Ceramic & Glass MANUFACTURING

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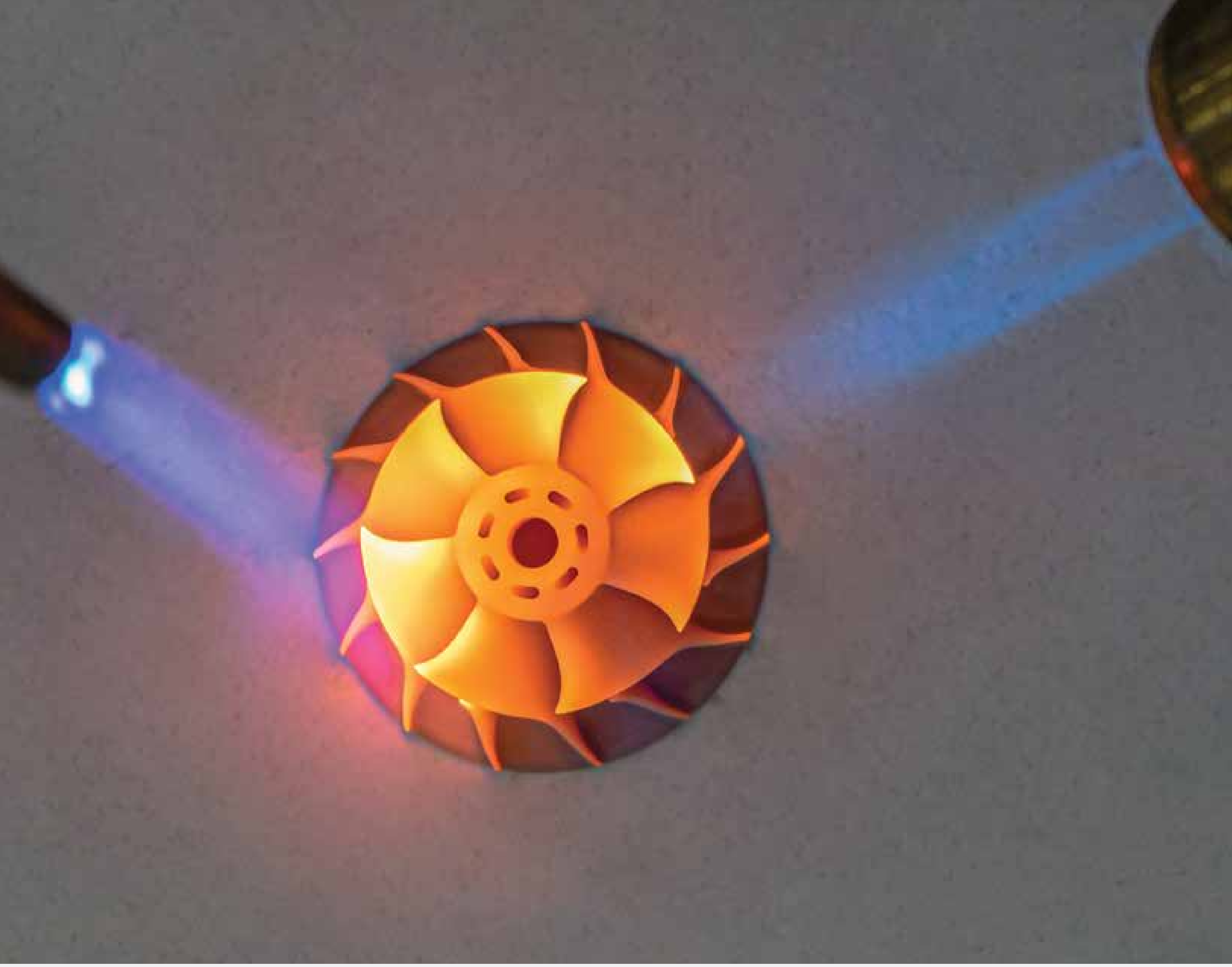

A BRIGHT AND BOLD FUTURE AHEAD: HOW CERAMIC ADDITIVE MANUFACTURING IS DRIVING GROWTH

THE PROMISING PATH FORWARD FOR ADDITIVELY MANUFACTURED CERAMICS

ALFRED UNIVERSITY-CACT PARTNERSHIP SUPPORTS LAUNCH OF START-UP COMPANY AT INCUBATORWORKS

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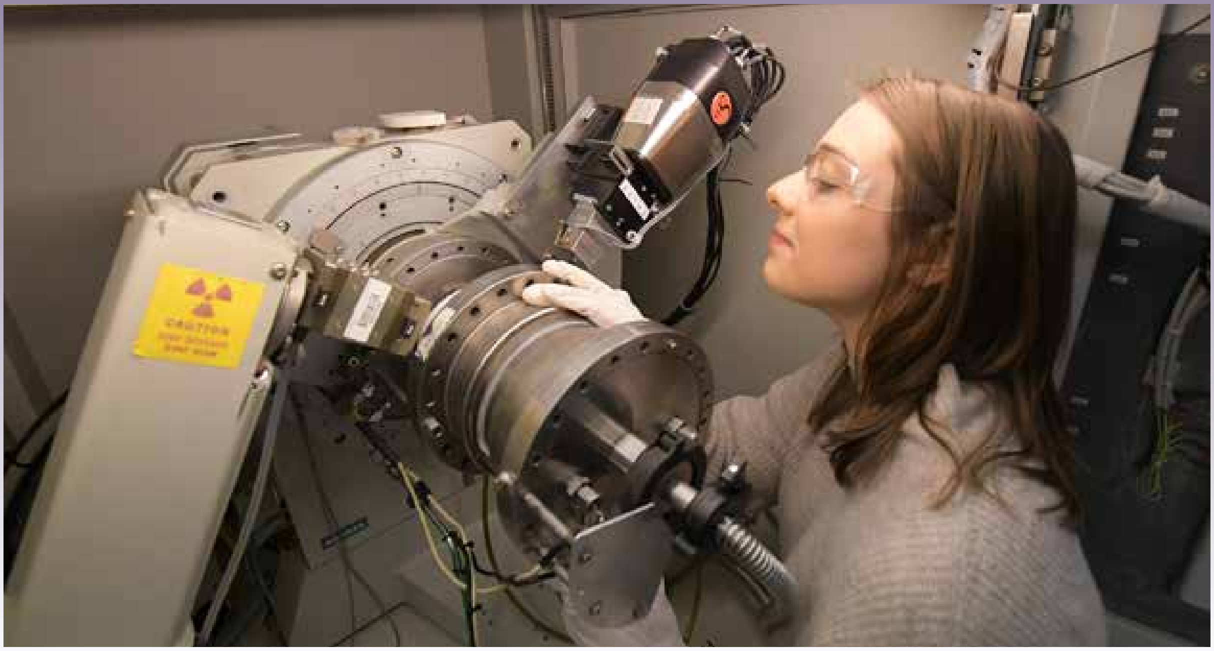

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THE PROMISING **PATH FORWARD** FOR ADDITIVELY **MANUFACTURED** CERAMICS

The Army's Bradley Fighting Vehicle is being us

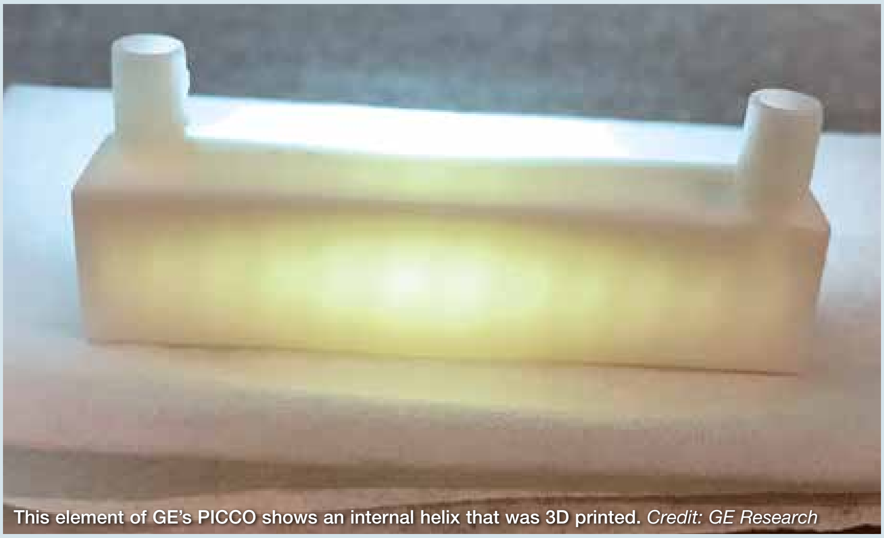
By David Holthaus

The U.S. Army is building a growing fleet of electric vehicles that demand resiliency, as well as speed and durability.

Military vehicles, of course, must perform in high-stress situations, and the inner workings and power drive systems of an electrified fleet must withstand high voltage and temperatures. The silicon carbide semiconductor chips used in these vehicles can improve the efficiency and performance, but they can face thermal challenges when pushed to extremes.

As a potential solution, the U.S. Army Research Laboratory and GE Research are working together to develop a next-generation cooling system called the Package Integrated Cyclone Cooler (PICCO) that uses additive manufacturing to create a critical component.

In PICCO, a cold plate for electronics cooling is fabricated with an internal helix that swirls boiling fluid to increase the heat transfer coefficient and the critical heat flux, says Cathleen Hoel, a senior materials scientist at GE. The cyclone cooler is made using cutting-edge additive manufacturing, or 3D-printing technology, to produce ceramic parts that will permit the power electronics packages to stay cool and maintain their performance, even when transmitting heavy loads of power.



This element of GE's PICCO shows an internal helix that was 3D printed. *Credit: GE Research*

It is a prime example of how additive manufacturing, or AM, can be put to use in advanced systems that use ceramic materials.

"At GE, we are working closely with system and component designers and learning about areas where ceramics formed by AM can play a critical role in enabling next-generation systems," Hoel says.

Additive manufacturing of ceramics, although in its early stages, is growing rapidly and the market has significant potential, experts say.

The ceramics 3D printing market is expected to generate overall revenues of more than $3.6 billion by 2028, rapid growth from

ed to prototype hybrid electric drives to reduce costs and fuel consumption. *Credit: U.S. Army photo*

$185 million in 2019, according to SmarTech Analysis, a Crozet, Va.-based market research firm.

"It has a tremendous amount of upside and development potential and hasn't even scratched the surface yet," says David A. Gottfried, deputy director of business development at the Center for Advanced Ceramic Technology at Alfred University.

The Center is developing a new $7.75 million Center for Advanced Ceramic Manufacturing (CACME) at the University, which is focused on helping industry develop and commercialize additive manufacturing of ceramics and glass.

"It's not for blue-sky research," Gottfried says. "It was done as an economic development project for companies that want to develop new materials and processes."

The biggest strength of AM for ceramic manufacturing lies in its ability to make designs that cannot be made any other way, Hoel says. "Expanding the design space of ceramics, as well as metals and polymers, allows more efficient systems and the ability to overcome limitations imposed by traditional manufacturing methods," she explains.

Cathleen Hoel

Sectors that are strong candidates for ceramic AM include aerospace, power generation, energy storage, and health care, according to Hoel.

AM helps engineers with rapid prototyping and demonstrations of new designs without a big investment in new tooling, says Igor Levin, a leader in the materials structure and data group at the National Institute of Standards and Technology (NIST). By offering "tool-free" fabrication, AM allows for design flaws to be discovered early, without the investment that other methods would require, he says.

The technology also holds promise for replacing parts that may have become obsolete, says Brandon Ribic, technology director at America Makes, the Youngstown, Ohio-based additive manufacturing accelerator of the National Center for Defense Manufacturing and Machining. America Makes is one of eight Manufacturing Innovation Institutes established and managed by the U.S. Department of Defense as public-private partnerships.

Researchers there conducted a project called "Maturation of Advanced Manufacturing for Low-Cost Sustainment (MAMLS)," which was partly funded by the Air Force Research Laboratory. Air Force aircraft have an average lifespan of about 27 years, according to the America Makes website, meaning critical parts are often out of production because they are obsolete, cost too much to create, or are made in small quantities.

The first phase of the project showed promise for additive manufacturing. "In terms of the ability to readily get out a product that gets to the customer in a shorter period of time and with low-volume production, it does offer a cost benefit and time savings," Ribic says.

The project was able to demonstrate that AM technologies could improve the ability to rapidly replace parts and improve maintenance for legacy aircraft, as well as enable on-demand replacement of damaged or obsolete components that could not be replaced through conventional supply chains.

Scaling up the volume of additively manufactured ceramic parts is something that needs more research. "That was low volume," Ribic says. "How does that scale to thousands and tens of thousands? We have a lot to learn still."

Additive manufacturing is an emerging technology, so there are growing pains. One that is unique to the ceramics industry is the need to debind and sinter parts after printing, Hoel says. The process can lead to stress and defects in the printed part, she says.

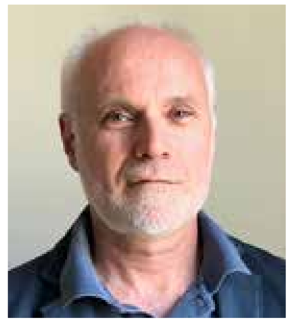
"The ceramics community has been debinding and sintering green parts for many years, so the difficulty is appreciated," she says. "AM uses binder chemistries that are not often used in traditional forming methods, so these differences need to be understood to overcome the defects."

AM can enable part designs of greater complexity, but that complexity can aggravate the challenges that are already present for printing, debinding, and sintering.

"Designs can be printed that could not be made by other methods, but the cost associated with those parts can be high because complex parts are generally more prone to defects," Hoel says.

The cyclone cooler also is an example of the challenges that can be associated with fabricating with additive. The PICCO is a complex design that can experience stress during debinding and sintering due to the nonuniform wall thicknesses in the design, Hoel says. The right ceramic slurry composition must be used to reduce those stresses.

Brandon Ribic



Igor Levin

Because AM is a nascent technology, parts made by it will be more expensive than those made by traditional methods. For that reason, GE researchers are focusing on parts that can only be made by AM and play a critical role in an advanced system, according to Hoel.

"AM is best leveraged in next-generation systems where the design benefits can be maximized and challenging aspects, such as anisotropic strength, can be managed," she says.

For example, GE is researching artificial bone scaffolds that can be used to repair damaged bone in patients. 3D printing allows for fine pore sizes to be fabricated in the artificial bone. However, removing uncured material from the pores can be challenging. "We are developing methods to effectively and consistently clean printed parts with fine pores," Hoel says.

Post-processing of additively manufactured parts is one of the main challenges for ceramic parts, Levin said. Debinding can be a source of defects, and sintering of green parts can also introduce defects and failures.

Biomedical applications are among the most promising areas for the use of additive manufacturing. The technology can enable patient-specific solutions, including for bone implants, dental implants, crowns, and bridges, as well as for medical device components and surgical tools, Levin wrote in a paper he co-authored for NIST.

"AM is envisioned to reduce the complexity of surgeries, improve biological response to implants, and lower cost" compared to conventionally manufactured materials because there is less machining, according to the paper, "Materials Research and Measurement Needs for Ceramics Additive Manufacturing," published in November 2020.[1] The paper reports on a November 2019 NIST-sponsored workshop to identify the most pressing research and metrology issues for additive manufacturing of ceramics.

The paper notes that a challenge for the health industry is to validate parts manufactured by AM. That is true for other industries using AM, Ribic says. "Inspection can be a challenge. If we're going to introduce complexity, being able to confirm that the interior features that I've put in there, that I can't see, are in the correct form and they're going to function as I anticipate them to—there needs to be a means to certify that," he says.

X-ray computed tomography has become a standard tool for certifying additively manufactured parts, but it presents challenges in ceramics because of variation in the densities of the material, Ribic says. Using acoustic sensing techniques could play a role in certifying ceramic parts, too, he adds.

Much more research is needed in this area and others, Levin says, before the technology can be more widely adopted. That is especially true for the creation of standards for feedstock materials and for identifying best practices for post-processing methods.

As the technology becomes more accessible, collaborations among industry, government agencies, and academia will help move this promising manufacturing method forward, the NIST authors say, as well as periodic meetings to review and share data.

REFERENCES

[1] Allen, A. J., Levin, I., and Witt, S. E. "Materials research & measurement needs for ceramics additive manufacturing." *Journal of the American Ceramic Society*, Vol. 103, Iss. 11 (November 2020): 6055–6069.

ALFRED UNIVERSITY-CACT PARTNERSHIP SUPPORTS LAUNCH OF START-UP COMPANY AT INCUBATORWORKS

By Mark Whitehouse and David Gottfried

ALFRED, NY—Alfred University and its Center for Advanced Ceramic Technology (CACT) are supporting the launch of a new business that will commercialize a new additive manufacturing-based system for the terra cotta industry.

William Carty, professor of ceramic engineering and the J.F. McMahon Chair in Ceramics at the Inamori School of Engineering at Alfred University, launched the new firm Replacement Tiles Solutions, which is located at the IncubatorWorks facility in Alfred. IncubatorWorks—established in 1992 and previously operated as the Ceramics Corridor Innovation Center—is a state-of-the-art incubator offering services and facilities to foster growth of entrepreneurial businesses in ceramics, glass, advanced materials, and related technology-based industries.

Replacement Tiles Solutions is developing innovative solutions to 3D scan terra cotta roof tiles and other terra cotta elements in order to produce high-resolution molds used to make precise duplicates of the material needing replacement. Because this unique process allows for near-perfect color matching, replacement terra cotta can be installed without negatively impacting a roof's aesthetics.

Replacement Tiles Solutions is working closely with Orchard Park, N.Y.-based Boston Valley Terra Cotta, a global manufacturer of architectural ceramics that will serve as a subcontractor to the new company. Alfred University alumnus John Krouse '85 (B.S., ceramic engineering) is president of Boston Valley Terra Cotta, a company with over 40 years' experience as a grade 1 terra cotta roof tile replacement company, which will assist Replacement Tiles Solutions in bringing their new process to market.

Steven Hyde, left, and Mark Ciccarella, junior ceramic engineering majors at Alfred University, observe two sample molds created in a 3D printer at Replacement Tiles Solutions, where the students work as research assistants. *Credit: IncubatorWorks/Replacement Tiles Solutions*

"Thanks to significant advances in additive manufacturing, and leveraging our decades-long experience in working with terra cotta materials, we are transforming the way terra cotta roofs are repaired," Carty says. When terra cotta roofs are damaged, it is not uncommon for the entire roof to be removed and replaced, which can be an extremely expensive proposition. "Using our process, a homeowner can not only save thousands of dollars in materials and contactor costs by replacing only the damaged tiles, but also significantly reduce the amount of time needed to conduct the repairs," Carty adds.

Replacement Tiles Solutions also partnered with CACT, one of 15 NYSTAR Centers for Advanced Technology. The CACT is providing support for internships, access to analytical services, and partnership opportunities. One such partnership includes restoration of the historic Celadon Terra Cotta building located on Alfred Village's Main Street. Built in 1892 by the Celadon Terra Cotta Company, the building was designed as a sales office and display center for the company, and was considered a "catalog" of their work. Due in large part to the Celadon Terra Cotta Company's location in Alfred, this prompted then Governor Theodore Roosevelt in 1900 to establish the New York State School of Clay-Working and Ceramics (now the New York State College of Ceramics) in Alfred.

"Thanks to funding being made available through Governor Cuomo's Smart Growth Community Grant program that was awarded to the Village of Alfred, we're able to utilize state-of-the-art technology to scan and duplicate certain terra cotta elements on that building that could otherwise never be reproduced," says John Simmins, CACT executive director.

A committee of faculty, staff, and students from Alfred University have begun the process of identifying the repairs needed to both preserve its historic elements and ensure the building is structurally secure for another hundred years.

Adds Simmins, "The CACT was launched to support the growth of New York State's ceramic industry, including the creation of start-up companies like Replacement Tiles Solutions. This is an exciting opportunity to support the growth of a new business in Alfred, leading to significant capital investment and sustainable job creation in our region."

To date, Replacement Tiles Solutions has invested approximately $500,000 in specialized equipment used in its process, and the firm employs a handful of part-time and student workers. The firm hopes to graduate from the IncubatorWorks facility within the next two years and relocate to a larger facility to allow for expanded manufacturing while remaining in the Alfred community.

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