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By Stephanie Hendrixson

Carpenter engineers hold metal 3D-printed parts at the company's AM lab in Reading, Pennsylvania. Ongoing R&D work focuses on studying AM materials and their behavior in printing as well as postprocessing. Images courtesy Carpenter Technology.

Toward Tailored Materials

As AM moves past existing materials, what will it look like to develop specialized and eventually fully custom options?

Within the additive manufacturing space, there's a model for the evolution of design thinking that goes something like this: You might start with AM by 3D printing a part design you're already making, which may be an easy win but doesn't provide any real advantage. You might then improve the part—consolidate an assembly, reduce weight—taking advantage of some of the inherent benefits made possible by 3D printing. But the end of the model is to implement design for additive manufacturing (DFAM) from the very beginning to create parts that couldn't be made any other way. This is the ultimate goal: to make the best parts by designing them to make the best use of the technology.

In some ways, this design thinking evolution mirrors what is happening in another area of AM: materials. I recently spoke with some representatives of Carpenter Technology, a company that has been providing metals for manufacturing since 1889. Today, its product mix includes metal powders and wire engineered for additive manufacturing, and Carpenter's role has expanded beyond material supplier into a solutions provider, a role that is proving particularly valuable in AM.

"We want to build the correlation from powder to part, or wire to part, and be an end-to-end player in this space," says Mike Murtagh, chief technology officer.

Carpenter is moving toward this goal with its acquisition in February 2018 of CalRam, a Camarillo, California-based parts producer specializing in metal powder-based AM. The benefits to this acquisition are twofold. First, a close relationship with a production house gives Carpenter insight into how materials behave inside specific machines with given parameters, and offers more direct access to customers and their challenges. Second, CalRam and its customers benefit from Carpenter's vast materials knowledge and capacity to provide not just feedstock for additive manufacturing today, but also the next generation of AM materials. More on that in a moment.

Working with the Known

If the use and development of 3D printing materials is following that same three-stage trajectory as design thinking, then today manufacturers are largely in the first stage, relying on known alloys that can be applied for additive manufacturing. In the near term, therefore, these users need to understand how to optimize the AM processing of these existing materials.

"Today, there are about 5 to 10 alloys that we see being ordered 90 percent of the time," says Will Herbert, director of corporate development for Carpenter Technology. These alloys are familiar from the cast-wrought world, compatible with 3D printing and known to be effective.

Final part properties are one reason for the limited number of alloys used in AM today. "When you're forging, you work the material and can confer additional properties to the alloy, such as strength or fatigue resistance for example," Herbert says. In the 3D printing process, where the material is formed simultaneously with part geometry, "We've been fairly limited in the universe of alloys because we have to select metals that you can strengthen without putting in this additional energy after the process."

Yet even these existing alloys are still not perfectly understood. "We've translated those directly to additive manufacturing, but I don't think those materials have necessarily been tailored accordingly to the new technology," Murtagh says. "They've kind of been force-fit to some degree, because that's what we know today."

In its own AM materials research and through collaboration with CalRam, Carpenter is exploring how material properties translate to the final part, and how factors such as particle size, shape and distribution affect the build.

This research is already expanding material options for metal 3D printing by encouraging a revisiting of what Herbert calls "back catalog" alloys—materials that are difficult to forge as large billets or to investment cast, for example, but may be good candidates for laser sintering or another AM process.

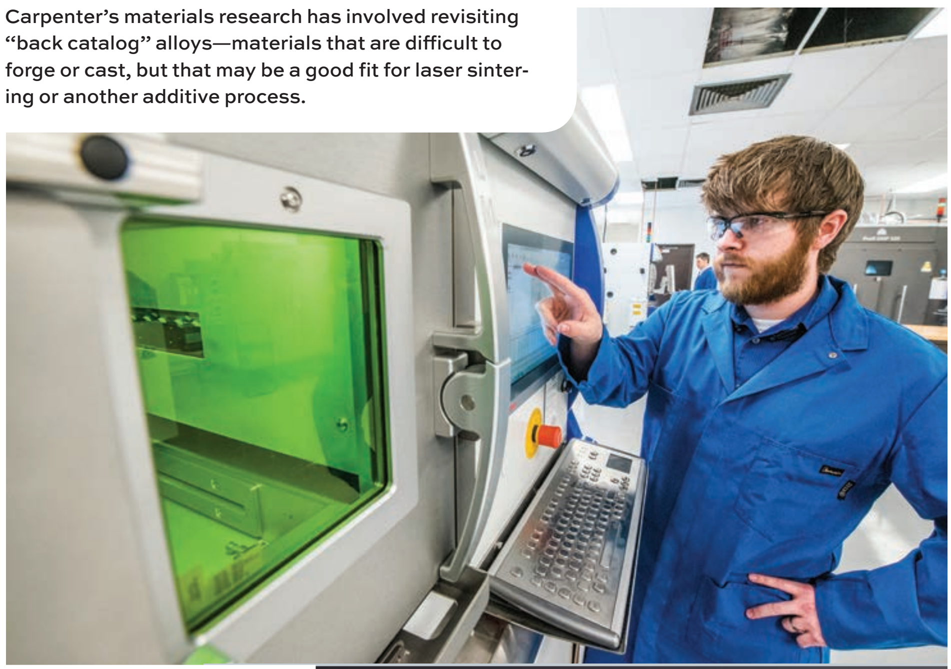
"When you wrought process these materials, the material composition can change very widely from the center of the billet to the outside," Herbert says. "You can mitigate these types of segregation issues when you start with a powder, and your particle size is on the order of 30 microns, and your freezing rates can be very high. Suddenly we have all these 'new' alloys we can try out."

Update and Innovate

Carpenter is also beginning to optimize materials specifically for additive, creating variants that meet existing standards while being at least somewhat customized to the 3D printing process.

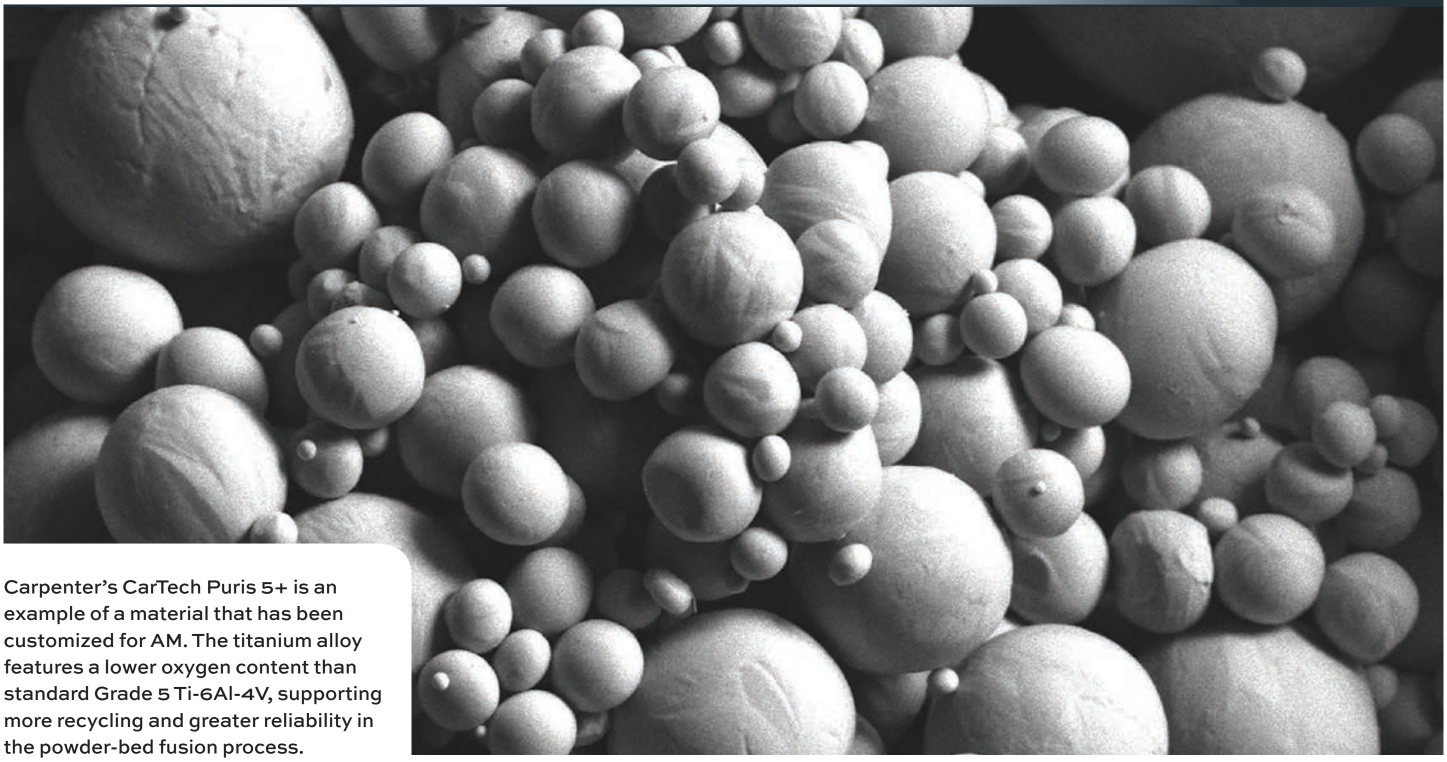
"In the medium term we can continue to take existing alloys within the industry standard specifications and tweak them, finding a way to optimize the chemistry, the particle shape and size, in order to deliver additional benefits," Herbert says.

The company's recently launched CarTech Puris 5+ titanium alloy is an example of this sort of tweaking. This material grew out of the difficulty that CalRam (before its acquisition) was experiencing in 3D printing with Grade 5 titanium alloy (Ti-6Al-4V), says Eric Bono, manager of Carpenter Technology's Additive Manufacturing Group. "They could not meet required mechanical properties with adequate ductility, and they came to us to solve the problem," he explains.



Carpenter's materials research has involved revisiting "back catalog" alloys—materials that are difficult to forge or cast, but that may be a good fit for laser sintering or another additive process.

In early 2018, Carpenter acquired CalRam, a California-based company that specializes in metal 3D printing of production parts such as this landing gear knuckle, 3D printed from Ti-6Al-4V. (The blue insert is the digital model of the component.)



Carpenter's CarTech Puris 5+ is an example of a material that has been customized for AM. The titanium alloy features a lower oxygen content than standard Grade 5 Ti-6Al-4V, supporting more recycling and greater reliability in the powder-bed fusion process.

While Ti-6Al-4V is widely used, Bono says, the material itself has some issues when paired with AM. Namely, oxygen. Per ASTM International standards, Grade 5 titanium can contain no more than 0.2 percent oxygen. However, each time titanium powder is used and recycled, the oxygen content increases. Standard Grade 5 titanium powder used in critical applications has a starting oxygen content of approximately 0.17 percent, which doesn't leave much leeway for reuse.

CalRam's application challenged Carpenter to create a low-oxygen titanium allow to facilitate more recycling, reduce overall cost, and provide a better guarantee of part quality. But it wasn't just a simple matter of reducing the oxygen content.

"The problem is that low oxygen also results in low strength," Bono says, explaining that oxygen in dilute amounts is an important strengthening agent in titanium and the reason for the 0.17 percent oxgyen content of standard Grade 5 titanium.

Carpenter's technical team modified the alloy's chemistry to create a powder that was still within Grade 5 strength specification, but better tailored to additive manufacturing. "We were able to give them very low oxygen by tightly controlling several other strengthening elements," Bono says.

The resulting material more than met the strength requirements of Grade 5 titanium. In fact, in testing CarTech Puris 5+ alloy consistently exceeded Grade 5 strength requirements by 20 percent. The virgin powder has an oxygen content of 0.13 percent, providing more space for recycling and reuse, while also reducing the burden of testing and the risk in the final part. Furthermore, the new composition enabled CalRam to meet both the strength and ductility requirements of the application.

"Our ability to improve the alloy ultimately drove improvements in their process," Murtagh says, referencing lower rejection rates and increased part strength achieved through CalRam's use of CarTech Puris 5+.

"It has since become our most popular titanium alloy," Bono says. "We solved one customer's problem, but it's really indicative of a problem across the entire industry."

Customized materials like this could be a major boon to manufacturers in the middle term. But in the long term, AM materials development will mean going back to the drawing board and creating new powders that are optimized for additive applications and systems from the beginning.

"I think we're just scratching the surface in terms of new material development," Murtagh says. "The more we understand about the actual printing technologies and the design capabilities of additive, the more we can work on the front end to tailor materials for throughput, speed, repeatability and the properties you want in the final part." AM