Reinforced Plastics • Volume 00, Number 00 • February 2017

Lowering the cost of carbon fiber

Mark Holmes

Carbon fiber offers a great many performance and lightweighting benefits for composites. Lower cost manufacture and increased use of recycled material now promise to widen the range of applications that could benefit from its properties.

High cost has been a major block to widespread use of carbon fiber as a strong, stiff reinforcement for advanced composites. One initiative underway to reduce these costs is taking place in the United States where researchers at the US Department of Energy's Oak Ridge National Laboratory (ORNL) have demonstrated a production method they estimate will reduce the cost of carbon fiber as much as 50 percent and the energy used in its production by more than 60 percent. ORNL's new lower cost method, demonstrated at its Carbon Fiber Technology Facility, builds on more than a decade of research in the area. The researchers' success promises to accelerate adoption of carbon fiber composites in high-volume industrial applications including automotive, wind turbines, compressed gas storage and building infrastructure. After extensive analysis and successful prototyping by industrial partners, last year ORNL made the new method available for licensing.

FIGURE 1
The Carbon Fiber Technology Facility at ORNL.

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''Through a competitive selection process, ORNL is working to negotiate up to five license agreements for its low-cost carbon fiber process,'' says Dr. Alan Liby, deputy director of the Advanced Manufacturing Program at ORNL. ''LeMond Composites was the first to sign a license agreement and other licenses are still in negotiation. The licensees range from start-ups to established players in the carbon fiber production field. Partners will be selected based on their capabilities, business plans, and commitments to manufacture in the United States. Expectations are to see this technology in the marketplace by 2018 and the licensees will explore additional market opportunities.

''The innovation is about the production of low-cost carbon fiber,'' he adds. ''The properties of the material that the licensees produce will dictate the end-use applications. The carbon fiber produced by ORNL meets the performance criteria prescribed by some automotive manufacturers for high strength composite materials used in high-volume applications. However, the process promises to accelerate adoption of advanced composites in other industrial applications. Future markets for this material could include applications in the wind turbine and gas storage industries. The technology was developed at the Carbon Fiber Technology Facility as a pilot scale plant with a capacity of up to 25 tonnes per year. The expectation is that licensees will increase that capacity in their own operations.''

First licensee

LeMond Composites – headed by three-time cycling Tour de France champion Greg LeMond – is a new company offering solutions for high-volume, low-cost carbon fiber. The licensing agreement with ORNL will make the Oak Ridge-based company

0034-3617/ http://dx.doi.org/10.1016/j.repl.2017.02.001

FIGURE 2
The 118-meter (390-foot) process line has been designed to be flexible and highly instrumented to demonstrate advanced technology scalability and produces market development volumes of prototypical carbon fibers.

the first to offer this new carbon fiber to the transportation, renewable energy and infrastructure markets.

LeMond Composites adds that the carbon fiber will provide advantages to many industries by improving strength, stiffness and weight reduction, and the process will have global applications. The company is now ready to move forward with scaling up the technology.

Growing demand from the automotive industry is due in large part to the global push to increase the fuel economy of nearly every vehicle produced. In the USA, the demand is being driven by the Corporate Average Fuel Economy standards. These standards demand a fleet-wide average fuel economy of 54.5 mpg by 2025. The single best way to improve fuel economy is to reduce the weight of the cars and their component parts. For the wind power industry, carbon fiber can be used to make turbine blades lighter and stiffer, thereby increasing the efficiency of the system. Previously, carbon fiber was too expensive for maximum utilization in this market. Additional sectors, including shipping, air travel and marine, could see significant energy savings through the use of carbon fiber in the lightweighting of their containers, planes and ships. Carbon fiber composites can also be used to build, reinforce, or repair bridges, tunnels, commercial and residential structures.

The low-cost process

According to ORNL, more than 90 percent of the energy needed to manufacture advanced composites is consumed in manufacturing the carbon fiber itself. Reduction in energy consumption in manufacturing will enable earlier net energy payback – energy savings gained in using products made from lighter weight material compared to the energy consumed in making the material. A detailed analysis compared the new process to a published baseline for conventional carbon fiber production. Cost factors were considered for nine major process steps, starting with the precursor and pre-treatment and finishing with surface treatment, sizing, winding, inspection and shipping.

Carbon fiber is produced by converting a carbon-containing polymer precursor fiber to pure carbon fiber through a carefully controlled series of heating and stretching steps. In current commercial practice, the precursor – polyacrylonitrile, or PAN – is chemically modified and optimized to maximize the mechanical properties of the end product. The high cost of specialty precursor materials and the energy and capital-intensive nature of the conversion process are the principal contributors to the high cost of the end product.

However, acrylic fiber of similar chemistry is produced on a commodity basis for clothing and carpets – a high-volume product that costs roughly half as much as the specialty PAN used in the carbon fiber industry. ORNL researchers believed textile-grade PAN was a pathway to lower-cost carbon fiber, but laboratory-scale experiments could not fully explore its potential at a production scale. In order to provide that capability, the US Department of Energy's Advanced Manufacturing and Vehicle Technologies offices have funded research and operations at ORNL's Carbon Fiber Technology Facility, a highly instrumented, semi-production scale carbon fiber conversion plant. Extensive mechanical property tests have been performed on carbon fiber from the new process, and several automotive manufacturers and their suppliers received quantities suitable for prototyping, with encouraging results.

The Carbon Fiber Technology Facility at ORNL was designed, manufactured and installed by Harper International – a company specializing in thermal processing solutions and technical services essential for the production of advanced materials. The 118-meter (390-foot) process line has been designed to be flexible and highly instrumented to demonstrate advanced technology scalability and produces market development volumes of prototypical carbon fibers, and serves as a key step before commercial production scale. With a production capacity of 4.3 kilograms per hour, it allows industry to validate conversion of carbon fiber precursors at semi-production scale.

With a rated capacity of 25 tonnes per year based on 24k PAN tows, the carbon fiber line is configured for PAN, polyolefins, lignin and pitch precursors, as well as being upgradable for rayon and high-modulus carbon fibers. Internally, it has been designed with high degree of corrosion resistance for alternative precursors. The facility is designed for 3k to 80k tows and web up to 300 mm wide by 12.7 mm loft. An oxidation temperature of 400 °C is possible with airflow configurable for parallel, cross or down flow, and driven pass-back rollers are installed for slip prevention at low

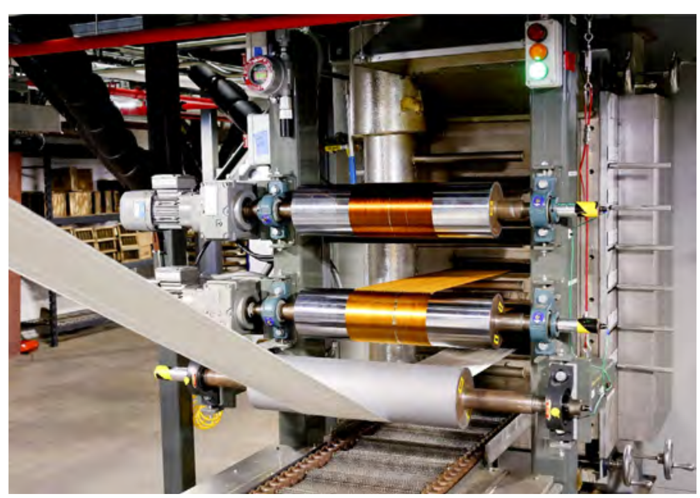

FIGURE 3
With a rated capacity of 25 tonnes per year based on 24k PAN tows, the carbon fiber line is configured for PAN, polyolefins, lignin and pitch precursors, as well as being upgradable for rayon and high-modulus carbon fibers.

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loading. Optimized for faster oxidation through elimination of the chimney effect, there is improved velocity uniformity and range, as well as an assurance of temperature uniformity at a variety of flow rates. Harper says that flexible internal design throughout the line allows material processing in either tow (unsupported) or web (supported by belt) formats. Low temperature carbonization up to 1000 °C is possible with the capability to produce structural or micro/nano-porous fibers. High-temperature carbonization to 2000 °C can also be achieved. A post-treatment is system designed for compatibilizing fibers with performance or commodity resins.

Higher capacities

In a further carbon fiber development, Harper has also partnered with ORNL on a project initiated through the U.S. Department of Energy Advanced Manufacturing Office's HPC4Mfg Program. The program was designed to spur the use of high-performance supercomputers to advance U.S. manufacturing via public-private partnerships. The project – *Development and Validation of Simulation Capability for the High Capacity Production Carbon Fiber* – will focus on analysis of critical processing factors, such as temperature, gas flow and chemical reaction, in carbon fiber production equipment. The purpose is to ensure designs provide the necessary uniformity to produce fiber of a certain quality, output and cost ideal for automotive applications. Results will then be validated at the Carbon Fiber Technology Facility, followed by testing in a commercial production facility.

According to Dr. Peter Witting, senior process technology engineer at Harper, the new one-year project with ORNL is a natural extension of the partnership forged over the pilot line for converting carbon fiber. "The project is not at this stage designed for use with the low cost carbon fiber process, but eventually it could help," he adds. "Right now the purpose is to develop an understanding of the chemical kinetics and the role that plays in making carbon fiber. This is a coupled thermal, chemical reaction, fluid flow model which requires sophisticated software and considerable computing power to tackle this inherently multi-physics problem appropriately in a reasonable amount of time. In addition, the ORNL and Harper personnel's understanding of the computational, chemical and process conditions complement each other in terms of a capability to address the difficult analysis.

"Initially what we are trying to do is establish a model for the critical processing factors, which will have to be verified at ORNL's pilot plant test facility, and then scaled to commercial size equipment. At that time, the analysis will help in process control and equipment design. So it is a multi-phase endeavour in which steps cannot be taken in parallel. At this stage the project will not address fiber uniformity. However, in one of the later phases it can help us design equipment so that material properties like linear density, strength and modulus are uniform across the entire tow band."

Dr. Witting believes that the potential of the project to deliver higher capacity and lower cost carbon fiber production when all the phases are completed is high. "This one year effort is one of many phases that will need to be executed," he says. "Once all the phases are complete, we can use this to design equipment which can handle the very high filament count towbands, such as 500k tows, that will have to be processed if carbon fiber is to be successful in automotive applications."

The recycling option

Another growth area in the drive for lower cost carbon fiber is the recycling option and one company pushing developments in the greater use of recycled material is UK-based ELG Carbon Fibre. "All of the recent market forecasts point to continued medium to high level growth in the carbon fiber market," says managing director Frazer Barnes. "One of the main drivers for this growth is new applications in the automotive industry. This is a very cost sensitive market and we expect that the lower cost of recycled carbon fiber, combined with the supply chain security and environmental benefits, will make this an attractive option for some of these applications.

"We generally see that using recycled carbon fiber has the potential to reduce the cost of the fiber by around 40 percent. In industries that use primarily carbon fiber tow, such as the compounding industry, this cost reduction is realized directly. Where there are further conversion steps required, such as producing a nonwoven fabric, the actual cost reduction can range from 20–40 percent. What we hear from the market is that these cost reductions, coupled with security of supply for high volumes of material with stable pricing, significantly increases the

FIGURE 4

Processing carbon waste.

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FIGURE 5
Incinerator at ELG Carbon Fibre's headquarters.

FIGURE 7
Carbiso^{TM} M nonwoven mats made from 100% recycled staple carbon fiber.

attractiveness of carbon fiber for the automotive and other transportation markets.''

Regarding the main trends and influences driving further development of recycled carbon fiber, Frazer Barnes believes that continued product testing is key to demonstrate performance and the development of design and manufacturing guidelines, particularly for the composites industry. ''In general, the composites industry is not yet aware enough of the potential for the use of recycled carbon fiber,'' he says. ''However, this is mainly because it is still a young part of the composites industry, and until recently there were not suitable product forms or design and manufacturing data available for the industry to be able to make good use of these materials.

''There are significant challenges in handling recycled carbon fiber materials in downstream conversion processes, and this has been one of the main barriers to the development of suitable product forms. We have actually had a very robust process for recovering high quality fiber, with little degradation compared to virgin carbon fiber, for many years, but the challenge has been developing ways of getting this back to the market.''

Carbon fiber reclamation firstly requires metal removal and the cutting of large composite structures to sizes suitable for downstream processing. In addition, shredding of laminates and prepreg enables efficient and consistent processing. Fiber recovery is via a modified pyrolysis process. Carbon fiber conversion is then through milling, nonwoven mat production and production of pellets.

FIGURE 6
Chopped fibers on shredder.

Successful recycling of carbon fiber requires a number of hurdles to be overcome. ''The major challenge is dealing with the complex nature of the waste streams,'' Barnes explains. ''Even relatively clean waste streams from composites manufacturing still contain resins of varying chemical composition and unwanted materials such as paper or plastic backing films, and the recycling process has to be optimized to ensure the complete removal of these unwanted materials without damaging the fibers. The second challenge is classification of the fibers. The composites industry has grown up with a wide variety of carbon fiber grades available from different manufacturers. Although the recycling process has only a small effect on the properties of the fiber, it is not desirable to retain the original fiber designation after fiber recovery. ELG has addressed this by introducing a generic classification system based on the Young's modulus and tensile strength range of the recovered fibers.

''The final challenge regarding carbon fiber recycling is to do with the development of the business. The major barrier that must be overcome is one faced by all new materials – lack of knowledge about mechanical properties and processing characteristics, and lack of large scale demonstrators that prove the economic, technical and environmental justification for using these materials. Whilst there are a number of projects that are addressing these issues, the push from the manufacturing side of the supply chain to find a solution to its carbon fiber waste problem generally is not matched by a pull from the design side of the supply chain to find ways of using recycled carbon fiber products.''

Frazer Barnes adds that the company now has a good understanding of the performance of recycled carbon fiber materials in compounds and composites. He says that the next steps are to enhance performance further through product optimization, and to get an understanding of the long term performance of recycled carbon fiber materials. ELG is undertaking this through internal R&D programmes, as well as working with UK universities including Warwick, Nottingham, Bristol and Oxford Brookes.

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FIGURE 8
Recycled carbon fiber pellets suitable for thermoplastic applications.

FIGURE 9
Carbiso™ TM nonwoven mats made from a blend of recycled carbon fiber and thermoplastic fibers.

ELG Carbon Fibre has currently developed five products from reclaimed fibers. Carbiso™ MF is a milled random short length carbon fiber used to make thermoplastic and thermoset compounds and for additive manufacturing processes. The main benefits conferred by milled fibers are increased stiffness, higher electrical and thermal conductivity and reduced coefficient of thermal expansion. Carbiso™ CT chopped tow is a precision chopped virgin carbon fiber product with 6 mm and 12 mm fiber lengths that are claimed to be a good reinforcement for thermoplastic injection molding compounds, cements, elastomers and coatings. Chopped tow offers higher structural and electrically conductive properties than ELG's milled fibers. The lightly sized fibers are compatible with most thermoset and thermoplastic matrices.

In 2017, the company is launching CT+. In comparison to the standard chopped tow CT product, this new plus version is characterized by improved flowability for 'easy dosing' in gravimetric feeding systems for plastic compounding. Carbiso™ MB carbon fiber masterbatch products will be fully commercialized in 2017. These pelletized products are made from chopped fibers that ELG Carbon Fibre converts for use in the compounding industry. These smaller sized pellets make them easy to dose, contain less dust when handled and are more consistent to work with.

Carbiso™ M nonwoven mats are produced from 100% recycled carbon fiber and can be processed by conventional composite techniques to manufacture structural and semi-structural parts. Carbiso™ TM hybrid nonwoven mats combine carbon fibers with thermoplastic fibers such as PP and PA. The company says that Carbiso™ M and Carbiso™ TM isotropic mats are easy to handle, drapeable and compatible with most thermoset and thermoplastic polymers and deliver good mechanical properties. They are available in standard 100–600 gsm weights and widths up to 2.7 m. To offer customers total flexibility and an entirely tailored solution, the mats can also be manufactured to bespoke specifications.

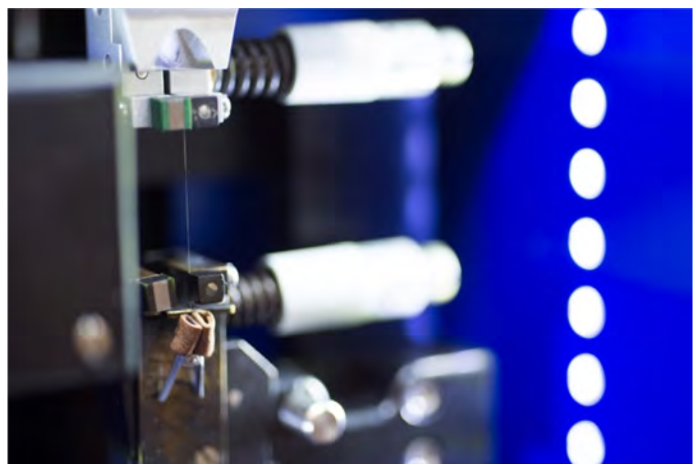

FIGURE 10
Fiber testing by ELG Carbon Fibre's R&D department.

"ELG Carbon Fibre views high volume transportation applications as the key emerging market that could best benefit from the company's products and services," concludes Frazer Barnes. "If the vehicles of the future are manufactured from increased quantities of recycled carbon fibers, these lightweight structures will be more cost effective and in turn reduce CO_2 emissions, increase compliance with fuel economy regulations and also support the European Union (EU) end-of-life-vehicle (ELV) directive."

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