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CompositesWorld

CW COLLECTIONS

Recycled Composites

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Introduction

The desire for sustainability and recyclability of materials continues to increase across end markets, and recycled composite materials are rising to meet that need. *CW's* editors are tracking the latest trends and developments in recycled composites. What follows is a collection of three recent *CW* features that detail the current state of the industry and recent success stories across aerospace, automotive and rail applications.

In Part One, "The state of recycled carbon fiber,"" *CW* senior editor Scott Francis discusses the current state of the industry on recycled carbon fiber technologies and challenges and applications in the automotive and aerospace markets.

In Part Two, "Recycled thermoplastic composites for production," *CW* senior editor Ginger Gardiner outlines a multi-year collaborative project demonstrating the economic advantages and feasibility of serial production using recycled thermoplastic composites.

In Part Three, "Recycled carbon fiber on the rails," *CW* contributing writer Karen Mason explores the cost-weight advantages of recycled composites for structural components in railway vehicles, detailing the design process for a prototype rail bogie that prominently features recycled carbon fiber.

Continue following *CompositesWorld* for the latest updates in this field.

The state of recycled carbon fiber

As the need for carbon fiber rises, can recycling fill the gap?

By Scott Francis / Senior Editor

»The case for recycled carbon fiber is a complicated one. The industry is built on the hope of solving problems — namely, the desire to keep carbon fiber waste out of landfills and to fill a potential gap between carbon fiber supply and demand. It is commonly estimated that around 30% of produced carbon fiber ends up as waste. Meanwhile, as valuable material ends up in landfills, most analysts agree that the annual demand for the material could surpass the current annual production capacity within the next few years. The average estimated global carbon fiber demand is around 65,000-85,000 metric tonnes per year, with a global nameplate capacity (which is more than actual capacity) of around 150,000 metric tonnes, according to estimates presented by Brett Schneider, president, global fibers, Hexcel (Stamford, Conn., U.S.) and Dan Pichler, managing director of CarbConsult GmbH (Hofheim am Taunus, Germany) at the December 2018 Carbon Fiber conference. As reported by *CW* contributor Amanda Jacob in March, some analysts estimate that carbon fiber demand could exceed supply by about 24,000 metric tonnes by 2022. (See Learn More.)

And while commercial suppliers of recycled carbon fiber (rCF) point to reclaimed and repurposed material as a potential solution to this supply and demand gap, the rCF industry has its own challenges. While the technology to recycle carbon fiber composites has existed for several years and is capable of yielding a product with mechanical properties very near that of virgin material, the composites recycling industry is relatively young and is still in the early stages of developing markets for the materials it produces from recyclate. As confidence in the quality of fiber being produced by recyclers increases, questions about cost and availability have come to the forefront. Perhaps the largest challenge for the industry is the concern over supply chain security.

"The technologies are actually there, and they've existed for quite a while, but the supply chain just hasn't been vetted," says Andrew Maxey, CEO of Vartega (Golden, Colo., U.S.). "Without the right pieces coming together you can have the best technology in the world, but you're not going to have material to recycle and you're not going to have any products to put it in."

Commercial suppliers often look to the aerospace industry as a source of production scrap and end-of-life material to be used as recyclate, yet while the amount of waste created by the aerospace industry is large in terms of what is going to the landfill, many OEMs and fabricators have been reluctant to rely on it as a steady supply source for a high-volume product line.

On the other hand, some progress is being made. In December 2018, Boeing announced it will supply carbon fiber recycling specialist ELG Carbon Fibre Ltd. (Coseley, U.K.) with cured and uncured carbon fiber waste to be recycled for use in secondary products for other composites manufacturing applications. The agreement is the first formal material supply relationship between a carbon fiber recycler and a major aircraft OEM and seems to be a good portent for the industry.

> "Anywhere the industry is using discontinuous or chopped carbon fiber, recycled [fiber] should be the first consideration"

It's not just about environmental concerns

The argument for using rCF goes beyond sustainability. Reduced cost is also a benefit. For example, ELG Carbon Fibre's rCF costs around 40% less than industrial grade carbon fiber. Other commercial suppliers claim their material is anywhere from 20% to 40% less expensive than virgin carbon fiber. Plus, for many applications there is a need for discontinuous fiber formats — which suggests an opportunity where rCF might offer a more sustainable and economical alternative to virgin material.

"Anywhere the industry is using discontinuous or chopped carbon fiber, recycled [fiber] should be the first consideration," says Maxey. "We spend all this money to make virgin carbon fiber in a continuous format why do we then take that and go chop it up to put into thermoplastic? If we already have a discontinuous format in those scraps, that's the best material to use, in my mind, for those molding compounds where you're just going to chop it up anyway."

Plus, the quality of rCF being produced has been shown to be on par with virgin fiber. ELG Carbon Fibre, which reclaims carbon fibers using pyrolysis, says its fiber typically retains at least 90% of its tensile strength with no change in modulus. Vartega uses a chemical recycling process and claims that its fiber exhibits the same mechanical properties as virgin carbon fiber. Shocker Composites (Wichita, Kan., U.S.) uses an inline

It's not just about environmental concerns

Recycled carbon fiber nonwoven mat from ELG Carbon Fibre.
Source | Scott Francis

solvolysis process to reclaim the fiber and claims high quality with no apparent damage to fibers.

According to Vamsidhar Patolla, Wichita State University Ph.D. student and founder of Shocker Composites, the challenge is all about getting the cost down to a level comparable to that of other materials such as aluminum. "Processability needs to match the high-volume production scale," he says. Shocker Composites' process offers this advantage because it is an inline process, not a batch process.

Given recent improvements over the past several years in rCF processing and fiber quality, commercial suppliers have begun to shift their focus from the downcycling of rCF into lower-performance products and more toward finding appropriate applications that benefit from the material's properties.

"We'll never displace virgin fiber completely, especially in aerospace where there are high strength and stiffness requirements, but people are coming around to the idea that recycled fiber isn't just recycled fiber with weak potentials," says Benjamin Andrews, field technical services engineer with ELG Carbon Fibre. "It has its own benefits that are superior to virgin fibers in some applications. Drapability and surface finish are both better than that of virgin fiber this isn't just a reusable material; this is a material that has its own benefits."

What's up with automotive?

When it comes to markets, the automotive industry seems like it should hold the most potential for using rCF. The material's ability to combine lightweighting with good surface finish makes it a natural fit for body panels, not to mention various interior components. Commercial suppliers of rCF have long looked to the industry with bated breath, hoping for widespread adoption, but a tipping point has yet to arrive. Process time and cost continue to be stumbling blocks for the industry.

> "It pays to be smart about where you put it in automotive…Picking specific parts on specific models of cars that make sense."

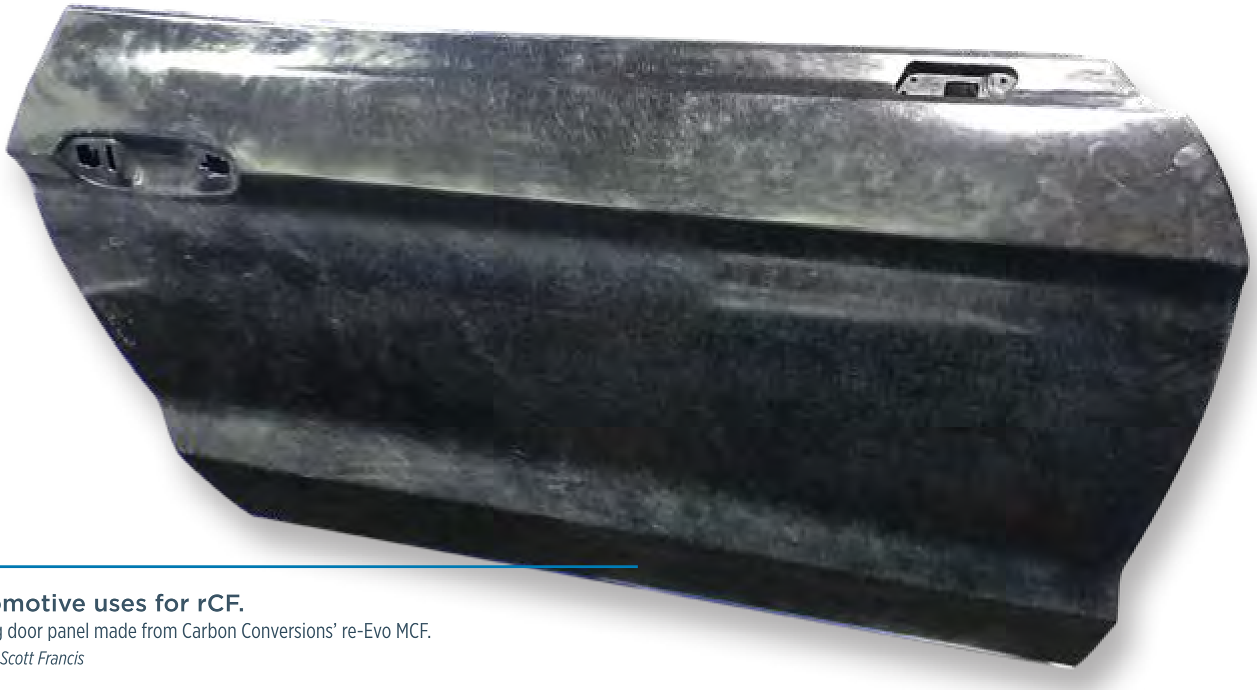
Mark Mauhar, CEO of Carbon Conversions (Lake City, S.C., U.S.), argues that these concerns are a bit of an excuse given the progress that has been made, and he feels that the main barrier to adoption into any market is actually risk aversion.

"Nobody wants to be first to adopt a new material ecosystem," he says. He also stresses that large-scale adoption of rCF by the automotive is not necessarily even desirable, pointing out that usage adoption by a dozen major automotive platforms could quickly use up the supply of rCF. He says the approach should be targeting niche programs, which will, in turn, make the supply chain more robust from a business perspective.

"It pays to be smart about where you put it in automotive," he says. "Picking specific parts on specific models of cars that make sense."

Mauhar is hopeful that automotive will be the first major

Sporting recycled carbon fiber.
This lightweight Griffin sportscar body panel prototype developed by Gordon Murray Design, Formaplex and TVR combines ELG Carbiso-M recycled carbon fiber, woven carbon fiber fabric and resin infusion.
Source | Scott Francis



Automotive uses for rCF.

Prepreg door panel made from Carbon Conversions' re-Evo MCF.
Source | Scott Francis

market space to consume a decent fraction of the available carbon fiber. "In the next 24 months we'll start seeing some movement there," he predicts.

Composites, in general, are working their way into the automotive industry incrementally in the form of parts such as battery boxes, pressure vessels, leaf springs and even lift gate systems. It would make sense for rCF to follow the same trajectory.

One interesting example of such a niche approach is ProDrive Composites (Milton Keynes, U.K.), manufacturer of advanced lightweight composites for applications ranging from automotive and motorsport to aerospace and defense. The company has been collaborating with the University of Sheffield Advanced Manufacturing Research Centre (AMRC, Sheffield, U.K.) and ELG Carbon Fibre on its P2T (Primary To Tertiary) process, a new process that uses a reactive thermoplastic resin for manufacturing recyclable composite components. A plastic monomer is reacted with a catalyst in the presence of recycled fibers to produce a cured laminate, out of the autoclave.

Applications of the P2T process.

Example of a tertiary part produced using ProDrive's P2T process.
Source | Scott Francis

"[We] have demonstrated that recyclable composite panels can be produced at a rate and cost to suit many industries," says John McQuilliam, chief engineer at ProDrive Composites.

The company says P2T allows a composite material to be used three or more times. At the primary part's end-of-life, the fibers and potentially the resin can be recycled, supplying raw material for a thermoplastic secondary part, such as a body panel. When that part reaches its end of life, it can be chopped and remolded into new parts. (See Learn More)

Meanwhile, Vartega is leading an Institute for Advanced Composites Manufacturing Innovation (IACMI, Knoxville, Tenn., U.S.) consortium focused on the automotive industry. The two-year technical collaboration is designed to address the challenges of creating consistent recycled carbon fiber-reinforced thermoplastics for use in vehicle lightweighting applications. Maxey says the project is making progress toward a robust dataset that offers a full characterization of materials, from the fiber interface to the finished part properties.

Of course, when considering the auto industry, the best bet might be on related emerging technologies. Electric vehicles, autonomous vehicles and connectivity aspects in cars bring new parts and applications opportunities where composites will likely play a large role.

Maxey offers his assessment of where the auto industry is heading: “There’s a lot that’s gone on in the past couple of years in the auto industry, where the focus will shift from fuel economy to other priorities depending on what the regulations are and what the administration is saying,” he says. “[We’re] not seeing any major pullback on lightweighting, but maybe the motivation for it evolves. I think what you’ll see in the industry is the focus on lightweighting for mobility applications.”

Can aerospace close the loop?

The aerospace industry generates the most carbon fiber waste, and commercial suppliers often look to the aerospace industry as a source for recyclate. Excess material, typically uncured thermoset composite prepreg, is collected and the resin is removed via heat (pyrolysis) or a chemical solvent (solvolysis) to yield fiber that is milled, chopped or pelletized.

As the industry moves toward increased use of thermoplastic composites (TPCs), that material presents a new set of recycling opportunities. Because thermoplastic polymers can be remelted and reshaped, the aerospace industry has more opportunity to reabsorb some of its own scrap into secondary applications, potentially reusing both fiber and matrix. Thomas de Bruijn, researcher at the Thermoplastic Composites Application Center (TPAC, Enschede, Netherlands) — a thermoplastic composites R&D center working alongside the Thermoplastic Research Center (TPRC, Enschede, the Netherlands) at an applied research level — points to efforts in the industry being made to recycle the material internally.

“From a feasibility point of view, for thermoplastic composites, an in-house approach makes much more sense,” he says.

According to de Bruijn, aircraft OEMs are more likely to recycle internally than turn to a commercial supplier of rCF. The main reason for this is traceability. Matching polymer types to a given application becomes much more difficult when the supply is moved out-of-house.

Johan Meuzelaar, engineering stress specialist at GKN Fokker (Hoogeveen, Netherlands), thinks the answer is to try to find as many applications as you can within your own production environment. “If I look at the type of thermoplastic components we make from virgin material, there’s a lot of parts in them which we could make recycled,” he says. “[We could] certainly use up a significant amount of waste that we’re generating.”

“We already have the facilities,” adds Guillaume Vincent, thermoplastic composites engineer at the TPRC. He explains

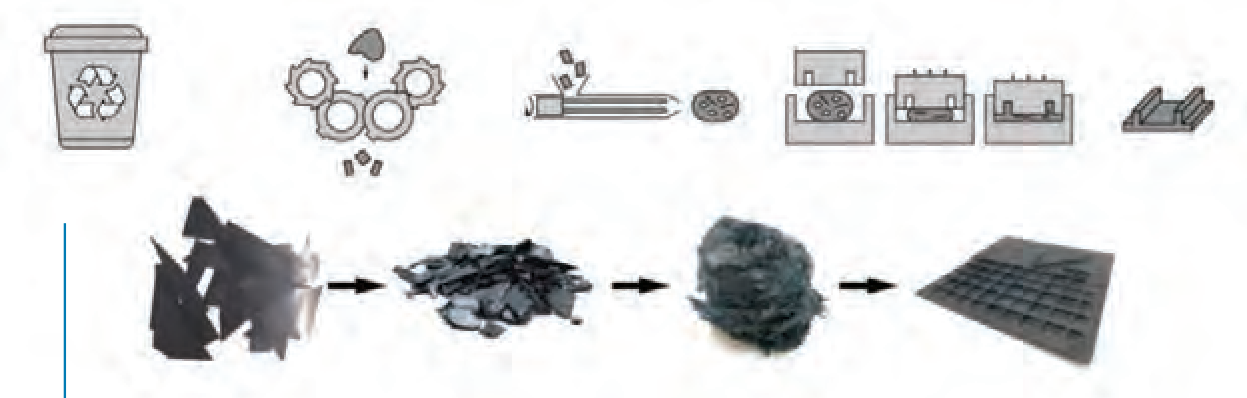
> “If I look at the type of thermoplastic components we make from virgin material, there’s a lot of parts in them which we could make recycled.”

that recycling internally fits within the normal process chains and that the majority of the equipment is already in place, making it the most affordable avenue. “[It] fits into activities we have in a normal production environment.”

De Bruijn, Vincent and Meuzelaar are involved in the TPC-Cycle project, operated by TPAC and the TPRC. The project is aimed at the re-use of production scrap from thermoplastic composites processing for aerospace and high-volume applications. The objective is to retain the high mechanical properties of thermoplastic composites and to reduce the overall environmental impact at an affordable cost. The TPC-Cycle boasts short cycle times and is said to enable the production of complex shapes.

Several industrial partners including GKN Fokker, Toray Advanced Composites (Morgan Hill, Cali., U.S.; Nijverdal, Netherlands), Cato Composite Innovations (Rheden, Netherlands), Dutch Thermoplastic Components (Almere, Netherlands) and Nido RecyclingTechniek (Nijverdal, Netherlands) are involved in the TPC-Cycle project, representing different segments in the value chain from material, manufacturing, design and application.

According to de Bruijn, the TPC-Cycle project is now looking into completing cost analyses and life cycle analyses to prove that the process is economically beneficial.



From collection to finished product
The TPC-Cycle recycling route.
Source | TPRC, TPAC

TPC-Cycle for rotorcraft
Demonstrator access panel for rotorcraft developed using the TPC-Cycle process.
Source | TPRC, TPAC, GKN Fokker

In addition, programs such as the Clean Sky 2 Joint Undertaking (which is funded by the EU's Horizon 2020 programme) are encouraging R&D that focuses on closing the loop for aerospace scrap. OEMs are looking to the potential of using recycled factory waste for interior parts, access panels, small components and even airframe clips and system brackets.

Dr. Bas Veldman, GKN Fokker program manager for the lower half of a thermoplastic Multifunctional Fuselage Demonstrator, is fostering this concept by launching a call for proposals (CfP) topic under the Clean Sky 2 program on clips and brackets. An important element in the development of the demonstrator is to reduce environmental impact through the use of factory waste for such products as frame clips and brackets. The demonstrator also aims to replace fasteners with welding, thereby saving materials, energy and cost while contributing to lightweighting.

> "The reason for looking at a thermoplastic fuselage is cost, and we think this is a cost economic production method, which also incorporates recycling."

According to Meuzelaar, GKN Fokker is investigating how recycling technology might be part of the company's fuselage of tomorrow concept. He says the concept will potentially use a lot of thermoplastic composites, which in turn could generate a lot of waste that could be used for recycled bracketry, fittings and nonstructural parts.

"The reason for looking at a thermoplastic fuselage is cost, and we think this is a cost economic production method, which also incorporates recycling," he says.

Meuzelaar says the goal at a high level is to make more affordable and more sustainable products in aerospace. While strides are being made toward big series production in thermoplastics, this will also yield waste (as is unfortunately the case for composites in general). But he believes that waste can be commercially viable and says that low-shear mixing/compression molding of recycled carbon-TPC offers design freedom not afforded by traditional laminating with continuous fibers. "You get a lot of additional options to make very interesting non-structural parts like panels, small fairings or system brackets which usually in aerospace tend to be overdesigned in terms of materials used, alloys used, [and] the production systems used," he explains.

He believes the opportunity lies mainly in nonstructural parts of medium size and medium complexity, which are still a significant part of the total cost of the larger components.

"We won't make wings out of recycled thermoplastic," says Meuzelaar. "But inside the wing, there are parts we can make that make economic sense."

All of that said, it's a bit far out to predict the impact thermoplastic composites will have on the recycling industry.

"Percentage of waste will decrease probably due to new production methods like tape placement or tailored blanks, which probably produce less waste than the current typical nesting and stamp forming processes that we see," de Bruijn says "But in general I think there will be more thermoplastic waste in the coming years and decades."

And while this interest in recycling in-house is on the rise, there will always be some waste that is not usable and companies unwilling or unable to recycle in-house. In those cases, those materials might be reclaimed by a material supplier. Time will tell what the increased use of thermoplastic composites might mean for the supply chain. (See Learn More.)

Additive manufacturing

Additive manufacturing is another area that holds potential for rCF. For example, Shocker Composites has compounded its recycled carbon fiber into 20-40% reinforced ABS filament and demonstrated its successful use with Cincinnati Inc.'s (Harrison, Ohio, U.S.) Big Area Additive Manufacturing (BAAM) 3D printing process.

In addition, Vartega says it is leveraging its carbon fiber recycling technology and material development expertise to advance polymer feedstocks for powder bed fusion additive manufacturing. The company was recently awarded a National Science Foundation (NSF, Alexandria, Va., U.S.) Small Business Innovation Research (SBIR) grant to conduct research and development (R&D) in the area.

Vartega claims to also be developing a process that will allow thermoplastic powders to be reinforced with carbon fiber while ensuring the materials will produce functional parts in infrared additive systems. This advancement will reportedly enable digital manufacturers to realize the full potential of new powder-based hardware platforms to produce parts that perform similarly to injection molded materials at medium-volume production rates.

"By offering carbon fiber-reinforced polymer powders, manufacturers in sectors like [unmanned aerial vehicles] UAV and medical prosthetics will realize the benefits of fast, complex and customized 3D printing, while ensuring that their material selection will exhibit the structural integrity required for their product," says Alice Havill, chief operating officer at Vartega.

Other applications

Meanwhile, other markets and applications in which recycled carbon fiber can play a role continue to emerge.
The Composite Recycling Technology Center (CRTC, Port Angels, Wash., U.S.) has been exploring use of recycled carbon fiber in a variety of products, from park benches to high-performance sporting goods to composite tubing. The company works with reclaimed uncured prepreg material from Toray Composite Materials America (Tacoma, Wash., U.S.) as well as rCF from ELG Carbon Fibre.

Combining rCF with wood
This construction grade cross-laminated timber (CLT) combines thermally modified lumber with recycled carbon fiber from the Composite Recycling Technology Center.
Source | Composite Recycling Technology Center

Dave Walter, CEO of the CRTC, points to the construction industry as an area of potential growth. The company recently developed a construction grade cross-laminated timber (CLT) under a patent-pending process that combines thermally modified lumber with recycled carbon fiber. The thermal modification process cooks off the sugars and lignin, providing rot and termite resistance, and then carbon fiber strips are integrated for strength.

The CRTC also uses recycled carbon fiber to create panels bonded with wood veneer. These panels showcase the beauty of wood with a strong, light and flexible substrate for various interior and exterior applications.

A mind change for the industry?

Big changes often happen incrementally, and the relatively young recycled carbon fiber industry continues to slowly push forward. While downcycling of rCF continues, the perceptions about the material are beginning to change. Quality of fiber has been proven and processes continue to evolve. Awareness of the necessity to recycle carbon fiber is high and more players are getting involved.

> "We have this enabling technology that sits in the middle of the supply chain, but it's really about connecting that stranded asset in the waste stream to an unmet demand downstream."

"The ELG & Boeing announcement was a really big deal; it helps everyone move the ball forward [and] to accelerate the supply chain connections," says Maxey.

"We're here to enable and connect the dots," he adds, summing up the industry. "We have this enabling technology that sits in the middle of the supply chain, but it's really about connecting that stranded asset in the waste stream to an unmet demand downstream."

The biggest change, according to Mark Mauhar of Carbon Conversions, is that suppliers now want to be part of the solution. "Prior to two years ago we'd get multiple calls a week from suppliers about getting rid of scrap, but no interest in using the material," he says. "Now, people are starting to walk the walk. Only recently, we are finally starting to see potential customers of reclaimed carbon fiber spend significant resources in cutting molding tools, building prototypes and mock-ups, solving process issues — all activities that are well down the line in terms of commercial adoption."

Perhaps what it really boils down to is patience. Detlef Drafz, CEO at ELG Carbon Fibre, points out that it's helpful to examine the recycling history for other legacy materials.

"For over fifty years, ELG has recycled raw materials for the stainless steel industry. With metal, it's accepted that you use the scrap even in vacuum furnaces for turbine blades it's accepted that recycled metal is a raw material, which properly processed can just be used. That wasn't common in the aerospace application 25 years ago; however, we established a supply chain in order to give the guarantees that the material performs. We do the same here," he says.

Exterior applications

Panels from a 2019 installation of recycled carbon fiber panels bonded with wood veneer for the Octave 9 Raisbeck Music Center – Benaroya Hall (Seattle, Wash., U.S.).

Source | Composite Recycling Technology Center

Recycled thermoplastic composites for production

Multi-year R&D at ThermoPlastic composites Applications Center (TPAC), Toray and Clean Sky 2 demonstrate economic advantage of serial production using recycled materials.

By Ginger Gardiner / Senior Editor

***Editor's Note:** This article was originally written before the acquisition of TenCate Advanced Composites by Toray Industries. All mentions of the TenCate company name or products have been changed to Toray throughout.*

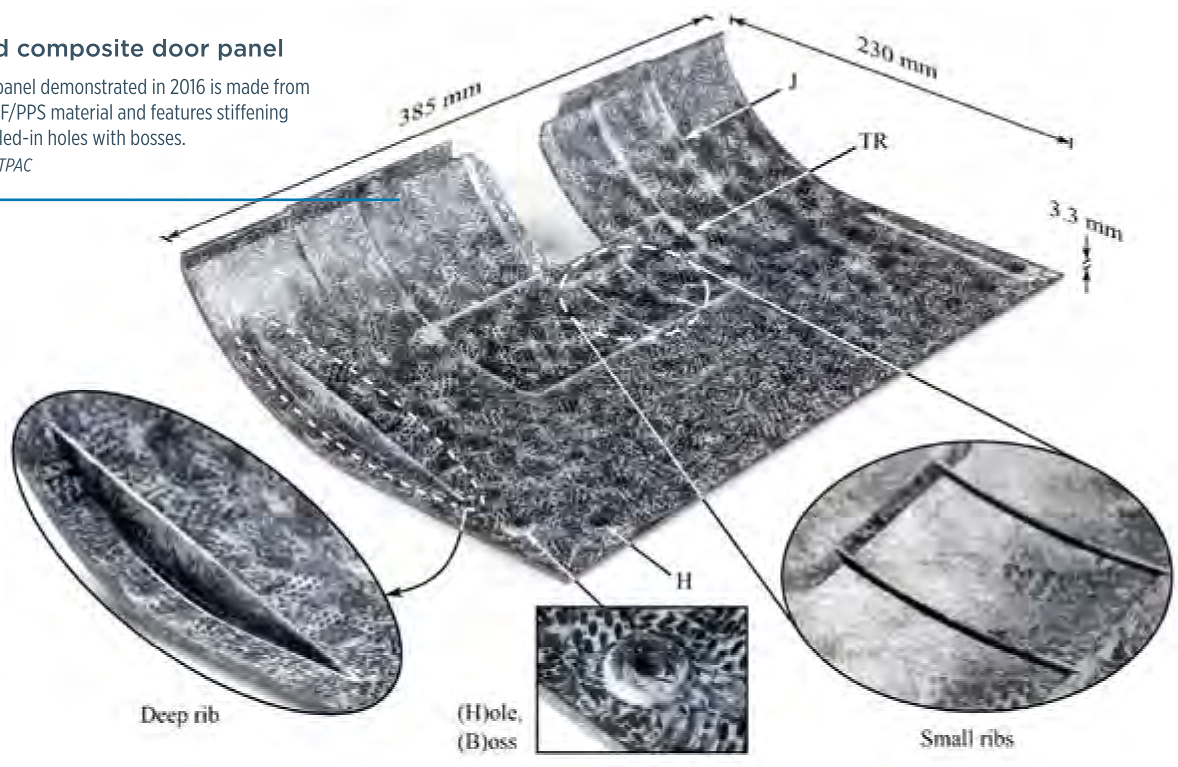
»Recyclability has been a long-promised benefit of using thermoplastic composites (TPCs). But it has yet to be used commercially on a large scale. Materials supplier TenCate Advanced Composites (now Toray Advanced Composites) and the ThermoPlastic composites Research Center (TPRC) partnered with Tier 1 manufacturer GKN Fokker to demonstrate such a process in 2016. The team developed an access door panel using scrap Toray Cetex TC1100 woven carbon fiber/polyphenylene sulfide (CF/PPS) material from GKN Fokker's production of the Gulfstream G650 elevator and rudder. The production waste was chopped and then compression molded using a process and mold designed by TPRC. The access door panel featured molded stiffening ribs, thickness variations and molded-in holes with bosses. (A boss is a protruding feature that guides a fastener into the hole). Use of the reclaimed material enabled a lightweight part with greater molded-in functionality while forming a closed-loop manufacturing process, as the access door panel was then used on the leading edge of the Gulfstream G650 rudder. The project won a JEC Innovation Award in 2016.

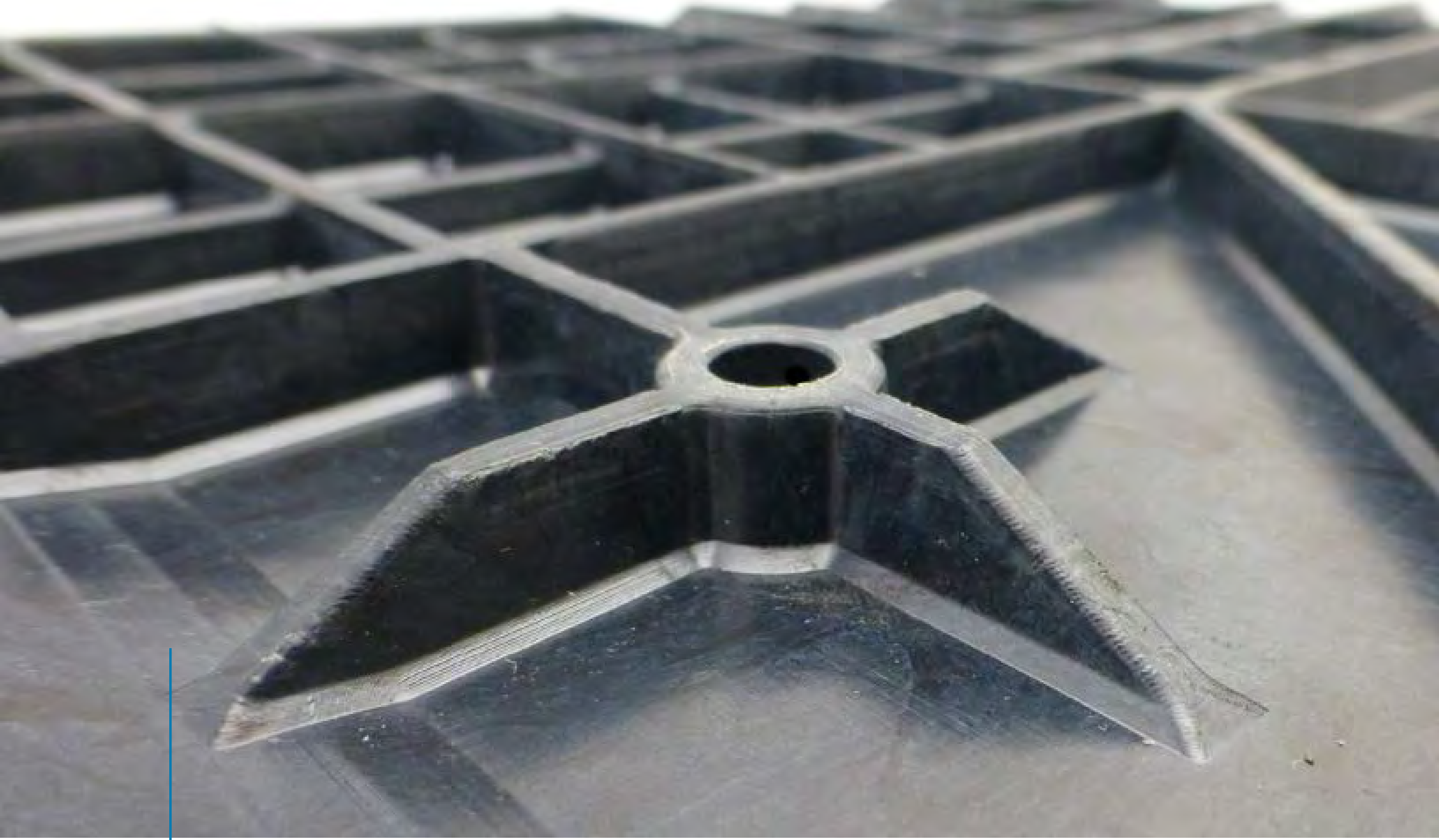
Since that research, a new organization has been established, the ThermoPlastic composites Applications Center (TPAC). "The TPRC was formed ten years ago and works mostly in fundamental TPC research for the aerospace industry," explains Thomas de Bruijn, a researcher in lightweight structures at TPAC. "The TPAC was formed roughly *two* years ago, and has a more applied way of working. It is linked to Saxion University and also with SMEs. We focus on bringing costs down by developing more cost-effective processes. Together, these two groups form TPC NL, a smart industry, digital innovation hub for TPC technology."

The involvement of the TPAC and also Toray's continued R&D have demonstrated that this type of closed-loop manufacturing is not only possible, but economically

Recycled composite door panel

Access door panel demonstrated in 2016 is made from scrap Cetex CF/PPS material and features stiffening ribs and molded-in holes with bosses.
Source | TPRC/TPAC





An access door panel with molded stiffening ribs was built from scrap material from Gulfstream G650 production.
Source | TPRC/TPAC

beneficial. Focus, initially, is on CF/PPS materials, and research is in collaboration with industry partners to help implement this TPC recycling-enhanced parts production.

> "This is not just to get a 'green label.' We are convinced that incorporating recycled material into your part offers very real economic and construction benefits."

However, the actual processes developed differ. Toray has focused on shorter fiber material used as a flow layer to add molded geometric features and functionality to continuous fiber parts. Meanwhile, TPRC and TPAC have sought to maintain greater fiber length, creating a dough-like material that can be compression molded into parts with higher mechanical properties than possible with traditional short-fiber compounds.

Toray — Flow layer enhanced organosheet parts

"Three years ago, we started investing more of our R&D budget into recycling," says Frank ten Napel, Toray product manager for thermoplastics. "This is not just to get a 'green label.' We are convinced that incorporating recycled material into your part offers very real economic and construction benefits. We can apply a level of geometry to a part that we could not achieve otherwise. By applying a flow layer of recycled material, we can mold in stiffening ribs and variable thickness across the part, as well as bosses around holes, which spread loads induced by fasteners. All of this enables using less continuous fiber material, for thinner, lighter and more cost-effective parts versus just using virgin material." He notes these molded features are difficult to achieve with continuous fiber materials, "but by combining both continuous fiber plus localized overmolding you get more freedom of design."

By using scrap from a program back into that same program, it is also possible to approach a 100% buy-to-fly ratio — i.e. zero waste. "This is ideal because there is a synchronized supply and demand," says Ten Napel. "It also solves issues with traceability and purity of the reclaimed/recycled material."

Toray has completed a lot of basic process development and material characterization work, both on its own and in collaboration with TPRC and other partners. It has demonstrated process repeatability and established the fiber length necessary to achieve a balance between mechanical properties and good flow for molding complex geometries.

This bracket-type demonstrator shows both sides of the same part, highlighting a conventional woven organosheet layer and recycled TPC flow layer. The latter features stiffening ribs and bosses for inserts.
Source | TenCate

"We shred the material into smaller chips than the process used by TPRC/TPAC," explains Ten Napel, "this results in a high flow layer comprising high fiber volume, long fiber reinforced molding compound." This can then be processed using conventional, short cycle time (e.g. 5-minute) stampforming in a compression molding press.

TPC-Cycle Project

This four-year project began in September 2015 and includes partners from throughout the thermoplastic composite (TPC) supply chain:

- Toray Advanced Composites (Toray Group) – materials
- GKN Fokker Aerostructures – Tier 1 design and manufacturing of aerospace structures and assemblies
- Dutch Thermoplastic Components (DTC) – SME design and manufacturing of aerospace ribs, stringers, brackets, clips, boxes
- Cato Composites – SME manufacturing and design of parts for aero, auto, defense, sports and consumer markets
- Nido RecyclingTechniek (NRT) – technology for shredding and reducing size of materials/parts to be recycled

> "We have also seen TPCs growing outside of aerospace, in applications like food crates, furniture and industrial components because they offer lower cycle times, light weight and smarter structures."

TPC-Cycle is facilitated by TPAC and Saxion University of Applied Sciences, particularly its lightweight structures research group, and funded by Regieorgaan SIA, part of The Netherlands Organization for Scientific Research (NWO).

Thomas de Bruijn is TPC-Cycle project manager and a researcher in lightweight structures at Saxion/TPAC. He explains there were many drivers for starting the TPC-Cycle project. "We could see an increase in the use of continuous fiber TPCs, especially for stamp-forming, as in clips and brackets. With this increase, the volume of post-industrial waste becomes substantial. So, recycling was necessary, both for the environment and economically, and also to meet regulations. For example, European end of life legislation demands that 95% of the material used in automobiles be recycled." He notes that Airbus too has set recycling and end of life goals, and has communicated these to their suppliers. "The supply chain should not only say they can meet these goals, but also prove that capability with demonstrators," de Bruijn adds.

"We have also seen TPCs growing outside of aerospace, in applications like food crates, furniture and industrial components because they offer lower cycle times, light weight and smarter structures," says de Bruijn.

He continues, "We wanted to prove out a commercially viable recycling process chain but not just grinding, which is downcycling. We wanted high performance. So, we chose a low-shear mixing approach to retain 0.5-1.0-inch fiber length. For stiffness, you only need a couple of mm length. But for strength and impact resistance, you need more than 0.5-inch length." In addition to maintaining fiber length, another key challenge was to get good homogeneity in mixing the materials and in the final recycled product.

"The goal is to collect waste, shred it to 0.5-1.0 inch flakes and transform it into a homogeneous dough, which is extruded and directly transferred to a compression molding press," explains TPRC researcher and Ph.D. student Guillaume Vincent. "The processing of the dough is done via feeding flakes and virgin polymer granules into a low-shear mixer, reducing the fiber weight fraction to 25-40%." He notes the process is very similar to direct compounding of long fiber thermoplastics (D-LFT), which is common in automotive. "However, D-LFT processes require millions of dollars of investment, so they are only used in high-series production. We have modified our approach by using smaller machines

TPC-Cycle: New recycling route for thermoplastic composites

yet we get similar results. Our volumes are low vs. D-LFT processes."

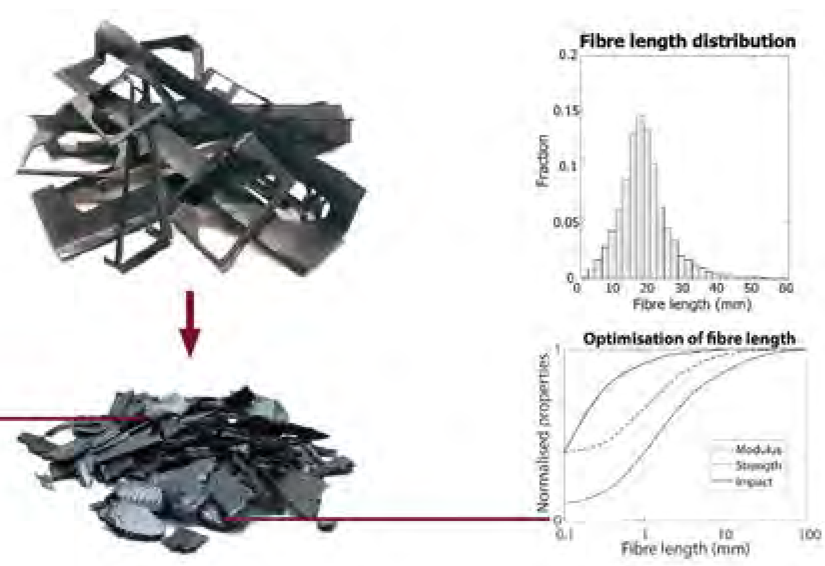
Vincent describes an example of where including the complete recycling value chain pays off: "NRT helped connect us with manufacturers of larger shredding machines, such as Untha." This is a key part of scaling the process for serial parts production.

The first process chain being developed is for CF/PPS. Vincent says TPC-Cycle has built simulation models and analysis methods to characterize fiber length and fiber distribution in the recycled material. "We are also understanding how these material characteristics transfer to the properties of the molded part," he observes. This is, in fact, the focus of his Ph.D. thesis, which will be published by the end of 2019.

This recycled dough is sometimes referred to as bulk molding compound (BMC). Historically, BMC was a dough-like mixture of short glass fiber ((<25mm), thermoset resin paste and fillers that was compression molded into composite parts. With less fiber volume and more flow versus sheet molding compound (SMC), it also offered slightly lower mechanical properties. Toray has sold thermoset and thermoplastic BMC for years, though the latter is a process where chopped unidirectional prepreg tapes are spread into a mold and pressed. "Our product is actually quite different," Vincent asserts. "With conventional thermoplastic BMC there is generally no mixing and requires a long heating and consolidation cycle. We found that with mixing you get a more homogeneous product and less stress concentrations in the part, so higher properties. With conventional thermoplastic BMC, you get thicker flakes that have matrix-rich regions at the ends which produce stress concentrations in the composite laminate."

The low-shear mixing process disentangles the flakes into layers and then separates the layers into bundles and the bundles into loose fibers. Polymer is also mixed in to decrease fiber content in order to get better flow properties, so that the

The TPC-Cycled project has developed a complete process chain for recycling thermoplastic composites, including cost-effective shredding and characterization of fiber length and distribution.
Source | TPRC/TPAC



material is easier to process into shapes.

"The dough is extruded and then robotically placed into an open, isothermal [heated] compression mold," explains de Bruijn. "After mixing, the fibers in the dough are randomly oriented. But during pressing, the flow of material re-orients the fibers. This orientation is less compared to mixtures using shorter fibers that are injection molded, but it's similar from part to part. This is one of our topics of continued study."

Cost

The TPC-Cycle process chain developed to date appears economically beneficial. "We hope to answer how much we can lower part costs by later in 2019," says de Bruijn. "But this is complex because you need a market and have to sell the recycled material." He notes there are many economic factors. For example, most manufacturers today are simply throwing production waste away. Local cost to dispose in landfill is €80 per ton ($90). "But this material being thrown away has value," says de Bruijn. "Also, you must account for the costs to collect the waste, shred it, mix and then compression mold into new parts. However, this is also a near net-shape process with short cycle times due to the isothermal mold." In other words, there should be a drastic reduction or elimination of secondary finishing and machining. De Bruin says TPC-Cycle is now looking into completing cost analysis and life cycle analysis.

Clean Sky RESET

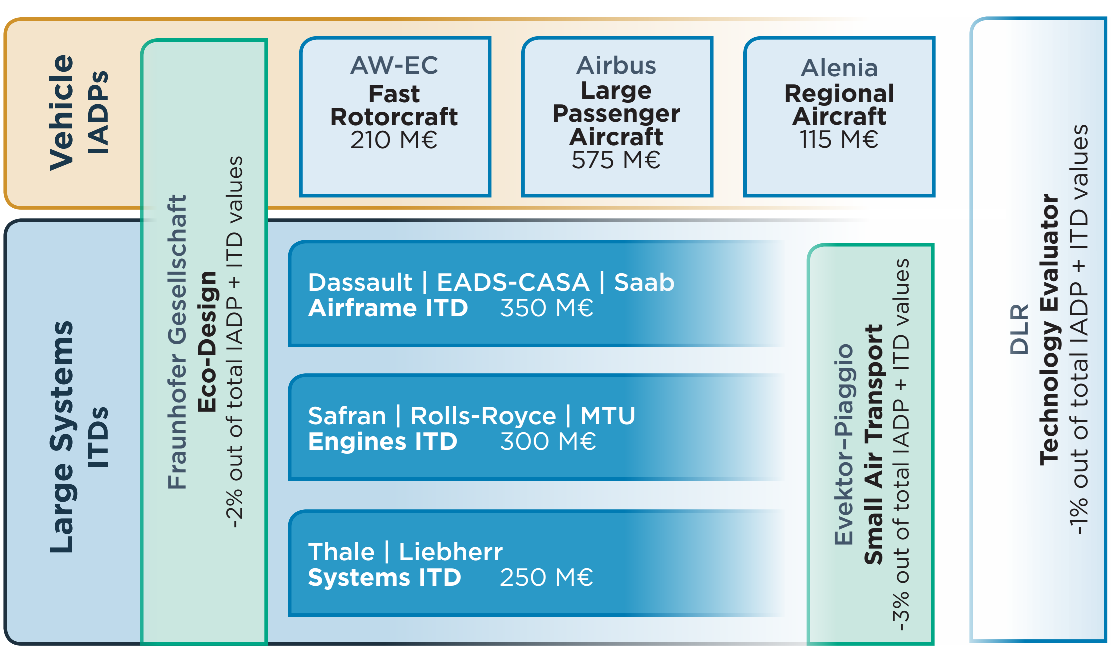
A third project which reiterates the importance of the work completed by Toray and also in the TPC-Cycle project is the RESET project, which ran from January 2016 until December 2017 and was coordinated by the Leitat Technological Institute in Barcelona, Spain. It appears that RESET was begun under Clean Sky (2008-2016) and completed during Clean Sky 2 (2017-2021).

The Clean Sky and Clean Sky 2 programs are organized into a top tier of Innovative Aircraft Demonstration Programs (see Vehicle IADPs in the image below) and a lower tier of Innovative Technology Demonstrators (see Large System ITDs in the image below). RESET was completed as part of the Airframe ITD, specifically Work Package (WP) A-3.4 Eco-Design for Airframe.

According to Clean Sky project officer, Elena Pedone, the RESET team at Leitat developed a process to recycle previously used aircraft composite material and use that to manufacture new parts. They compared these recycled parts to those made commercially and found them to have similar mechanical characteristics. "The technology developed in this project could be realistically commercialized in the aeronautic sector in the next few years and possibly spill over to other economic sectors," says Pedone.

During the RESET project, work was completed to investigate effects from PEEK and PPS thermoplastic

Clean Sky 2 Joint Technical Proposal



matrix materials and the chemical nature of carbon fiber reinforcement. The reinforcement shape was studied, including fiber length and woven versus nonwoven. The effect of fiber content (polymer to fiber ratio) was also studied.

In a second work package, the main objective was the conditioning and characterization of recycled CF/PPS based on extrusion and the resulting molded composites. Two parts — a thermoplastic bracket and a thermoplastic cleat — were created by injection molding and another two by thermoforming, explains Leitat's scientific coordinator of the project Claudia Aguilar. These parts were then tested. "The mechanical properties of the material were found to be comparable with the commercial counterpart," says Aguilar.

The RESET project claims to have demonstrated a recycling process that can take TPC waste material from aircraft production and use it as raw material to produce new parts for aircraft. "Up to 70% of recycled material was used to produce a new family of composite materials," says Aguilar. She adds that "the recycling process of RESET allows European aviation to limit the environmental footprint and to reduce production costs of new aircraft parts. Hence, the project makes the aviation industry more competitive and greener."

TPC future starts with design

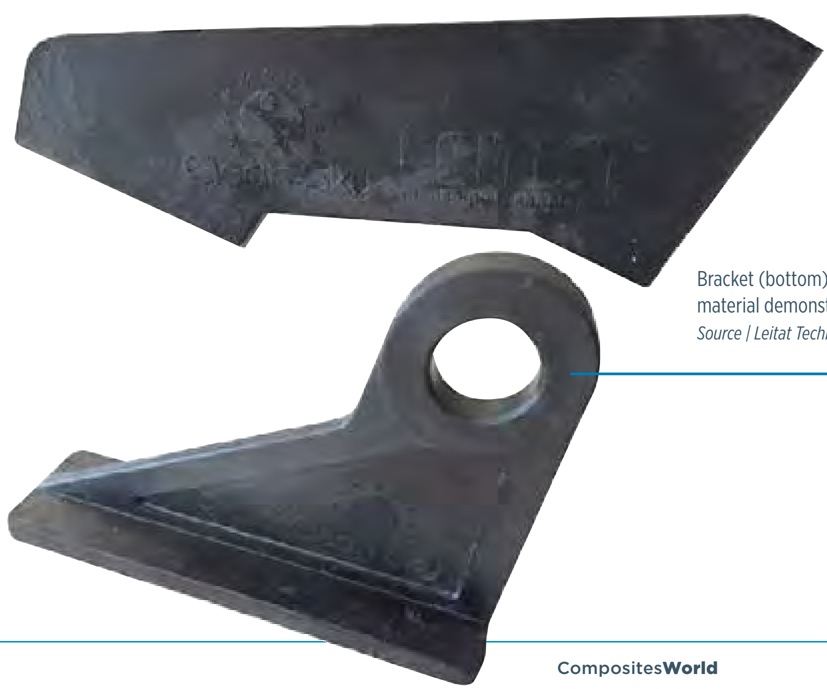
The assertion by Toray and TPRC/TPAC is that these recycling processes that have now been demonstrated are not just green, but economically attractive. So, what kind of investment is required? "It depends on the production volume," says Ten Napel at Toray. "The shredding machines needed are not large or expensive and the process has been developed to where it is fairly straightforward." Does matrix type affect recyclability? "No," says Ten Napel, "but in terms of economic viability, carbon fiber and PPS, PEEK or PEKK are more viable than glass fiber and polypropylene because of their higher value versus the latter."

"I think if this is going be taken up by the industry, it should start with design," he continues. "The biggest hurdle right now is the mindset of engineers. To actually go out and design with recycled material (or design these partially into a new product) is pretty new to them."

> "If we as an industry can get used to reusing our own scrap and waste, then we can take the next step and begin looking at how to address end of life parts."

Ten Napel concedes that Toray neither designs nor manufactures parts commercially, "but we are trying to inspire designers to think this way in developing their new parts and structures." He cites aircraft interiors and access panels and access doors as low-hanging fruit for re-using recycled material. "If we as an industry can get used to reusing our own scrap and waste, then we can take the next step and begin looking at how to address end of life parts."

The mantra on recycling thermoplastic composites—simply grinding and remolding— can definitely be adopted, says Ten Napel, but it often does not make a lot of sense economically. "We have demonstrated a better process and one that can actually create more cost-effective parts and overall programs. We have chosen to disseminate this knowledge, along with the TPRC and TPAC, in order to inspire the industry as to what is fully possible with thermoplastic composites." If thermoplastic composites are to be adopted on a grand scale, recycling as an inherent part of production is no longer an option, it is a necessity.



Bracket (bottom) and cleat (top) made from recycled CF/PPS material demonstrated by the Clean Sky RESET project.
Source | Leitat Technological Institute

Recycled carbon on the rails

Aiming to increase the cost-weight viability of carbon fiber-reinforced composite structural components in railway vehicles, a prototype rail bogie prominently features recycled carbon fiber.

By Karen Mason / Contributing Writer

»A large market for composite structural components may be opening up within a decade, and recycled carbon fiber may be the key. At least, this seems to be the promise proffered by the recent completion of a prototype rail bogie by a United Kingdom industrial-academic consortium. Bogies are the four- or six-wheel trucks that support rail vehicles and provide traction and braking. Usually each rail vehicle has two bogies, one near either end. Funded by the U.K.'s RSSB (Rail Safety Standards Board), the composite bogie prototype represents the culmination of a three-year effort,

The CAFIBO rail bogie is constructed from recycled and surplus carbon fiber and was developed by ELG Carbon Fibre and partners.
SOURCE / ELG Carbon Fibre Ltd.

which has included conceptual and design work, materials testing and qualification, manufacturing engineering and fabrication of the bogie and assembly with standard fittings. The bogie, which is made primarily with recycled carbon fiber composites but is supplemented by virgin carbon fiber composite in places requiring additional strength or stiffness, was the subject of two presentations at the "Unlocking Innovation Scheme — Composites in Rail" event in June, and it is scheduled to undergo full-scale testing this month.

Initiated by ELG Carbon Fibre Ltd. (Coseley, Dudley, U.K.), the consortium now consists of ELG, which supplies the recycled carbon fiber and performed much of the materials testing; Magma Structures (Portsmouth, U.K.), designer and fabricator of the rail bogie; the University of Birmingham (Birmingham, U.K.) Sensors and Composites Group, which worked with Magma to develop an embedded health monitoring system for the bogie; and the University of Huddersfield (Huddersfield, U.K.), on whose dynamic test rig the prototype is to undergo initial full-scale testing. Alstom U.K. (London) helped to assemble the consortium and has provided additional support through consulting and existing bogie design information.

In the past, this market's pursuit of composite structural components has stalled due at least in part to the high cost of carbon fiber. The lower cost of recycled carbon fiber has tipped the scales enough to prompt the consortium's funding and current work, and perhaps enough for the eventual opening of this market to production bogies. With the potential for some 36,000 bogie frames to be built in the next 10 years for passenger rail vehicles in the U.K. alone, pursuing this market is certainly a worthwhile endeavor.

A promising application

The RSSB's interest in the project stems from the U.K. government's expenditure of millions of pounds each year in track repairs and maintenance. Railway service providers offset this cost to a degree through track access charges, which are computed based on railcar weight and stiffness (both of which affect track wear and tear), but maintenance costs still add up. This means that both the track provider and the service providers are financially motivated to reduce railcar weight while optimizing structural strength and flexibility. Rail operators employing composite bogies will also be able to optimize operating costs by balancing the energy savings gained from the lighter weight bogie with the opportunity to increase payload weight and thus increase delivery volume per railcar.

One kilogram of carbon fiber-reinforced composite typically replaces 3 kilograms of steel in a structural application, so considering that the typical steel rail bogie with fittings weighs about 1,500 kilograms, lightweighting can be expected to reduce railcar travel costs substantially. In fact, using the annual miles traveled by trains in the U.K. and inflation-adjusted RSSB values for the cost of electricity and maintenance, the consortium estimates potential annual savings ranging from £10.16 per kilogram of weight saved in inner suburban rail transit, to £105.80 per kilogram of weight saved for high-speed rail transit.

The consortium selected the Alstom Class 180 bogie frame as the target application, reports Frazer Barnes, managing director of ELG Carbon Fibre, because it is representative of many bogie frame designs, has well understood performance and has a ready supply of the fittings that attach to the frame. These advantages, however, also placed restrictions on the prototype's design. Specifically, the geometry of fitting attachment points on the composite bogie had to conform to those on its steel counterpart in order to properly incorporate existing fittings and equipment. The prototype's design therefore is not fully optimized to take advantage of composite properties, but this leaves a good opportunity for greater benefits in future designs.

> "Many composite designs aim to optimize stiffness more than strength," Roberts notes. "In the bogie design, we have introduced more flexibility with plenty of strength."

A lighter bogie directly contributes to the anticipated cost-in-use savings generated by a composite version, and so will the greater flexibility afforded by composite materials. As a train travels around curves, it places dynamic forces on the rail, explains Damon Roberts, Magma Structures engineering director, and the bogie needs flexibility in the lateral plane as it negotiates these turns. Optimizing the bogie's rotational (yaw) stiffness could contribute to a reduction in lateral loads on the track rails of up to 40%. "Many composite designs aim to optimize stiffness more than strength," Roberts notes. "In the bogie design, we have introduced more flexibility with plenty of strength."

Additionally, the lighter weight bogie should experience reduced suspension maintenance costs. In fact, Roberts reports, at the conceptual stage the design team considered integrating suspension and steering functionality into the bogie, which would result in a more flexible primary suspension that would further reduce lateral forces on the rail tracks. This plan proved too involved to incorporate in the prototype, but is under consideration for future efforts.

Building a case for recycled carbon fiber

With recycled carbon fiber reducing the cost premium of a composite bogie, one of the early tasks for the consortium was to characterize recycled carbon fiber-reinforced composites to the satisfaction of rail stakeholders. This characterization was especially important given the rail industry's perception that composites are a basic material for non-structural, interior applications. "This is a very, very conservative industry," Barnes says, "and rightly so. They are extremely safety conscious, given the impact that an accident or structural failure might have."

> "This is a very, very conservative industry...and rightly so. They are extremely safety conscious, given the impact that an accident or structural failure might have."

In an effort to convince this industry that recycled carbon fiber-reinforced composites are suitable for primary structures, the consortium reported numerous physical and mechanical property comparisons. ELG Carbon Fibre has demonstrated that interfacial shear strength, critical to the performance and durability of a composite material, is comparable between recycled and virgin carbon fiber reinforcement in epoxy. The recycled carbon fiber/epoxy selected for the rail bogie demonstrates comparable tensile strength to bogie frame steel. (The consortium chose epoxy resin because of its adaptability, durability and well-understood mechanical properties.)

Specifically, the consortium needed to demonstrate that the recycled carbon fiber would meet the fatigue and fire performance requirements of rail applications. The consortium selected ELG Carbon Fibre's Carbiso M, a nonwoven mat made with standard modulus fiber (strength of 4 to 5 GPa) in an epoxy matrix. They demonstrated that the fatigue performance of the recycled carbon fiber/epoxy is similar to that of conventional woven carbon fiber laminates — and better than that of structural steel, Barnes emphasizes. Finite element analysis (FEA) performed by Applied FEA Ltd. (Southampton, U.K.) verified fatigue service loads as well as exceptional static loads.

For acceptable fire performance, the consortium selected a fire-retardant epoxy that offers properties similar to a conventional epoxy. Determining how to test the composite for fire performance presented another hurdle for the team to overcome. "The standards are there, but how do you test for those standards?" Barnes asks. "For example, does the standard apply to the surface of composite laminate or the full depth of material? We decided to have all the material pass the fire test standard, taking a conservative approach." The composite material was required to achieve the HL2 rating under the European Union's EN 45545-2 railway standard for fire safety, which includes specifications for spread of flame, heat release, smoke density and smoke toxicity. It achieved the more stringent HL3 rating.

Design particulars

The Carbiso M recycled carbon fiber nonwoven is the key reinforcement used in the "skin" of the rail bogie, prepregged with the selected epoxy by Gurit (Newport, Isle of Wight, U.K.).

Full-scale tests

In late 2019, full-scale tests were scheduled to take place at the University of Huddersfield on the Huddersfield Adhesion and Rolling Contact Laboratory Dynamics (HAROLD) test rig.
Source | University of Huddersfield

Reduce, reuse, recycle
The primary reinforcement in the prototype rail bogie is ELG Carbon Fibre's Carbiso M recycled carbon fiber nonwoven. Extensive material testing showed this reinforcement, combined with a fire-retardant epoxy resin, to provide interfacial shear strength, fatigue performance, fire performance and other properties similar to those of a composite using virgin carbon fiber nonwoven. Unidirectional virgin carbon fiber/epoxy supplementing the composite in areas where additional strength and stiffness are required. *Source | ELG Carbon Fibre*

Virgin carbon fiber composite makes up XX percent of the total composite material in the bogie. The design analysis that led to this combination took into account the complex interaction on each leg of strength, stiffness and safety factor calculations in the three principal planes (x, y, z) and torsionally.

With Magma Structure's experience in building high-pressure offshore composite pipes with robotic material deposition, the company was able to employ some robotic deposition to lay up the prepreg plies, followed by autoclave cure. Roberts reports that the company intends to increase the level of robotic deposition when the bogie development process reaches a large batch production stage. "When it first came up to do this, one of the main aims was to do it with a cost-effective technique," he recalls.

The consortium also benefited from Magma Structure's experience with embedded fiber optic strain monitoring and managing fixtures on composite structures like the large composite masts for which they are known. Magma has built some of the largest and most highly loaded carbon fiber composite structures in the world, including the masts"We rely on monitoring technology very heavily on our composite rigs," Roberts says. "We see the rigging's loads every day; they come to me on my desk." The company worked closed with the University of Birmingham to incorporate the bogie's fiber-optic strain monitoring system.

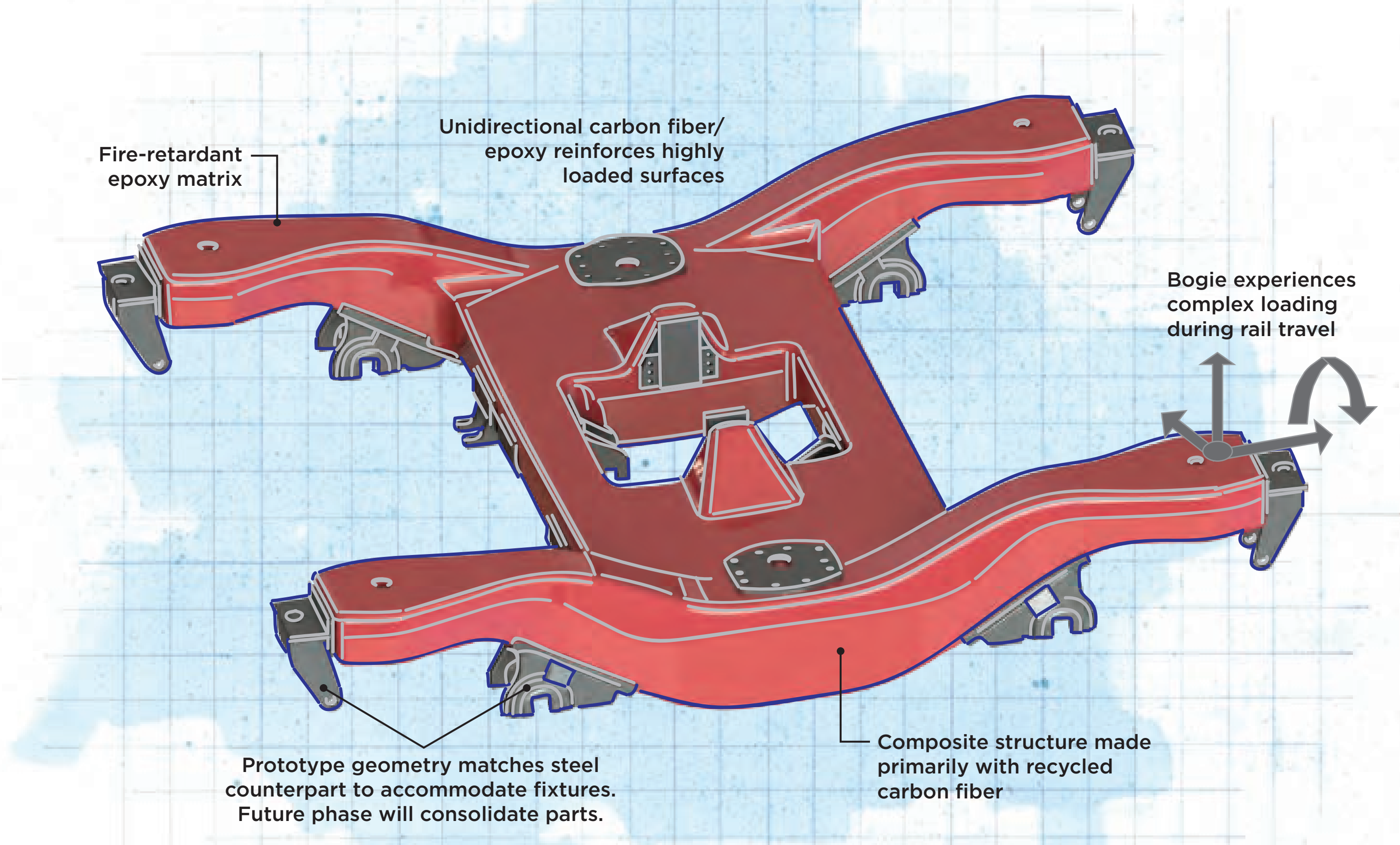
Compared to the original steel Alston 180 bogie frame and fittings, the prototype is 36% lighter. The composite frame itself yields a 64% weight savings, but the prototype suffers a weight penalty from paint and the tapping plates needed to attach the steel fittings — a penalty that may be largely eliminated in a fully optimized design. Considering the frame alone, the 590 kilograms of weight saved is estimated to produce an annual savings in operating costs of between £8,000 and £62,000, depending on the train's service type and mileage. Additionally, each bogie frame could reduce CO2 emissions through its lifetime by as much as 68 metric tonnes.

In transit

The full-scale tests scheduled for late 2019 to take place at the University of Huddersfield on the Huddersfield Adhesion and Rolling Contact Laboratory Dynamics (HAROLD) test rig. During this testing, the fiber-optic monitoring system will collect data to be evaluated against design and FEA models, and at the same time the testing will verify that the monitoring system itself can withstand proof and fatigue loading.

Development and track testing of a more optimized bogie prototype is next for the consortium. Magma Structures plans to build two such bogies for this in-field testing. Barnes points out that the integration of fittings into the composite structure may save another 100 kilograms per bogie. "It would make the structure more elegant but not significantly more complex to manufacture," he says.

Roberts sees future developments taking a path similar to that seen in other composites markets: start with a metal



DESIGN RESULTS **Carbon fiber-reinforced rail bogie**

- Basic frame structure 590 kg (64%) lighter
- Bogie frame and fittings: 36% weight reduction in prototype; up to 50% in future versions
- Up to 40% reduction in wheel-rail transverse loading
- Reduction in cost and environmental footprint through recycled carbon fiber

Susan Kraus / Illustration

may save another 100 kilograms per bogie. "It would make the structure more elegant but not significantly more complex to manufacture," he says.

Roberts sees future developments taking a path similar to that seen in other composites markets: start with a metal design and substitute with composites, then take greater advantage of composite materials' heterogeneous, anisotropic properties.

"Steel structures have often been designed on an empirical basis with a homogenous isotropic material," Roberts says. As the consortium moves forward, they'd like to take a different approach. "We want to move back one stage and ask what we are trying to achieve, and whether we can quantify it. You need to know what you want. It sounds obvious, but if it's difficult to define what you want, it's difficult to achieve what you don't know."