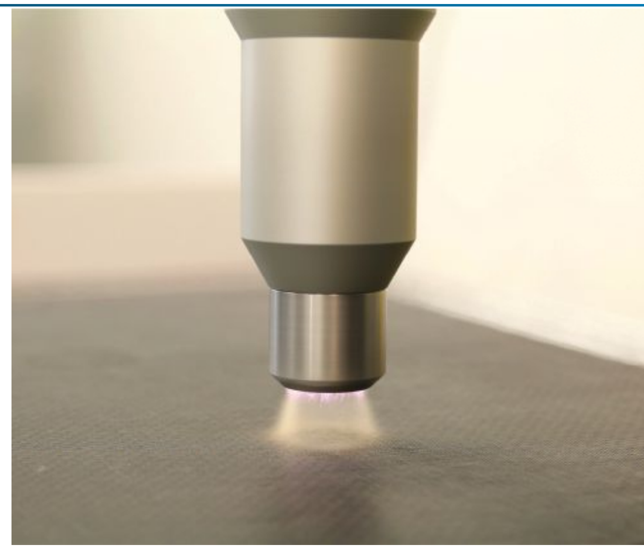
The Stuttgart Stadtbahn bridge, installed over the A8 motorway in Germany, is the world's first network arch bridge that hangs entirely on tension elements made of carbon fiber-reinforced plastic (CFRP). The 72 hangers are produced with Teijin (Wuppertal, Germany) Tenax carbon fiber by Carbo-Link AG (Fehraltorf, Switzerland), and differs from the original plan for a conventional steel bridge.

In the end, CFRP cables conveyed more advantages than steel. The carbon fiber cables were cheaper, enabled the crossing of the eight freeway lanes without supporting pillars and ideally fulfilled the requirements for hangers of network arch bridges: the cross-sectional area of the CFRP cables was only a quarter compared to the steel solution. Further, due to their light weight, the 72 CFRP tension elements could be installed without a crane and with only three construction workers.

Incorporation of CFRP in the 127-meter-long railway bridge also is said to enable sustainability. The EMPA (Federal Material Testing and Research Institute, Switzerland) proved that CO_2 emissions during carbon fiber manufacturing are one-third that of steel, and the energy consumption is more than halved.

Teijin is accelerating the development of applications for carbon fiber in the architecture and construction industries, and intends to further strengthen its position as a leading provider of cost-effective and sustainable composite solutions. Dr. Bernd Wohlmann, president of Teijin Carbon Europe GmbH says, "The Stuttgart railway bridge as the first network arch bridge solely made of CFRP cables should be groundbreaking for other bridges and constructions comprising CFRP. We are only at the beginning of manifold possibilities."

Surface treatment for adhesive bonding: Thermoset vs. thermoplastic composites



When optimized and verified through reliable testing, plasma is an effective way to change the chemical composition of the surface of a material that is to be bonded. Source, all images | BTG Labs

Surface treatment — involving some method of treating, abrading or cleaning a part or material surface — can be essential to achieving the necessary properties for successful adhesive bonding, coating or even painting. However, some methods are more effective than others for certain materials.

According to Giles Dillingham, CEO and chief scientist at BTG Labs (Cincinnati, Ohio, U.S.), surface treatment of materials for bonding, coating or sealing needs to accomplish three things:

- *Cleaning:* This means reducing the amount of detrimental contaminants on the surface to a level where intimate (molecular level) contact of the adhesive with the surface is achieved. Anything that gets in the way of this contact is a contaminant that must be removed or reduced to a non-threatening level by means of any number of cleaning techniques.
- *Activation:* The clean surface must be chemically active enough to form primary or secondary chemical bonds with the adhesive. A clean surface that is chemically inert cannot form the chemical bonds necessary for strong and reliable structural adhesion.
- *Stabilization:* The surface must be resistant to degradation (usually this means oxidation) when exposed to the service environment. The cleanliness and chemical activity of the surface needs to be maintained until the actual bonding or coating operation takes place.

The relative importance of these three aspects of surface treatment depends on the class of material under consideration, according to Dillingham. For example, metals have very high surface energies, meaning the surfaces are highly chemically reactive and contaminate quickly. Surface treatment for metals focuses on cleaning and creating a stable oxide. For composite materials, a different approach is needed for successful bonding and coating, because thermoset and thermoplastic polymers have relatively low surface energies and, therefore, do not contaminate as readily as metals and are relatively stable during environmental exposure. However, these same characteristics make adhesives less likely to stick to composites. As a result, surface treatment of composites usually focuses on the second factor listed above: increasing the surface energy so that a strong bond can be formed with an adhesive.

Manual abrasion is a common method of surface preparation for composites, but it may not be effective at cleaning a surface on its own.

Determining surface energy

Though generally low, surface energies can vary in different materials and composite parts, and surface treatments vary accordingly. According to Dillingham, the ability to quickly and quantitatively *gauge* the surface energy of an object or material is the important first step to designing, implementing or understanding the correct surface treatment.

There are several approaches to testing surface energy; one popular technique that BTG Labs often uses involves measuring the contact angle formed by a drop of fluid onto the test surface. In this method, if the liquid beads up upon contact with the surface, this indicates that it is not being attracted to the surface. Likely, an adhesive or paint will not be strongly attracted to this surface, either, and adhesion will be poor. Contamination is one cause for a surface to repel a liquid drop in this way.

However, if the liquid readily spreads out rather than beads up, this indicates that the surface is attracting the liquid strongly. Such a surface has high chemical energy and will, in general, adhere well to an adhesive. Dillingham notes that contamination with a surfactant, *(continued on p. 20)*

(continued from p. 19)

such as soap, will also cause liquids to spread on a surface, but that surfactant-induced wetting can be readily distinguished by the rate at which the liquid spreads.

The angle between a liquid drop and the surface — in other words, the contact angle — puts a value on the attraction of the surface for the liquid. There are several factors that determine what the target contact angle should be for a good adhesive bond on a given surface, including whether adhesion is being evaluated via a lap shear joint or a double cantilever beam (DCB). Generally, low contact angles (from 0 degrees to ~30-40 degrees) indicate a clean, high-energy surface that will establish good adhesion to adhesives and paints; high angles (60-90 degrees or more) indicate a low-energy or contaminated surface that will generally be difficult to bond to. A contact angle in the 40-60 degree range is less clear-cut: this can indicate a surface that is less predictably clean and ready for bonding than that with a lower contact angle, but that isn't as certain to create weak bonds as a surface producing a contact angle measurements above that range.

Thermosets vs. thermoplastics

Thermoset composites (such as epoxies, polyimides, bismaleimides) and thermoplastic composites (such as PAEK, PEEK, PEKK and polyphenylene sulfide) have different surface characteristics and require different surface preparation strategies.

In some cases, Dillingham says, thermoset resins can benefit from surfacing films designed to increase the chemical reactivity of the composite surface. These surfaces typically show water contact angles in the 30-degree range after peel ply removal and are usually bondable. In other cases where the polymer surface is particularly unreactive, water contact angles are around 50-60 degrees, and surface treatments may be necessary for good adhesion.

Another surface treatment technique that has had some success with thermoset composites is abrasion, performed manually or via grit blasting. According to Dillingham, abrasion works because thermoset matrix resins are brittle polymers that fracture under abrasion by actual breaking of the polymer chains to create a chemically active surface. This surface can react with an adhesive to form a strong, stable interface. Depending on the chemical composition of the thermoset polymer, abrasion can reduce the water contact angle by 10 degrees or more, which can be sufficient for good bonding.

However, thermoplastic polymers behave differently from thermoset polymers. Because the polymer chains are not locked into a rigid network by crosslinking, Dillingham says, they tend to flow — in other words, deform *plastically* — under abrasion, rather than fracture. While an abraded thermoplastic composite may be rough, it is still chemically unreactive and unable to establish a good bond with an adhesive, coating or sealant. In addition, water contact angles on these surfaces generally do not change significantly with abrasion. For thermoplastic composites, plasma treatments can be an effective method for increasing surface energies. The figure above shows lap joint strength (vertical axis) versus contact angle (horizontal axis) for PEKK bonded with Solvay 377S film adhesive. According to the data, solvent wiping, hand sanding and grit blasting did not improve joint strength in this case, while plasma treatments increased strength by >30%. Furthermore, the plasma-treated samples failed cohesively in the adhesive, whereas the other samples failed at least partially interfacially between the adhesive and the substrate.

Strong, reliable adhesive bonds suitable for structural purposes are achievable between most structural materials, Dillingham concludes. However, surface treatments that work well for one class of material may not be appropriate for another; surface treatments need to be engineered with the specific chemical characteristics of the substrate and adhesive in mind. Most applications for thermoplastic composites require treatments that increase surface energy to an even higher extent than thermoset composites, so surface treatments should be treated differently. Combining surface treatments with appropriate measurement and control strategies ensures that surface treatments are effective and reliable.

Source | Kitty Hawk

AEROSPACE

eVTOL: Flight tests, groundings, investments, certification

Kitty Hawk (Palo Alto, Calif., U.S.), eVTOL specialist, announced on its online blog post that the company is winding down the *Flyer* (left), its first electric vertical take-off and landing (eVTOL) vehicle flown by non-pilots. The single-seat composite-intensive vehicle, designed for use over bodies of water, was another milestone for Kitty Hawk and its later eVTOL aircraft developments. Over the project's five years, more than 75 people flew the *Flyer,* and in total, Kitty Hawk conducted more than 25,000 successful flights crewed and uncrewed with its *Flyer* fleet. Read the full article online short.compositesworld.com/KittyHawk.

Lilium, the Munich-based aviation company developing an eVTOL aircraft for regional air mobility, welcomed Baillie Gifford (Edinburgh, U.K.) as a new investor. Historically investing in high-impact technology companies, Baillie Gifford has invested $35 million in Lilium, extending the current funding round to more than $275 million, and total investment to date to more than $375 million. Combined, these funds will support the development of the *Lilium Jet*, which uses carbon fiber composites. The money will also fund preparation for serial production in Lilium's recently completed manufacturing facilities. The company seeks to bring emission-free, regional air mobility to the market as early as 2025. Read the full article online short.compositesworld.com/eVTOLlil.

Wisk (Mountain View, Calif., U.S.), the urban air mobility (UAM) company behind the world's first all-electric, self-flying air taxi, *Cora*, reported that it has resumed flight testing in the U.S. and in New Zealand, after initial shelter-in-place restrictions imposed by the coronavirus pandemic temporarily paused operations. According to Wisk, the flight tests will evaluate the performance of the aircraft in a real-world environment, while collecting data that will inform further development, operation, safety features and certification of the aircraft and adding to the more than 1,300 test flights completed prior to the pandemic. The full article is online short.compositesworld.com/Wiskresume.

The European Union Aviation Safety Agency (EASA, Cologne, Germany) has published proposed methods for how to certify hybrid or electric air taxis, also known as vertical take-off and landing aircraft (VTOL). With the new report, EASA invites stakeholders and other interested parties to review the plans and provide comments. EASA says this is the latest and third milestone in its roadmap to enable safe VTOL operations and new air mobility in Europe. Published on May 25, the third block proposes means of compliance for key certification requirements such as the structural design envelope, flight load conditions, crashworthiness, capability after bird impact, design of fly-by-wire systems, safety assessment process, lightning protection and minimum handling qualities rating. The full article and other preliminary information can be read online at short.compositesworld.com/EASAprog.

EHang Holdings Ltd. (Guangzhou, China), an autonomous aerial vehicle (AAV) technology platform company, reported that it has obtained its commercial pilot operation approval from the Civil Aviation Administration of China (CAAC) to use *EHang 216* passenger-grade AAVs for air logistic purposes. EHang says this makes the company the world's first AAV manufacturer approved by a national aviation authority to carry out commercial pilot operation for the category of 150-kilogram-plus heavy-lift air logistics uses. This approval enables commercial operation of the *EHang 216* for cargo transport, and the company plans to gradually expand the aerial vehicle to other sites in China as it accumulates operational data and experience. Find the full article online at short.compositesworld.com/EHangAAV.

BIZ BRIEF

An agreement secured between aerospace company, **Lilium,** (Munich, Germany) and carbon fiber manufacturer **Toray Industries** (Tokyo, Japan) promises high-performance carbon fiber supplied from Toray to Lilium to manufacture composite parts and structures for the *Lilium Jet* eVTOL craft, such as the fuselage, wings and flaps.

The agreement promotes further collaboration, both in the provision of other high-performance materials and the establishment of research and development partnerships.

CAMX 2020 Preview

What:
2020 Composites and Advanced Materials Expo (CAMX)

Who:
American Composites Manufacturers Assn. (ACMA, Arlington, Va., U.S.); Society for the Advancement of Material and Process Engineering (SAMPE, Diamond Bar, Calif., U.S.)

When:
Sept. 21-24, 2020

Where:
Completely virtual event

By Jeff Sloan / Editor-in-Chief

The CAMX 2020 conference and exhibition, originally scheduled for Orlando, Fla., U.S., will be held Sept. 21 – 24, 2020, and has transformed into a completely virtual event. CAMX organizers say that a virtual event allows the entire global composites and advanced materials community to network, share and learn together during these unprecedented times. Attendees and exhibitors will still be able to participate in the same education, demonstrations and networking opportunities that have always made CAMX so important to the composites industry.

CAMX is scheduled to kick off on Monday, Sept. 21 and will continue through the week with live featured panels and sessions, real time Q&A for speakers, a robust exhibit hall and other on-demand content. Prior to that, a series of free webinars will begin on Aug. 12 and run for four weeks leading up to CAMX as a preview of the full event. Tutorials will also be offered during the week of Sept. 7.

In addition, there will be multiple opportunities for attendees, exhibitors and speakers to network through online campfire chats, one-on-one virtual meetings, matchmaking functions and more.

Topics for CAMX 2020's featured sessions include urban air mobility, bonding and joining technologies, composites for modern architecture, future factories, high-performance thermoplastic composites, Industry 4.0, infrastructure durability needs and sustainability.

CAMX is co-produced by the Society for the Advancement of Material and Process Engineering (SAMPE; Diamond Bar, Calif., U.S.) and the American Composites Manufacturers Association (ACMA; Arlington, Va., U.S.). Visit www.thecamx.org for more information and go to compositesworld.com for updates and show coverage.

The industrialization of thermoplastic epoxy

Fast-processing composites that are strong yet tough, thermoformable, reformable, recyclable and even FST-compliant save cost in aircraft and rail equipment.

By Ginger Gardiner / Senior Editor

Fast-molding and reformable epoxy

RocTool molded Cecence K_Chips thermoplastic epoxy material in 2 minutes, 40 seconds with excellent matte and gloss surface finish (right). Having the high-strength and bondability of epoxy, K_Series materials are also thermoplastic, reformable at 180-200°C without chemical reaction or exotherm (left). Source | Cecence

» Cecence (Salisbury, U.K.) was established in 2014 by three founders with decades of composites experience. Director Mike Orange had a long history in carbon fiber-reinforced polymer (CFRP) rigging and masts for yachts. Head of innovation Humphrey Bunyan was previously head of innovation at Future Fibres (Valencia, Spain). "They [Future Fibres] were making all-composite rigging for America's Cup and other racing vessels, as well as CFRP tethers to hold the wheels onto Formula 1 cars," Orange says (see Learn More). "We understood the advantages of light weight but were engaging with other sectors who didn't have our experience and struggled with cost, scaling up manufacturing and meeting fire regulations."

Thus, Cecence (pronounced "see-sense," as in common sense with carbon fiber composites) was founded to focus on fire resistance, industrialized manufacturing and sustainability. This resulted in developments such as a compression molded carbon fiber/bioresin composite seatback for passenger aircraft that weighed only 7.5 kilograms, reduced seat thickness to less than 20 millimeters and increased passenger space *and* comfort, while meeting all fire, smoke and toxicity (FST) requirements.

"In a previous project, Cecence had developed a hot press manufacturing method which shortened cycle time from 2.5 hours to 7 minutes for an economy class seatback using snap-cure phenolics developed with U.K. prepregger FTI (Somerset)," Orange says. For this latest seatback described above, which it developed with Design Q (Redditch, U.K.), Cecence expanded its FST portfolio by using a polyfuryl alcohol (PFA) resin prepreg developed by SHD Composites (Sleaford, U.K.). PFA is a thermoset polymer derived from biomass that performs like a phenolic with excellent surface processing and sustainability (Learn More). "We worked with SHD Composites and pushed their chemistry for a faster cure," Orange says. "That is what we do: take materials, processes and designs and further develop them so that composite products can be manufactured at scale in a way that is commercially viable yet sustainable."

Manufacturing speed and sustainability were key factors when Cecence encountered a thermoplastic epoxy resin system several years ago. "This thermoplastic with epoxy components at the end of its polymer chains was being used by a fabric company that didn't realize its potential in composites," Orange explains.

"We understood immediately the advantages of a low-viscosity thermoplastic that could impregnate fibers really well while enabling a thermoformable epoxy," says Humphrey Bunyan. Cecence developed a prepreg based on this thermoplastic epoxy technology, and then a family of products under the K_Series brand: coilable K_Rod, 0.25- to 1.98-millimeter-thick semi-preg K_Plate and K_Chip molding compound (Fig. 1). "We have been able to press-mold components in under 3 minutes," says Orange, "and have demonstrated an FR variant that meets FST requirements for aircraft interiors." Cecence has also used the material to develop a composite overhead line equipment (COHLE) system for electric rail lines that reduces the number of support pylons/poles by half and overall installation and operation cost by £100,000 ($124,200) per kilometer.

Thermoformable epoxy

"With typical thermoplastics, you have a high-viscosity matrix polymer that is difficult to force into the fibers," Bunyan explains. "Thus, it's hard to get good impregnation of the tows or fabrics. But the K_Series thermoformable epoxy has very low viscosity — 80 centipoise at 100°C. This allows us to prepreg glass, carbon and natural fiber reinforcements with excellent resin-to-fiber distribution and typically 60% fiber content by weight. We can also use fibers with sizing for epoxy, which is typically not compatible with thermoplastics." And yet, this system is a true thermoplastic, enabling reforming of finished parts at 180-200°C with no chemical reaction or exotherm.

"Like epoxy, it adheres well to the fiber, so there is no fiber separation from the matrix, even if you use higher pressures during molding," Orange notes. This refers to an issue he has seen with short fiber-reinforced polyamide (PA) and polypropylene compounds. "We were working with a layer of PA melted onto a fabric via hot pressing to make a flat sheet. The matrix wasn't sticking to the fibers, just surrounding them. So, when it was pressed into a part, you would get fiber pullout."

K_Plate, which processes at 150-220°C, offers a service temperature of 100°C for short exposures and continued use at 90°C. Chopped unidirectional tow K_Chip compounds are pressed at 240°C. "The T_g [glass transition temperature] and onset of heat deformation for K_Series are lower than typical epoxies, but this is also what makes reforming and recycling feasible," says Orange. K_Series processes are also fast. "Cecence worked with RocTool [Le Bourget du Lac, France] at JEC 2016 to demonstrate the fastest-forming thermoplastic they had seen," he says, noting a cycle time of 2 minutes, 40 seconds for an automotive hood. "The dwell time was only 25 seconds before cool-down, using 8-9 bar of pressure above the vacuum membrane. They were also pleased with the finish of both matte and gloss surfaces [see opening image], noting our material provided the best finish of all those trialed."

Also, the epoxy components in the K_Series products makes composite parts easy to paint and bond, without the special primers and preparation required for traditional thermoplastics. "You can secondary bond them using standard adhesives," adds Bunyan. "You also get good interlaminar shear properties and, overall, these make tough, energy-absorbing structures, thanks to the thermoplastic."

> The overall system cost is reduced from £512,000 to £413,000 per kilometer.

CFRP catenary for lower-cost electric railways

This thermoplastic epoxy's dual nature is exemplified in an overhead line equipment (OHLE) system developed by Cecence using a CFRP catenary made with K_Rod. The catenary and the current-carrying contact wire are the two main wires in an electric railway's OHLE (Fig. 2). Electricity is delivered to a train's locomotive through a pantagraph, which extends from the top of the locomotive to press against the contact wire. "The catenary acts like a suspension bridge between pylons (masts, poles), which are spaced every 25 meters along the tracks," Orange explains. The copper contact wire is suspended from the catenary by vertical dropper wires or droppers, much like the roadway is supported from cables in a suspension bridge.

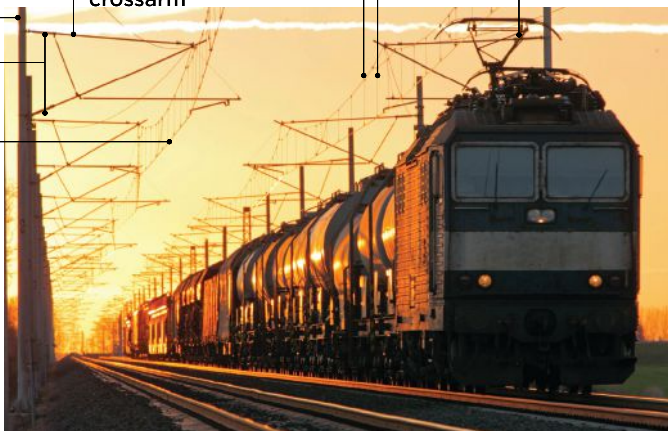
"By using a K_Rod tension cable as the catenary, it can sit only 70 millimeters above the copper contact wire," Orange points out (Fig. 3). "The whole system is more compact with much lower visual impact on the environment." Current OHLE systems use steel catenary cables, which change length with change in temperature. "In the summer, they extend by as much as 400 millimeters »

FIG. 1 Family of K_Series products

From left to right, K_Rod bonded into a steel socket, cut carbon fiber/thermoplastic epoxy tows for K_chip molding compounds, and compression-molded, fabric-reinforced K_plate. Source | Cecence

FIG. 2 Traditional OHLE

Overhead line equipment (OHLE) for electric railways have traditionally used steel catenary wire, which requires pylons every 25 meters and numerous steel cable droppers to support the current-carrying copper contact wire. Source | *CW*

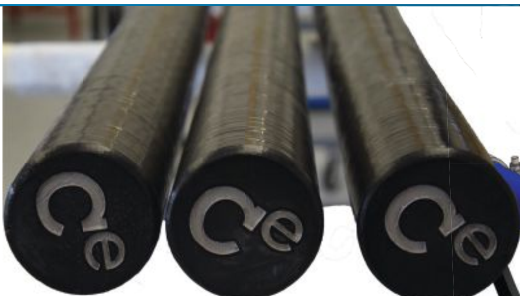


per kilometer," he notes. To counteract this sagging in the lines, concrete counterweights on pulleys are installed as an auto-tensioning system, but add to overall cost.

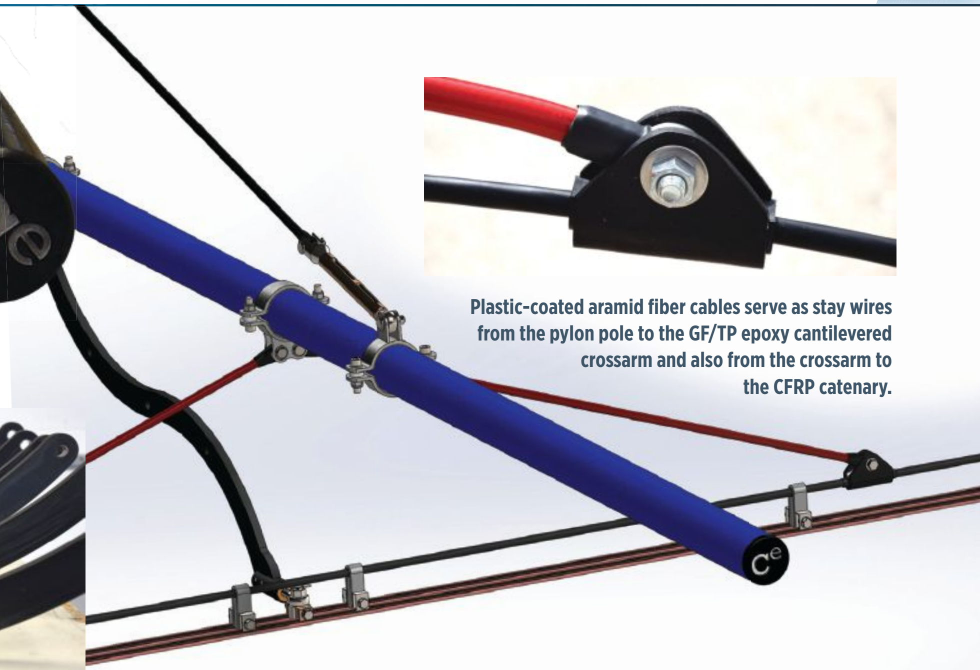
"The weight of the steel line and its sag profile are also why so many poles are needed," Orange notes. "Our CFRP cable changes length by only seven millimeters per kilometer in the summer because the negligible thermal expansion of carbon fiber creates a thermally stable composite. It is also 80% lighter than steel cable, doesn't sag and enables spacing the pylons 50 meters apart, which halves the number of pylons required." This enables further cost savings because for every pylon there is a cantilevered crossarm, supported by a stay wire.

Further, conventional OHLE systems use all-metal components, which requires adding insulators to prevent unwanted conduction of the electric current. "The Cecence COHLE doesn't need all of the insulators because it uses nonconductive glass fiber (GF) composite poles and crossarms with nonconductive composite stay cables," Orange explains. "We also use intermediate droppers made from 3D-printed polylactic acid (PLA). Unlike a metal system, the poles do not need regular painting and the corrosion-resistant composites require less maintenance."

"The thermoplastic epoxy plays a key role in the CFRP catenary," he continues. "Cecence uses it in both the carbon fiber K_Rod core and in the overbraided GF composite jacket. The result is a lightweight, high-strength, insulated cable that is coilable and bonds well when glued into a socket, resolving the normally tricky termination issue for carbon fiber composite cables. Thanks to the amazing load transfer from the core into the socket through the overbraid, we don't

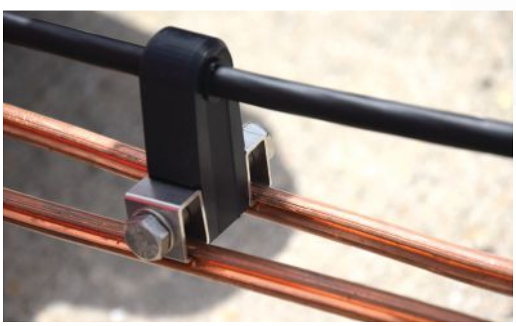


Glass fiber/TP epoxy cantilevered crossarms



Plastic-coated aramid fiber cables serve as stay wires from the pylon pole to the GF/TP epoxy cantilevered crossarm and also from the crossarm to the CFRP catenary.

Curved GF/TP epoxy registration arms provide a vertical support and separation between the cantilevered crossarm and catenary wire.



3D-printed PLA clips serve as intermediate droppers, attaching the CF/TP epoxy catenary 70-mm above the copper contact wire

FIG. 3 Composite OHLE

The COHLE that Cecence has developed is more compact and less costly due to high-performance, thermoplastic epoxy composite components, including glass fiber-reinforced cantilevered crossarms *(top left)* and carbon fiber-reinforced catenary made using the company's K_Rod technology, as well as glass fiber/epoxy pylon poles *(bottom right)*. Cecence components were constructed into a COHLE test track in 2019 and await electrification via contact wires, delayed due to COVID-19.

Source | Cecence

need a huge socket length and this system is easy, so it's practical to install in the field by railway technicians."

Even though the CFRP cable costs three times that of a steel catenary, the overall system cost is reduced from £512,000 to £413,000 per kilometer, Orange says. These costs, calculated with multinational engineering and infrastructure firm Atkins (London, U.K.), include operations/maintenance savings of £400,000 to £3.4 million per kilometer over the system lifetime.

"Cecence delivered the prototype components in May 2019," says Orange, "and our development partners had scheduled to put up the electric lines by February 2020, but that was delayed due to COVID-19. The whole system was displayed at the Advanced Engineering Show in 2019 and won the Composites UK Innovation Award."

Further K_Series applications and development

Beyond the OHLE application, Cecence is pursuing other opportunities to apply its K_Series products. "Cecence has also worked on projects where the K_Rod cables were used as anchors for a stone cliff face in a construction project in Switzerland," Orange says. "Our project partners were to drill 80-meter deep holes into the rock, insert the CFRP cables and then fill with concrete. There were some amazing test results, but the academic partner never connected with industry to develop the project beyond lab scale. We are pursuing other demonstrations, however, this system is corrosion-proof and provides good load transfer. It could also be applied as ground anchors for various construction systems, such as hurricane-proof buildings."

Videos on YouTube and the Cecence website demonstrate the thermoformability of its K_Plate products. "There have also been discussions to explore applications for variable geometry/morphing airfoils with a U.K. aerospace company," says Orange. Cecence demonstrated a cost-effective automotive material using K_Chip made with chopped composite tows as a hybrid CF/GF/thermoplastic epoxy material, maintaining a 2:1 ratio of carbon to glass, confirmed via testing.

The company has also developed a high-temperature K_Series » with a T_g of 250-300°C that processes at 360-400°C. "This was used for an automotive manufacturer that wanted the CFRP parts to survive their 180°C E-Coat painting process," Orange says. "We also have the K-FR material, which can pass aircraft FST vertical burn, heat release and smoke toxicity requirements, and we are looking at how to assist with vibration damping for reducing aircraft cabin noise. We can tune the thermoplastic and add elastomeric material layers to achieve significant noise reduction."

Samantha Bunyan, the third Cecence founder and its head of industry engagement, points out that recyclability is also a key area of development. Cecence is part of the ReDisCoveR Composites consortium, operated by the National Composites Centre (Bristol, U.K.). It was established in April 2019 and is pursuing 24 projects along the four streams: recycling, disassembly, circular materials and reuse. "Within these projects, we are looking at disassembly of components and demonstrating the real recyclability of thermoplastic composites," Bunyan says. "The industry is finally being forced to prove the recyclability it has claimed for many years. Cecence sees the benefits of being able to recycle K_Series thermoplastic epoxy products, but it also has to demonstrate the processes and economic feasibility for this."

"We believe there is much more room for sustainable composites in mass transportation, including aircraft interiors, seating and rail applications," says Orange, adding that Cecence is not just a partner in development but also in manufacturing. "We have made 2,500 composite seatbacks for A320-type aircraft to date and were on track to produce the lightest and thinnest seatbacks in the industry before the outbreak of COVID-19. Scrap from composite seats can be re-used in footrests and armrests. Recyclate can also be used in other auxiliary parts currently use virgin plastics. All of this can help to lower fossil fuel consumption and emissions as well as facilitate electrification and increase sustainability."

In composites, notes Samantha Bunyan, "sustainability is three-fold: materials, processing (fast and low-energy) and supply chain. We are disrupting all of these, working with innovators from all over the world who don't get seen because most people look only at the big companies. The world needs new solutions that work for industry. This is what Cecence does." CW

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Composites fill the gaps in museum dinosaur skeletons

Ontario-based Research Casting International uses composites to build lightweight, durable dinosaur fossil replicas for museums around the world.

By Hannah Mason / Associate Editor

Bone or composite?

Several of the dinosaurs on display at the Cincinnati Museum Center's Dinosaur Hall contain a mix of fossils excavated by the museum's paleontology team and casted bones built and mounted by Research Casting International.

Source | *CW*

» "Dinosaur skeletons are never complete." Glenn Storrs, Ph.D., associate VP for collections and research and Withrow Farny Curator of vertebrate paleontology at the Cincinnati Museum Center (Cincinnati, Ohio, U.S.), adds that if you are able to dig up 50% or more of a dinosaur's bones out in the field, you can build a pretty accurate restoration.

Composite materials — whose light weight, strength and other properties lend themselves to high-profile applications such as structural parts for commercial aircraft, wind turbine blades and pressure vessels for energy storage — can also be used, it turns out, to fill gaps in the fossil record. In some cases, replicas also enable museums to display their specimens to the public, while the original bones are kept behind-the-scenes for research and study.

"Back in the day — and when I say that, I mean as far back as the 1800s — museums originally used plaster of paris," Storrs says. "It was about 40 years ago that resins came into wider use."

For smaller bones and replicas for exhibits within the museum — plants or fish, for example — museum staff use urethane foams to cast and sculpt the replicas themselves, says Dave Might, exhibits coordinator/artist at the Cincinnati Museum Center.

Dinosaur bones and larger museum displays can pose a unique challenge, however. Although bones range in size, they can be massive, and any material replicating them must be light enough to be suspended in the air on a mounted display, and durable enough to last for many years. "Depending on the size of the skeleton, we may need a strong, rigid exterior surface and hollow inside," Storrs says. He adds, "A big, heavy piece of plastic won't work, and, frankly, wouldn't cure properly anyway." Composite materials, whether solid or foam-filled, are often able to fill these material needs.

Dave Might remembers the animals in the Ice Age exhibits, built decades ago for the Cincinnati museum — a mastodon, a giant bison and others, now on display at the Cincinnati/Northern Kentucky International Airport — that museum staff made replicas of on-site using fiberglass composites. They even produced a large, fiber-reinforced lizard once, he recalls.

More recently, though, for the dinosaurs now on display in the

■ **Almost complete**

The skeleton for the Cincinnati Museum Center's *Galeamopus* was an almost complete skeleton, excavated by Glenn Storrs and his team. Research Casting International filled in the missing bones. Source | *CW*

■ **Making the molds**

Technicians from RCI painstakingly build silicone molds of *Brachiosaurus* vertebrae. Source | RCI

museum's Dinosaur Hall, the Cincinnati Museum Center, like many museums around the world, turned to a company called Research Casting International (RCI, Trenton, Ontario, Canada) for its fossil replicas.

Molding and casting composite dinosaur bones

RCI operates a 50,000-square-foot facility in Ontario, Canada, alongside a 10,000-square-foot facility to store the company's roughly 15,000-20,000 molds from about 270 different dinosaur skeletons. The company does everything from aiding museums in fossil digs, to molding and casting bones, to mounting exhibits within the museums.

Matt Fair, general manager of operations at RCI, has been in the business of molding and sculpting dinosaur bones for 30 years, starting at RCI three years after the facility opened in 1987. Sometimes, Fair says, a museum just needs to fill in missing bones that were not retrieved in the field excavation, such as the case with the Cincinnati Museum Center's *Galeamopus* skeleton, collected by Storrs and his team with almost 80% of fossils intact. RCI can use its collection of bone molds from other museum fossils to create a replica based on another skeleton of the same species.

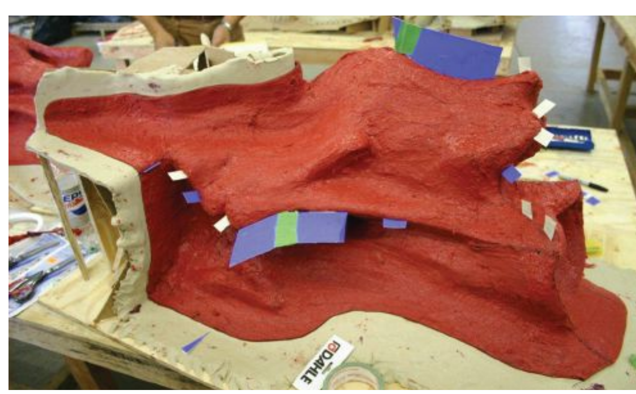
Alternatively, some entire skeletons can be purchased "off-the-shelf" from RCI. "For example, take *Tyrannosaurus rexes*," Fair says. "There are only about 29 or so skeletons in the world, and that's not nearly enough for all of the museums and theme parks that want one. So we produce 100% composite T. rexes."

According to Fair, a typical dinosaur replication project takes about three months to complete if RCI already has a mold in stock for that species, and longer if the project does not.

First, when needed, the company helps in the collection of fossils in the field — in addition to the replication side of its business, RCI also helps with fossil preparation and specimen storage. Then, back at the Ontario facility, the casting department makes a mold directly from the bones. Applying digital laser scanners from Artec 3D (Luxembourg, U.K.) to scan the original bone, RCI is able to create an accurate reconstruction or, depending on the need, to enlarge »

■ **Off-the-shelf T. rex**

This T. rex on display at the Royal Ontario Museum (Toronto, Ontario, Canada) is a 100% fiberglass/polyester replica built by RCI. Source | RCI



■ **Ready for casting**

The finished mold for a *Brachiosaurus* vertebrae replica is made of silicone (red) on top of a fiberglass mother mold. Source | RCI or reduce the part for the exhibit, create mirror-image replicas, or digitally sculpt missing parts. The molds themselves are made of room temperature-vulcanizing (or curing) RTV silicone rubber, and fiberglass for the mother mold. According to Fair, the company's 3D Systems (Rock Hill, S.C., U.S.) 3D printers are also sometimes used to create molds, or to build larger or smaller replicas.

Depending on the size and weight requirements for the part, RCI uses mostly fiberglass mat or roving from suppliers including INEOS (Columbus, Ohio, U.S.), Polynt (Brampton, Ontario, Canada), or Composites Canada (Mississauga, Ontario, Canada), but the company also has used carbon fiber for some of the large parts that need to be the most lightweight, as well as Kevlar and other materials. Resins, often epoxy or others depending on the project, are supplied by companies including West System Inc. (Bay City, Mich., U.S.) and Smooth-On Inc. (Macungie, Pa., U.S.). The replica itself is then produced mainly via hand layup, which for some large parts may also be vacuum-bagged; smaller parts may be made with chopped fiber dispensed via a spray gun. Next, the part is demolded, trimmed and set up on a metal armature alongside the rest of the skeleton. The composite designs, unlike the actual fossils, Fair says, often account for the metal frame passing through the middle of the part, to hide the framing better. Finally, the part is finished with paint to give the appearance of actual bone, and sometimes sculpted to give the appearance of skin.

Composites on display around the world

The first project Fair ever worked on was a fiberglass/polyester *Allosaurus* on display at the American Museum of Natural History in Washington D.C., U.S. Some of the largest projects RCI has done to date include nine all-composite replicas of "Sue," the most complete T. rex skeleton discovered, which can be found in several museums as well as Disney World's Animal Kingdom in Orlando, Fla., U.S.

RCI's dinosaur replicas can be found in museums globally, but the company's work isn't limited to museum dinosaurs, Fair says. Other projects topping his list include dinosaur replicas for the *Jurassic Park* movies, planetarium planets and fiberglass composite panels depicting geographical surfaces from around the world for the American Museum of Natural History. "It's pretty neat to walk into a museum somewhere, or a theme park," notes Fair, "and see your work on display." CW

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ABOUT THE AUTHOR

Hannah Mason joined the *CompositesWorld* team in 2018 after working as an editorial intern for sister magazine MODERN MACHINE SHOP and earning a Masters of Arts in Professional Writing from the University of Cincinnati.


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Ready, set, go!

McLaren in action at the Brazilian Grand Prix. Source | McLaren Racing

The untapped potential in Formula 1 composite manufacture

Formula 1's midfield teams are struggling to bridge the gap to their better-resourced, frontrunning counterparts. Could Industry 4.0 composites manufacturing automation level the playing field?

By Ben Skuse / Contributing Writer

» Formula 1 (F1) is widely regarded as the pinnacle of auto racing, where the best drivers in the world race the most advanced single-seat, open-cockpit cars ever built. But in recent years, this ultimate merging of human and machine has not offered a parallel ultimate racing spectacle. If anything, F1 has become a two-tier competition, with just six cars built by Red Bull, Ferrari and Mercedes — known as The Big Three — battling at the front, their huge performance advantages leaving the remaining seven teams with little hope of winning a race, let alone the World Championship.

This dominance is leaving the chasing pack scratching their heads. Is it The Big Three's management? Recruitment? Drivers? Their design philosophies? Though all of these factors undoubtedly contribute, what sets Mercedes, Ferrari and Red Bull apart is their ability to constantly enhance and upgrade the aerodynamics of their cars — faster than anyone else — throughout the season.

An F1 car's performance is dictated by grip, mass, power/energy and aerodynamics. Of these, aerodynamic improvements offer the smallest performance gains: a 10% improvement in aerodynamics equates to just a 0.9-second gain in lap time on average, whereas the equivalent improvement in grip, for example, offers a 3-second lap time advantage. Yet ever since Lotus introduced the first primitive rear wing in 1968, aerodynamics has consistently been the difference between winning or losing. To put it bluntly, the faster a team can iterate its aerodynamic package, the faster its car will go. And given that 80% of an F1 car by volume is made from composite materials, rapid iteration rests on extremely short composite manufacture lead times.

Concept to car

The processes involved in taking a composite component from concept to fitting it on a car have been optimized throughout the F1 paddock to maximize just one parameter: performance. Serviceability, cost and durability are secondary considerations. “A lot of our designs are driven by a relentless quest for increased aerodynamic performance,” explains a member of the U.K.-based McLaren Racing team. “We have to work very closely with the aerodynamicists at the concept stage to ensure that we can give them as much design freedom as possible whilst satisfying weight budgets, reliability targets and very tight manufacturing lead times.”

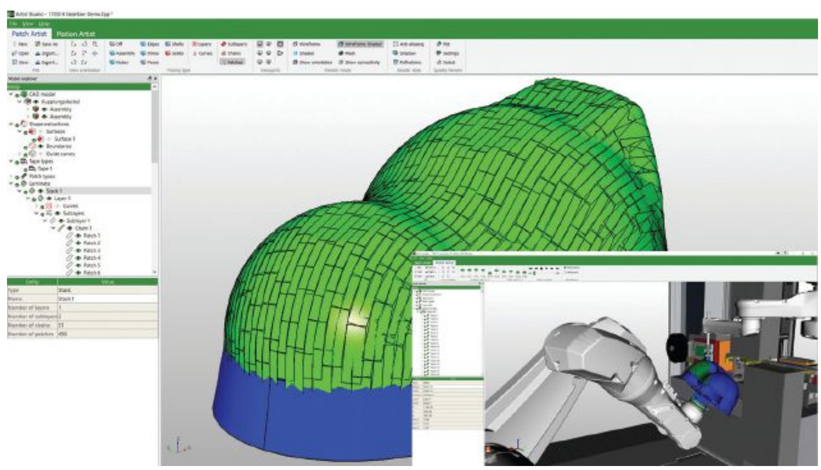
A suite of advanced software assists aerodynamicists in stress analysis (including linear and non-linear finite element analysis), structural optimization and crash analysis, as well as full 3D CAD software to model aerodynamic surfaces and component modeling.

After this, and if time and regulations allow, 60% scale parts are manufactured for wind tunnel testing. High-volume manufacturing techniques, such as resin transfer molding (RTM), are simply not viable in terms of cost and lead times, so the vast majority of F1 composite components are made using the latest technology available in prepreg carbon fiber materials.

McLaren stocks a variety of prepregs — made with different fibers, fabric styles and resins —that it keeps in frozen storage for 12 months or more. “We generally make molds from carbon fiber tooling prepreg cured onto tooling block patterns, rapid prototype materials or machined and polished aluminum,” notes the McLaren team. “The choice depends on the size of component, whether it is open- or close-molded, the accuracy required and how much time we have available.” Part layup is still done by hand, assisted by ply nesting and templating software that guides a laser ply placement system. The parts are then cured in one of several autoclaves within the McLaren Technology Centre in Woking, U.K. Should the 60% scale parts perform as expected, full-size parts are made using identical processes for on-track testing on the real car. »

3D printing solution

Stratasys 3D printers at the McLaren Technology Centre. Source | McLaren Racing



Going virtual

Laminate designed with Patch Artist, robot programming on Motion Artist, complete virtual product development with Artist Studio CAD/CAM suite. Source | Cevotec

The final product.

Final cured part using fiber patch placement system Source | Cevotec

In-house manufacturing

Laminator technicians use tools when working in tight quarters with small aluminum molds. Source | Haas

A 3D printing revolution?

Mark Preston, formerly with Arrows F1, McLaren Racing and Super Aguri F1, and current team principal of the championship-winning Techeetah Formula E racing team, reveals that manufacturing processes have not changed markedly since he first entered F1, though some have become more efficient. "Over the years, the processes have got quicker, and cycles have got a lot shorter, mostly because of improved capacity and better software."

One element that *has* changed is the use of 3D printing. In 2017, McLaren introduced trackside 3D printing to F1 with the uPrint SE Plus 3D Printer from Stratasys (Eden Prairie, Minn., U.S.), which the team used to make small, last-minute modifications to the front or rear wings and areas of bodywork.

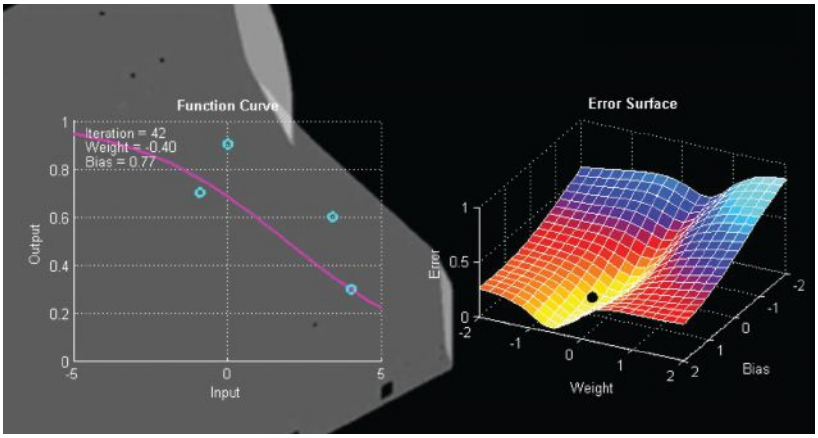
The team has since used 3D printing extensively trackside and in the factory for manufacturing, prototyping and composite tooling. The McLaren Technology Centre houses a suite dedicated to Stratasys 3D printing solutions with filament deposition modeling (FDM) and PolyJet capabilities, including a fleet of 3D printers from Stratasys' Production Series and others from their Design Series.

It is unsurprising that all competitors have since followed suit. "3D printing has greatly reduced the lead times to manufacture components and sped up the development loop — it's much quicker than producing all the associated machined tooling to arrive at the same point," says a McLaren engineer. "In one example, we were able to produce a full-size, FDM-printed rear wing flap mold in record time to form a test rear wing flap. This was done to find the right direction to balance aero load and reduce drag."

It would seem that 3D printing offers the ideal solution for Formula 1, producing parts on demand in a fraction of the time it takes to manufacture a composite equivalent. Unfortunately, materials are limited to laser-sintered nylons and high-performance polymers such as polyetheretherketone (PEEK) and polyetherketoneketone (PEKK), which are not appropriate for components that

have to withstand significant loads. And not all tools for composite components can be rapidly 3D-printed either, because the finished parts can often vary when it comes to final material and dimensional properties.

As a result, the majority of F1 components still follow the same largely manual manufacturing process. "Most of the F1 parts are still handmade," Preston confirms. "There are only a few things that I can think of that are done in an automated way." Yet new Industry 4.0 composite manufacturing automation technologies not only have the potential to speed up F1 part production, but also to level the playing field on track.



Plyable mold design automation

Screenshot from Tech - Computer vision combined with stochastic gradient descent to optimize pull direction. Source | Plyable

Robotic fiber patch placement

Cevotec GmbH (Munich, Germany), for example, has developed a fiber patch placement (FPP) solution for automated production of complex composite parts. The additive technology won the 2019 "Processes of the Future" award at the Industry of the Future Challenge, as well as the JEC Innovation Award in 2018.

FPP technology uses software called ARTIST Studio that goes from the laminated design phase all the way to simulating and programming the automated production process. Within ARTIST Studio, a module called Patch Artist allows engineers to define exactly where composite patches are going to be laid, so that they can tailor patch orientation according to the requirements of each part. Internal algorithms then optimize the patch positions to maximize the mechanical properties of the part. Next, a second module called Motion Artist simulates the manufacturing process and creates the machine program, optimizing the patch sequence and the movements of the robot that will be putting the patches into place.

Patching is done by one of Cevotec's SAMBA *Series* production systems. Fed with composite tape, SAMBA automatically cuts the tape into patches and inspects patch quality. Its pick-and-place robot — up to six-axis using a form-flexible patch gripper to avoid draping effects — then picks up the patch, checks its position and finally positions the patch on a 3D preforming tool.

Currently, the company mainly services the aerospace sector. However, Cevotec business development manager Christian Fleischfresser says that there is a range of potential applications in motorsport, including the manufacture of carbon fiber hoods, roofs, spoilers, front wings, back and rear wings, air intakes and tailored reinforcements.

Fleischfresser outlines why he feels FPP could become a democratizing technology in motorsport, and F1 in particular. "The status quo is the artisanal hand layup of small product volumes involving high skilled labor," he says. "These high skilled workers migrate between teams and go to where the money is, and this is a problem for a lot of the teams." Removing this manual process for many types of parts would go a long way to leveling the playing field in F1. "Let's see if this technology could work in the motorsport industry."

> It would seem that 3D printing offers the ideal solution for Formula 1.

Automated mold pricing, ordering and design

Also aiming to level the playing field is Plyable Ltd. (Oxford, U.K.), but from a different angle. Where Cevotec focuses on the composites manufacturing process, Plyable addresses inefficiencies in part procurement and the supply chain.

Top teams have the staff and resources to manufacture almost all of their composite components in-house. McLaren, for example — which placed fourth in the 2019 F1 Constructor's Championship — outsources very little composites manufacture. "We have around 130 people working on composite parts at any one time, including in the cleanroom, trim and assembly, pattern shop and machine shops," explains a McLaren engineer. "We try to make as much as possible in-house, but at times of high workflow, especially over the autumn and winter periods when we are designing and building the new car as well as running and developing the 'old' car, some work is outsourced."

Further down the field, the picture is very different. Teams cut internal costs by designing components in-house, but outsource as much production to suppliers as possible. The Haas Ferrari F1 team (Kannapolis, N.C., U.S.) — finishing ninth in the 2019 Constructor's Championship — takes this cost-saving measure to the extreme, outsourcing all production. "We do not actually produce composite parts in-house; most of them are outsourced to Fibreworks Composites [Mooresville, N.C., U.S.] and to Dallara Compositi [Stradella, Italy]," says Guenther Steiner, team principal. "I am sure at peak times we have 200 people around the world working on our components."

The result of this disparity in resource is that the 'haves' can » iterate component design as quickly as possible by managing their 24/7 in-house facilities and workforce efficiently to produce parts rapidly, while the 'have nots' wade through various layers of communication with multiple suppliers before their mold is designed, made and delivered, and the part finally produced.

Plyable's solution to this is a mold design automation technology and online mold manufacture marketplace. Essentially, this brings mold design and manufacture under one roof for the first time to allow immediate pricing and ordering, and rapid mold delivery. "The time between the engineer completing the design and the manufactured part landing on the car is the inefficiency Plyable addresses," explains Plyable COO Adam England, a former composite technician for the F1 Renault Sport Racing team. "If you can optimize this, you can squeeze that time between going from the drawing board to the car — and the time required to make the car go faster."

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Customers upload a design to Plyable's secure online platform, select the preferred material and finish for the mold, and then receive an instant price based on mold complexity and material. Plyable then designs the mold and sends it to one of hundreds of manufacturing suppliers around the world, from which it is sent directly to the customer. This solution sounds simple, but in reality, machine learning algorithms automate a number of time-consuming manual mold design tasks. These include draft analysis, split line creation and determining an undercut-free pull direction for complex components.

By maximizing machine utilization and minimizing needless human-to-human interactions, the resulting Plyable process not only removes up to 20% of upfront costs, but also shrinks the mold design and manufacture process down from weeks to an average of three days. "For a race team, we have delivered tooling in less than 24 hours," says England. "Twenty hours after they uploaded it, they had the part."

What Cevotec and Plyable show is that there are more than marginal gains to be found in the way composite components are made if Formula 1 is willing to embrace Industry 4.0 automation technologies. Most importantly though, these technologies do not require huge investments in infrastructure or labor, allowing the less well-funded to iterate designs at the same rate as The Big Three — and potentially restoring Formula 1 to its time-honored status as the ultimate racing spectacle. CW

ABOUT THE AUTHOR

In a previous life, Ben Skuse was an academic, earning a PhD in Applied Mathematics and MSc in Science Communication. He is now a professional freelance science & technology writer, whose work has appeared in *New Scientist*, *Sky & Telescope*, *BBC Sky at Night Magazine*, *Physics World* and many more.

New Products

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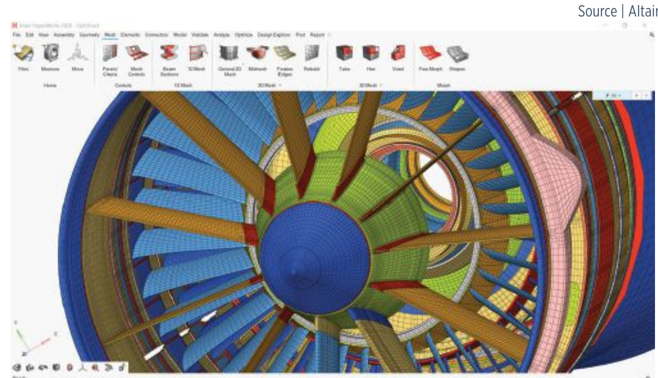


» SIMULATION SOFTWARE

Product software update expands user solutions

Altair Engineering (Troy, Mich., U.S.), a global technology company providing solutions in product development, high-performance computing (HPC) and data analytics, has announced the complete update of its software products, which is the largest collection of its applications for design, simulation and data analytics. In addition to expanding the number of solutions available for designers, engineers, data analysts, IT and HPC professionals and facility managers to drive better decisions and accelerate the innovation pace, the update release broadens the scope of the new user experience, enables access to more physics, data analytics and machine learning and makes the Altair software delivery method more flexible and accessible. Other features like intuitive workflows have also improved, enabling users to streamline product development and allow customers to get to market faster. Altair says the most notable software update capabilities can be found in its applications, including industrial design and structures, manufacturing, electromagnetics and multiphysics, data analytics and more. All products are available through the Altair licensing model. **altair.com**


Source | Toray

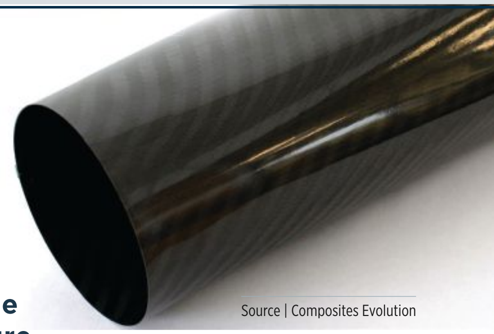
» CARBON FIBER/THERMOPLASTICS

High tensile modulus carbon fiber/thermoplastic pellet

Toray Industries Inc. (Tokyo, Japan) says it will, in the next three years, launch the Torayca T series of high tensile modulus carbon fiber and thermoplastic pellets. Ideal for injection molding, the pellets, the company claims, will enable production of complex, rigid parts that are also lightweight, reducing environmental impact. Toray also believes the materials could enhance cost performance.

Toray market this product toward pressure vessel, aerospace, next-generation automotive and other industrial applications. Toray says the new product series tackles a cost challenge the company had with its Torayca MX series control technology launched in 2018, which employed a nano-level fiber structure control technology to balance a high compression strength and a tensile strength of 5.7 GPa, with a tensile modulus of 377 GPa. The Torayca T series — compared to the MX's carbon fiber diameter of 5 microns — offers 7-micron fibers with uniform internal structures, resulting in a fiber with a tensile modulus of elasticity of 390 GPa, about 70% higher than the standard level of Torayca series offerings for industrial applications.

According to Toray, Torayca thermoplastic pellets maintain longer fibers than conventional high tensile modulus offerings after molding processes, enabling the pellets to attain a tensile modulus of 41 GPa, which is comparable to the 45 GPa of magnesium alloys. Additionally, the pellets have a specific gravity of just 1.4, versus the 1.8 of magnesium alloys, contributing to lighter parts and enhanced performance. At a nominal length of 7 mm, the carbon fiber and thermoplastic pellet is a much shorter pellet compared to the standard length (12-13 mm or 24-25 mm) used for conventional injection molding. **toray.com**


Source | Composites Evolution

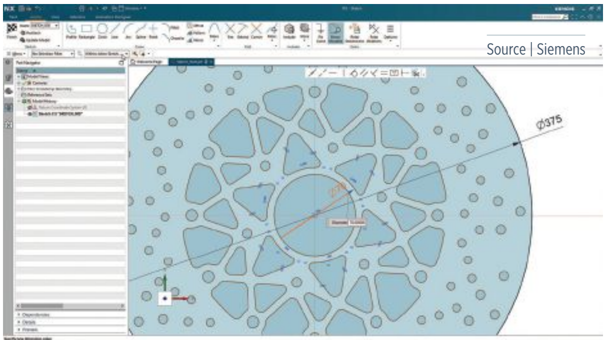
» CURE EPOXY

Epoxy prepreg enables variable temperature cure

Prepreg supplier Composites Evolution (Chesterfield, U.K.) has expanded its Evoprep EPC component epoxy range with the launch of its variable temperature curing prepreg, Evopreg EPC200. Based on a toughened epoxy resin system, the company says it enables curing between 65°C and 120°C when using press molding, vacuum bag/oven, or other out-of-autoclave (OAA) processes.

The company notes that Evopreg EPC200 is primarily aimed at fabricators using low-temperature, OOA molding processes who want to produce components with a high-quality surface finish. Composites Evolution also says the epoxy prepreg has a flexible cure profile, which makes it ideal for rapid processing at high temperatures, reducing production time while simultaneously maintaining the same level of performance.

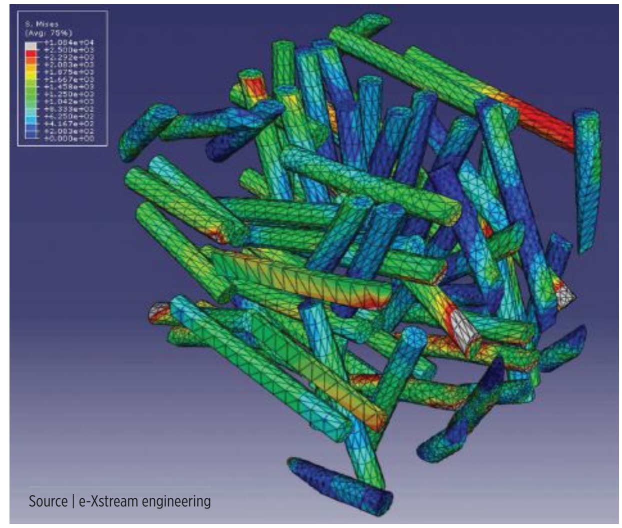
Composites Evolution Evopreg EPC component resins are available in a range of carbon, glass, aramid and ampliTex flax reinforcements. compositesevolution.com


Source | Siemens

» GENERATIVE SOFTWARE

CAD technology employs unconstrained concept sketching

Automation and digitalization specialist **Siemens Digital Industries Software** (Plano, Texas, U.S.) has unveiled its NX Sketch software tool. Offering the flexibility of 2D paper concept design sketching within a 3D CAD environment, the tool eliminates upfront constraints, such as pre-defining parameters, design intent and relationships. NX uses AI technology to help it recognize tangents and adjusts design relationships on the fly, which allow for rapid design iteration of legacy data, enables users to work with tens of thousands of curves within a single sketch and enables more accessibility with imported data. Part of the company's digital twin Xcelerator portfolio, NX Sketch is said to reduce traditional barriers and improves user productivity.
plm.automation.siemens.com



Source | e-Xstream engineering

» DIGITAL TWIN SOFTWARE

Multi-scale material modeling software

Hexagon's Manufacturing Intelligence (Luxembourg, U.K.) division, e-Xstream engineering, presents its enhanced version of the Digimat multi-scale material modeling software. As part of the Hexagon 10x Integrated Computational Materials Engineering (ICME) solution — digitally merging the materials development process into one holistic system — the software extends its advanced composite design capabilities across all scales.

To manage the complexity of composites development, Digimat's integration with molecular dynamics software extends micro-level capabilities to predict a material's properties based on its chemical structure. On the meso-level, the direct engineering workflow for unidirectional composites has also been enhanced, enabling ply properties prediction based on their physical and virtual constituents. Furthermore, Digimat can characterize the effect of defects, such as porosity or gaps from automatic fiber placement (AFP) at the full-scale coupon level using a failure analysis (PFA) model. According to Hexagon's intelligence division, Digimat's simulation advances will help designers account for all the complexities of the composite design process and improve the margins of safety engineers use to optimize material use and lightweight parts.

As part of the enhancement, e-Xstream engineering has also improved the system's design for manufacturing. New capabilities help manufacturers avoid costly tooling rework by embedding a digital twin of the composite manufacturing process from Digimat within thermo-mechanical finite element analyses tools, including Marc, Abaqus and LS Dyna. This open integration enables the designer to account for distortions introduced by processing and modifying their mold design to achieve the required geometry.

Furthermore, Digimat 2020 has made the PFA modeling available within Marc, MSC Nastran, as well as other structural analysis software via user subroutine to enable engineers to make detailed and accurate damage predictions of structures under load, reducing over-engineering. e-xstream.com

Recycled thermoplastic composite rotorcraft access panel takes flight

Designed as part of the TPC-Cycle program, the flight-tested panel demonstrates a lighter, cost-effective, sustainable thermoplastic composite application.

GKN Aerospace (Redditch, U.K.) reported in June 2020 that with the successful flight test of Bell Flight's (Fort Worth, Texas, U.S.) V-280 *Valor* military rotorcraft, several of its thermoplastic composite (TPC) components had taken to the skies. Among these components were two integrally-stiffened, compression-molded, thermoplastic composite access panel doors manufactured from recycled waste material via the TPC-Cycle program led by the ThermoPlastic composites Application Center (TPAC, Enschede, Netherlands) and Saxion University (Enschede).

The new recycled panel door was designed to replace a carbon fiber/epoxy part manufactured via hand layup, with the goals of reducing part weight as well as manufacturing cost and cycle time. The new component was designed and tested by GKN Aerospace and manufactured by the TPAC in collaboration with the ThermoPlastic Composites Research Center (TPRC, Enschede). The access panel doors are comprised of Toray Advanced Composites (Nijverdal, Netherlands) carbon fiber-reinforced polyphenylene sulfide (PPS), reclaimed from consolidated waste generated during the production of the rotorcraft's TPC V-tail empennage components, which are also designed and manufactured by GKN Aerospace.

The Bell V-280 *Valor* in flight. Source | GKN Aerospace

TPAC's proprietary re-manufacturing process involves three main steps: Shredding the waste into centimeter-long flakes, simultaneous heating and low-shear mixing and compression molding the part in an isothermal mold.

According to project partners, the demonstrator component offers weight savings of 9% compared to the original part, due to the thermoplastic material's processability, which enables the integration of stringers for geometric stiffening. The orientation of the stringers was chosen to distribute stresses more uniformly over the product, resulting in material reduction and weight savings. Material optimization, achieved by using reclaimed materials, reduced overall waste.

Significant production cost savings were achieved through the use of reclaimed materials, which eliminated the costs associated with new materials. In addition, the original process required hand layup and use of an autoclave; the out-of-autoclave (OOA), compression molding process involves an isothermal mold, fast demolding and near-net-shape manufacturing to maximize cost efficiency and reduce overall manufacturing cycle time.

"The current project underlines the role of *applied* research involving the total value chain in driving innovations from first idea to an industrially viable and tested product in record time," says Ferrie van Hattum, TPAC's scientific director.

In addition to meeting weight and cost savings goals, the application and process also demonstrate a step toward more sustainable manufacturing. Preliminary results of an ongoing life cycle analysis (LCA) performed by Saxion and TPAC show significant CO_2 reductions when using this material and manufacturing process, mainly due to the part's lower weight, the use of recycled material and the use of an isothermal mold during the out-of-autoclave process. According to project partners, application of reclaimed fiber reduced the CO_2 output from production of new materials and significantly increased the part's buy-to-fly ratio. The shredding, mixing and compression molding stages of the process also are said to reduce energy consumption by eliminating the autoclave from the previous thermoset composite production process. Thermoplastic composites also produce negligible amounts of harmful volatile organic compounds (VOCs) during processing compared to thermoset-based composites.

The TPAC says the manufacturing process used for this application looks like a promising solution for other high-end aerospace products, and its short cycle time may make it viable for end markets that require higher volume throughput. Work is ongoing to evaluate the production process for serial production, as well as in-depth cost and environmental impacts and quality control and inspection implications. A feasibility study is also being executed to see if the applied approach and recycling route can be applied to other aerospace applications such as non-structural fairings, covers and system brackets.

Additional TPC-Cycle project partners include Nido Recyclingtechnologie (Nijverdal, Netherlands); Cato Composites (Rheden, Netherlands); Dutch Thermoplastic Components (Almere, Netherlands), the ThermoPlastic Composites Research Center (TPRC); and Regieorgaan SIA, part of The Netherlands Organisation for Scientific Research (NWO, The Hague, Netherlands). CW

A demonstrator of the recycled carbon fiber/PPS access door panel. Source | TPAC

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Part 2: Beauty, speed, luxury — 2020 *Corvette*

Innovative composite materials trim mass, costs and noise on the high-volume mid-engine sports car.

By Peggy Malnati / Contributing Writer

Beauty, speed, luxury

The new mid-engine 2020 Chevrolet *Corvette Stingray* from General Motors Co. is said to be the fastest, most powerful entry-level *Corvette* in the model's 67-year history. It's also the most composites-intensive, with a host of innovative technologies. Source | General Motors Co.

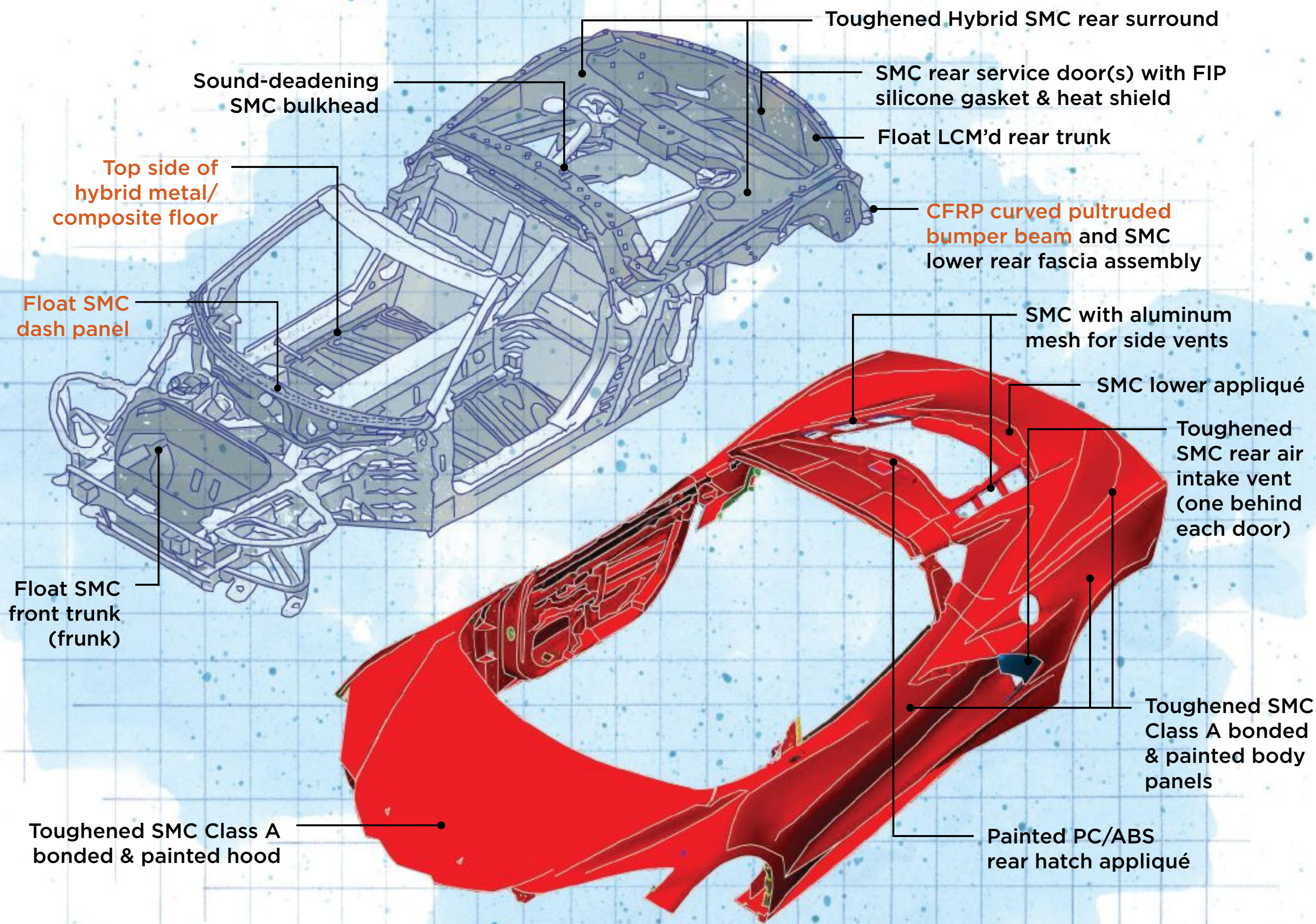
» Earlier this year, the first installment of eighth-generation Chevrolet *Corvette* sports cars (C8s) from General Motors Co. (GM, Detroit, Mich., U.S.) came rolling off GM's Bowling Green, Ky., U.S., assembly line. Described as the "fastest, most powerful entry *Corvette*" in the model's 67-year history, it's also the most composites-intensive *Corvette*, and the first to feature a mid-engine configuration. Not only is the 2020 *Corvette Stingray* beautiful and fast, but it's tricked out with a host of luxury features. However, don't let good looks and fast track times fool you: there's plenty of composites innovation on this car. *CW*'s two-part coverage of composites use in this vehicle began in the July 2020 issue. This is part 2.

Body structure: part B

The new *Corvette* features not one but two trunks that, combined, hold 12.6 cubic-feet/0.36 cubic meters of cargo. Both trunks are produced in 42 wt-% chopped fiberglass/vinyl ester-unsaturated polyester (VE-UP) resin, but use different processes driven by geometry and mechanical requirements. The front trunk (*frunk*) is compression molded 0.95-specific gravity (SG) "float" sheet molding compound (SMC), while the rear trunk is formed via the proprietary PRiME (Prepositioned Reinforcement ensuring Manufacturing Excellence) process, a liquid compression molding (LCM) variant. The float SMC and the PRiME processes were developed by fabricator Molded Fiber Glass Co. (MFG, Ashtabula, Ohio, U.S.). MFG produced all structural SMC and LCM'd parts on the car.

"Although both spaces are characterized by shallow-draft, long-draw walls, the *frunk* is smaller than the rear trunk, and could be compression molded," explains Chris Basela, *Corvette* body structure lead engineer. "The rear trunk needed higher mechanical performance and was a tough geometry to fill with an SMC charge. Because the PRiME process lets us change fiber length, we could use longer pre-positioned reinforcement in our preform. Flowing the resin [not the glass] proved the best approach."

Clever engineering and a new material were key to cooling the C8's engine. Multiple primary cooling paths (rear inlets behind each door, front wheelhouse vents, and outboard cooling inlets) feed highly complex induction ducts that funnel air through the vehicle and across the engine, before ejection through aluminum-mesh



DESIGN RESULTS / **Mid-engine *Corvette***

- The massive rear-surround frame in toughened, glass and carbon fiber-reinforced 1.2-SG, low-VOC SMC withstands engine-bay heat and forms the dimensional foundation for all rear exterior and interior panels.
- To reduce engine noise and manage engine heat, a unique fiberglass/beryllium graphite low-VOC SMC is used for the bulkhead (mid-window frame), eliminating the need for NVH countermeasures.
- The world's first induction ducts created via body-structure cavities (integral to the body frame) cool the naturally aspirated V8 engine. A special toughened float SMC (0.9 SG) in low-VOC resin reduced emissions, eliminated the need for resonators and lowered cost and mass vs. alternatives.

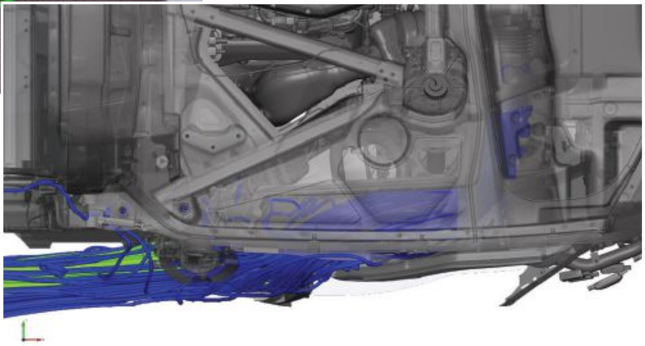
Susan Kraus / Illustration

vents and SMC appliqués on either side of the glass partition that showcases the *Corvette* engine. The appliqués are made with MFG's float (0.95-SG) SMC (chopped glass/UP-VE resin). Low in volatile-organic compounds (VOCs), the material reduces emissions and eliminates the need for resonators on rear-induction ducts, while reducing cost and mass (2.4 kilograms) versus other technologies.

The massive, customer-visible frame — 64 by 69 by 24 inches (163 by 175 by 61 centimeters) — that surrounds the rear-half of the passenger compartment is compression molded in toughened 1.2-SG SMC. This hybrid-reinforced material features carbon fiber at 15% fiber-volume fraction (FVF) and glass fiber at 30% FVF, with a low-VOC UP resin, formulated to withstand engine-bay heat. The frame forms the dimensional foundation for all rear exterior and interior panels, yet its flexible design enables it to be used for multiple model variants. Thanks to significant parts consolidation, secondary attachments were eliminated, increasing interior package space, reducing noise/vibration/harshness (NVH), providing better body structure and sealing performance, improving rear-hatch visibility and reducing mass (15%) and cost versus the outgoing frame. "Given the size of this part, which is almost 6 by 6 feet tall and 2 feet deep, we actually had to make »

Corvette airway

The 2020 *Corvette* is the first car to use body-structure cavities (integral to the body frame) for air-induction ductwork (below), which is fed by multiple primary cooling paths (left). The car's naturally aspirated V8 engine needs a lot of air, so it was important to ensure good, unimpeded airflow to keep the engine cool. Source (both images) | General Motors Co.



the material flow uphill in the mold, so we were all a little worried on that first shot," Basela recalls.

Equally interesting is the bulkhead (mid-window frame), which was custom-formulated by MFG to resolve high heat and noise challenges, since this portion of the cabin sits directly over the V8 engine. Fiberglass reinforcement combined with beryllium graphite filler in low-VOC VE-UP resin deadens sound transmission into the passenger compartment so effectively that it eliminated the need for secondary sound-deadening countermeasures. That, in turn, reduced costs, increased interior package space and passenger comfort, and improved body sealing and NVH. "With a specific gravity of 2.2, this is the first composite part I've ever been asked to add mass to rather than take it out," laughs Basela.

Closures and trim

Exterior body panels are all bonded (inner/outer), painted, toughened 1.2-SG SMC (22-28% FVF fiberglass/UP resin, depending on component) from Continental Structural Plastics (CSP), a Teijin Group company (Auburn Hills, Mich., U.S.). By bolting on composite closures, GM achieves the C8's aggressive styling, aerodynamics and functional cooling integration, with cost-effective lightweighting on multiple model variants using common parts. All body panels are painted inline on a "skuk system" in vehicle position, using Bowling Green's innovative robotic wet-sanding process.

Another innovation involves use of a one-part, thixotropic silicone elastomeric foam gasket applied to the back side of SMC service doors, which are located in the rear trunk (one on coupés, two on convertibles), and permit customer access to the air-filter system. Owing to proximity to the engine bay, the high-performance foam-in-place (FIP) elastomer (Silastic 3-8186 from Dow, Inc., Midland, Mich., U.S.) was specified to survive continuous-use temperatures up to 392°F/200°C while providing a durable seal with excellent compression-set resistance, even after repeated open/close cycles. GM reports that most other die-cut foams and gaskets would either have melted or broken down under continuous exposure to such temperatures. After dispensing, the applied gasket is heat-treated at 167°F/75°C for 10 minutes to expand the foam, eliminating die-cutting cost and waste. The doors themselves are toughened SMC (42% FVF glass in a VE-UP matrix). Heat shields, produced by Gentex Corp. (Carbondale, Pa., U.S.) using heat- and abrasion-resistant aluminized Kevlar aramid fabrics (from DuPont de Nemours Inc., Wilmington, Del., U.S.), give door interiors extra thermal protection.

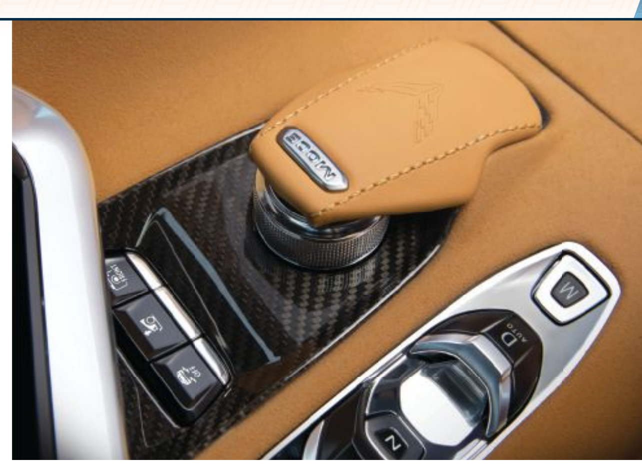
GM also used its second-generation, fully automated precision wheel-balance system on the C8. Developed with The 3M Co. (St. Paul, Minn., U.S.) and ESYS Automation (Auburn Hills, Mich., U.S.), the high-density (5.8-SG) composite wheel weights with tailored magnetic properties replaced traditional stamped metallic weights in painted steel, zinc or lead that have specific mass and must be hand-applied to wheels. The new system uses large spools of extruded tape with adhesive backing that contain 67% by volume post-industrial, corrosion-resistant, fully recyclable steel alloy in a fluoropolymer base. The automated system examines each wheel, then cuts and applies custom-weight tape segments in smaller, more

Rear surround frame

The very large, customer-visible rear surround frame provides the dimensional foundation for all rear exterior and interior panels. Each half of the mold in which the part is formed weighs ~35,000 pounds/15,900 kilograms and was produced by Century Tool, a division of Tooling Tech Group (Fenton, Mich., U.S.). The compression press itself has 2,800 tonnes clamping pressure and a platen that measures 108 by 68 inches (274 by 173 centimeters). Despite its size, cycle time is a nominal 3 minutes. Source | SPE Automotive Div.

Rear service doors

Rear service doors are molded from toughened SMC and feature a high-temperature, foam-in-place silicone gasket that provides a durable seal with excellent compression-set resistance while handling long-term exposure to engine-bay heat. Another composite — heat- and abrasion-resistant aluminized aramid fabric — is used as a heat shield to provide extra thermal protection on door interiors. Source | SPE Automotive Div.



Upgraded to the max

The *Corvette* is not only fast and beautiful but contains a host of creature comforts. For composites aficionados, the premium carbon-trim upgrade adds numerous clear-coated/visible-weave carbon fiber composite accents to exterior and interior surfaces, such as the ride-control plate shown here.

Source | General Motors Co

precise increments to improve ride and reduce tire wear. It also reduces assembly time and cost, simplifies inventory, eliminates scrap and labor and is offered in more colors than metal weights.

Coupé roofs are available in three trim levels: painted, low-density toughened SMC (from CSP); clear, hard-coated polycarbonate (PC); and clear-coated/exposed-weave carbon fiber composite with painted edges (from deBotech Inc., Mooresville, N.C., U.S.). CSP also supplies several Class A, toughened 1.2-SG SMC panels for convertible-model retractable-roof systems.

Other exterior trim panels include painted thermoplastic polyolefin (TPO) front fascia upper and lower, the latter with integrated ducts to direct air to brakes (Z51 package only) and outboard heat exchangers. Outer grille and brake cooling vents are painted acrylonitrile butadiene styrene (ABS).

The upper rear fascia is molded-in-color (MIC) TPO, but the lower rear fascia assembly is Class A painted, 1.2-SG SMC (glass/UP resin), owing to the part's close proximity to hot exhaust tips. SMC's excellent mechanical performance enabled GM to design an unsupported short rear overhang and use larger spacings between attachments without sagging. SMC also spreads loads efficiently over a larger area during low-speed rear crashes than thermoplastics. Brackets and rear parking-assist sensors are bonded to the SMC. This is said to be the first time SMC bumper fascias have been used on high-volume vehicles.

Rear-hatch appliqués feature painted PC/ABS for the upper panel, SMC with aluminum mesh for side vents and an SMC lower appliqué to accommodate thermal loading directly over the engine. These SMC panels are produced by LyondellBasell's Quantum Composites Inc. (Bay City, Mich., U.S.). Door-handle release switches are PC/ABS, while the rear air-intake vent is SMC. The base car sports a blowmolded, painted ABS spoiler and the rear air-exit grille is injection molded painted ABS. A-pillar and header appliqués are painted ABS, as are exterior side-view mirror caps and radiator inlet grilles. Depending on the option package, a toughened SMC front underwing and either a blowmolded TPO or carbon fiber composite front splitter/diffuser — clear-coated/visible-weave carbon/epoxy produced by deBotech using prepreg from Solvay Composite Materials (Alpharetta, Ga., U.S.) — contribute additional aerodynamic stability. A rear diffuser in toughened SMC mates to the SMC lower rear fascia in Class A painted SMC from MFG.

The premium carbon fiber trim package features various clear-coated/visible weave carbon fiber accents inside and out, including mirror caps, front grille insert, front splitter, accessory wing, engine-compartment covers, interior door switch plates, rocker moldings, instrument-panel cluster bezel, door-handle covers, quarter appliqués and ride-control plate. These components are produced by deBotech, SMI Composites LLC (Comer, Ga., U.S.) and Plasan Carbon Composites (Wixom, Mich., U.S.).

Advancing technology

The 2020 *Corvette* has already won many prestigious industry awards, including 2020 MotorTrend Car of the Year, 2020 Automotive News PACE (Premier Automotive supplier Contributions to Excellence) Partnership Award, and several awards from the Society of Plastics Engineers (SPE), including the 2019 Vehicle Engineering Team Award. "Although the new *Stingray's* mid-engine architecture has dominated headlines, no matter where the engine is — in front of or behind the driver — for eight generations, *Corvettes* have always advanced the state of the art in automotive materials technology," adds Tadge Juechter, executive chief engineer-Global Corvette. "Advancing technology is at the heart of what we do." CW

ABOUT THE AUTHOR

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

peggy@compositesworld.com

Post Cure

Highlighting the behind-the-scenes of composites manufacturing

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Molding a moose antler

Research Casting International (RCI, Trenton, Ontario, Canada) molds and casts composite replicas for museum exhibits globally, including dinosaurs (see story on p. 32) and other extinct animals. The pictured mold was used to cast the antler for a *Cervaces scotti*, also known as a stag moose, an extinct species of North American moose. Source | RCI


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