It’s not breaking news that GE Aviation has developed a material that has the desired qualities of ceramics—namely its light weight and ability to withstand the ultra-high temperatures generated by modern jet engines—without that material’s most serious drawback: brittleness. GE’s version of ceramic matrix composites (CMC) weighs a third of advanced alloys but reacts to stresses like a metal and can perform at temperatures as high as 2400°F (1316°C). It was first created in GE labs in the early 1990s, and for much of the past two decades it has been on a short list of materials seen to have great potential to revolutionize the aerospace and other industries.

It’s a long way from “potential” to production, however, and while GE quietly worked on developing CMCs, the

CMCs Make the LEAP to Production

GE Aviation’s ceramic composite material is, after decades of development, ready for use in the LEAP airliner engine

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industry, including GE Aviation, continued using nickel-based superalloys for the hottest parts of their turbine engines and worked to refine methods of cooling the alloys.

What makes CMC different from some other potentially game-changing materials (such as buckypaper, discussed in these pages in March 2013) is that after two decades of development, including over a million hours of testing, it’s actually ready to go into commercial aerospace production: In November GE Aviation broke ground for a new 170,000 ft² (15,810 m²) CMC factory near Asheville, NC, which will make a high-pressure turbine shroud for the LEAP engine, marking the first time CMCs will be used for a commercial application. The LEAP, a product of CFM International, a joint company of GE and France’s Snecma SA, will enter airline service in 2016 and will power the Airbus A320neo, Boeing 737 MAX and China’s Comac C919.

In other words, as Billy Ocean might put it; CMCs are finally getting out of our dreams and into our planes.

The Recipe

According to Wessels, the process for making CMC components begins in Japan at a Tokyo-based company called NGS Advanced Fibers—a joint venture of GE, Safran, and Nippon Carbon Co. that makes silicon carbide (SiC) continuous fiber or Nicalon. GE, at its Newark, DE, facility, puts several layers of “a very proprietary” coating onto the fiber via chemical vapor deposition. This coating does two things, Wessels says: “It provides the toughness needed later on in the process, when the silicon carbide fiber needs to slide within a matrix, and it provides protection that the fiber will need in downstream processes, which will involve a lot of high temperatures.” Others at GE refer to it as “the secret recipe.”

That coated fiber is then turned into a prepreg tape, in a process that will...

The turbine shroud, in a container, is placed in an autoclave at GE Aviation’s Newark, DE, micro factory. Which makes this a good time to ask two questions: First, just how does this stuff work? And second, just what happened in the two decades between its groundbreaking discovery and the groundbreaking ceremony for the Asheville production facility? Jeff Wessels, GE Aviation’s plant leader for the Newark, DE, CMC microfactory, recently spoke to Manufacturing Engineering Media to answer both questions and to walk us through how CMCs are made at GE.
sound familiar to those who work with carbon composites. “We put the fiber through a slurry compound that has all of the matrix constituents in it, including carbon, silicon carbide. It goes onto the fiber, and the fiber is wound onto a drum, with very close spacing between the fibers that is surrounded by this matrix material. We dry it, and what we end up with is a piece of tape, about 15” wide by 50” long by 0.007–0.008” thick [381 × 1270 × 0.17–0.20 mm].”

This tape is provided to a layup team, who again follow a process identical to that of more traditional composite layup: “They cut it into different shapes and lay those pieces over and on top of each other in a tool that imparts the final shape of the part that we’re looking to make,” Wessels said. “The next step is to use an autoclave to bake at temperature and pressure—all very similar to PMC—the polymer matrix composite-type process. But then we go on to a couple of extra steps to fully densify the component, and really turn it into a ceramic matrix.”

“It’s all silicon carbide but now it’s a fiber within a matrix. And that’s what imparts the toughness.”

The next step is pyrolysis, which burns off all of the organic constituents that are still left inside after the autoclave process. What’s left behind is a porous lattice made from the ceramic-coated silicon-carbide fibers in the shape of the desired part. This is then followed by what Wessels terms the melt-infiltration process:

“This is where we use another furnace to basically melt silicon in contact with the part,” Wessels explained. The silicon wicks its way into the lattice, turning all of the constituents that were left over in that matrix into silicon carbide. “Where previously you had a porous carbon matrix, you end up with a silicon-carbide matrix—it’s all silicon carbide but
now it’s a fiber within a matrix. And that,” he said, “is what imparts the toughness to these materials.”

“The beauty of what GE’s been able to develop is that we get very close to full density on these parts—maybe 98% density or more, without losing the properties of the fiber,” he noted.

The final step in creating a CMC part is finishing it with five-axis CNC milling machines. The CMC material is extremely hard and durable—too tough for traditional cutting tools, Wessels said. “Rather than conventional cutting tools, we have to use diamond-coated tools. They’re the one thing we have that cuts through this material effectively on a bulk scale. But other than the use of diamond-encrusted tools, the rest of the process is typical machining. We use the same kind of five-axis programming that’s used throughout the industry.”

Size Matters

The first part to be manufactured at Asheville is a turbine shroud that’s about 5” (127-mm) in circumferential length, but CMC components can be much larger and smaller. The pyrolysis and melt-infiltration processes aren’t affected at smaller sizes, Wessels said, but he noted that “when going small, the handling of the plies becomes more complex.” At somewhat larger sizes, in contrast, the plies become easier to handle when laying up the part. “But when you get too large,” he noted, “you end up needing a lot of silicon to infiltrate the part.

“We’ve been able to make pretty large parts, though. We’ve made a combustor liner from this material, a part that’s about 32” [813-mm] diam and with an axial length of 8-10” [203–254 mm].”

The Refinement

In the popular imagination, there is no intermediary step between the creation of a new material and its implementation in mass production: In Hollywood terms, we expect a scene with a lab-coated scientist holding a smoky beaker and shouting “Eureka!” and a quick jump to footage of an assembly line or conveyor belt, if not straight to scenes of happy consumers. Manufacturers know better, of course. At GE Aviation, this is where the ‘microfactory’ and Jeff Wessels come in.

“Our Global Research Center in Niskayuna, NY started developing this technology in the early to mid-1990s. They formulated the basic process and designed and made the necessary equipment. Around the early-2000s timeframe, that process was transitioned to our Newark, DE, microfactory site, where I’m at right now.”

In 2006, Wessels, who has been with GE for 28 years, was tapped to start up GE’s first microfactory, which was devoted to high-pressure turbine airfoils. There, he worked on ways to provide lean practices to improve the manufacturing processes, he says, resulting in a significant amount of cost reduction.

“Two years ago, because of the microfactory experience and my materials
background I was selected for this role,” namely plant leader, Ceramic Composite Products at the Newark site. The goal there is what he calls “industrialization—learning to scale up the process, to understand the variation associated with all of its different steps, reduce that variation, and work to make the program economically feasible.”

This is where plans for some would-be miracle products fall apart: It’s one thing to develop a material with the properties you desire, but another to be able to do so in a way that works in a business plan. Wessels and the Newark microfactory team have had to learn to efficiently process enough material to make it economically feasible: Where the Global Research Center made an initial coating reactor that would coat 11 strands of tow in one coating process, for example, the Newark facility has expanded that capability to 24 strands of tow, and plan to expand to 72 strands of tow—necessary, he says if they are to be able to keep up with expected production demands.

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“We’re scaling up each step of the process,” Wessels explained: “First it’s the fiber-coating, next is the tape-making process. Whereas at the GRC they had a small drum winder, we have a drum winder that’s ten times that size. And in the future we’ll be going to a continuous tape-making process, which gets us into more of what the PMC industry is doing now.

“On the layup portion too: at the Global Research Center, they were using scissors and knives to cut and shape their plies. Here, we’re using a standard Gerber Technology cutter of the type used throughout the PMC industry and now in the CMC industry for the rapid cutting of these plies,” he noted.

“The burn-out process has scaled up significantly; the melt-infiltration process has scaled up significantly—all of those major processes have to be scaled up,” he said.

But scaling up is not enough: they have been seeking ways to also improve the processes. “One we’re looking at right now is automation of portions of the layup,” Wessels said. “The layup is a very manually intensive process at this point. It’s manually placing layer over layer, getting each to fit in the right direction. We use orientation markers and everything to assure the plies get in the right place, in the right order. But hand layup leaves room for inconsistencies and, more important to us, it’s a repetitive process, and people who do it are subject to ergonomic injury. That’s something we’re very cognizant of, and so we’re taking steps to automate certain parts of the process—the parts that are the primary causes of fatigue in the workers’ hands.”

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At GE, the microfactory, then, is what comes between the ‘eureka!’ moment and full production: “At the microfactory stage, we explore all of the limits, we discover the parameters outside of which our parts become bad. We need to understand them, and narrow their range,” Wessels said, “so at Asheville, in that high-volume facility, they won’t have to vary it: they’ll know from our work here what the space is that they can operate in. That’s a great concept that we’ve really driven in GE Aviation, and it’s one that we’re really proud of.”

When asked if GE Aviation has looked at any specific suppliers of automated tape-laying equipment for use in the Asheville CMC facility, Jeff Wessels’ answer is, “not yet,” along with an observation about GE Aviation’s process: they themselves make the equipment that makes the CMC material.

“Part of what makes the microfactory concept a success is that we are a fully-qualified source to make the production hardware,” he noted. “That means we have the quality system in place that enables us to ship the hardware that is used to make production engines out of. We’re making certification-compliant parts right now for the LEAP.

“That’s a big deal. I think people in the R&D world sometimes have trouble understanding how hard it is to make production hardware as opposed to a development part here and there. These parts have to meet all of the extensive quality requirements associated with CMCs—and believe me, there are very rigorous quality requirements associated with this material and this hardware.”