Spotlight

Additive Manufacturing: Building the Future

March 2019

Success Stories

U.S. DEPARTMENT OF ENERGY | Office of TECHNOLOGY TRANSITIONS
energy.gov/technologytransitions
Success Stories
Solving Industry’s Additive Manufacturing Challenges

Contents

Development of BAAM System Spurs Birth of an Industry ................................................................. 1
BAAM System Demonstrates Potential for Innovation Across Multiple Industries .............................................. 2
Large Scale Metal Printing Opens Doors for Localized Manufacturing ...................................................... 3
New Generation of Miniaturized, High-Efficiency Heat Exchangers ......................................................... 4
Enabling Efficient Additive Manufacturing of Titanium Alloys ............................................................... 5
3D Direct Ink Writing with Graphene Aerogels ...................................................................................... 6
Additive Manufacturing of Precast Concrete Molds for Construction Applications ........................................ 7
X-Rays Help Identify and Avoid Flaws in Laser Metal Deposition ............................................................ 8
Additive Manufacturing of High Temperature Alloys for Energy Applications ............................................. 9
3D Printing Aerospace-Grade Carbon Fiber ......................................................................................... 10
3D Printing Enables Development of Cost-Effective Robotics ................................................................. 11
Developing a New Qualification Framework for Additive Manufacturing ............................................... 12
3D Printing Metal Parts Faster than Ever ......................................................................................... 13
Development of BAAM System Spurs Birth of an Industry

Oak Ridge National Laboratory in partnership with Cincinnati Incorporated and Strangpresse

Large-format 3D printer developed, licensed, and commercialized as industry adopts new additive manufacturing technology.

Innovation

Additive manufacturing (AM) processes had been widely limited by slow printing rates, a narrow range of source materials (e.g., extruded plastic), and small-volume product output capabilities. In 2014, Oak Ridge National Laboratory (ORNL) and Cincinnati Incorporated (CI) helped transcend these limits by developing the Big-Area Additive Manufacturing (BAAM) technology. Using new materials (carbon fiber-reinforced polymers), new processes (extruders) and controls, the team enabled an “out-of-oven” additive process that eliminated size constraints, enabled processing rates 500 times faster and build volumes 100 times larger than those of state-of-the-art commercial printing systems—with less material and energy waste.1,2

Outcomes

Technology Advancement

ORNL has used its large-area printers to demonstrate a variety of AM innovations ranging from full-scale prototype systems (cars, boats, submarines) to rapid low-cost tooling for the automotive, marine, aerospace, and construction industries. The system is the first to utilize plastic pellet feedstock reinforced with 20% carbon fiber, enabling production of stronger and stiffer parts. It has an 8-foot by 20-foot build area and can print structures up to 6 feet tall.1,3

Impact

ORNL licensed the BAAM technology and CI sold the first BAAM beta system in September of 2014. As of November 2017, CI has sold 14 BAAM systems to industries including aerospace, automotive, material providers, and tooling, among others. Since rolling out the BAAM, ORNL helped Cosine Additive with a medium-scale system, Strangpresse developed a line of BAAM extruders, Thermwood commercialized a large-scale additive manufacturing (LSAM) system, and ORNL partnered with Ingersoll to develop wide and high additive manufacturing (WHAM) machines.4

Using carbon fiber-enhanced polymers, the BAAM printer produced the frame and body of a full-scale Shelby Cobra in 2014; body panels feature a surface variation of 0.020 inches.

“**The auto industry could save energy and time with this type of additive manufacturing.**”

Rick Perry,
U.S. Secretary of Energy

Timeline

**February 2014**: CI signs a partnership agreement with ORNL to develop new, large-scale AM system1

**September 2014**: Strati car printed live at the International Manufacturing Technology Show with the BAAM4

**January 2015**: ORNL presents 3D-printed Shelby Cobra at Detroit Auto Show3

**September 2016**: Ingersoll and ORNL partner to develop WHAM

**October 2017**: Strangpresse commercializes ORNL extruder technology

**November 2017**: CI has sold 14 BAAM systems4

---


2 EESD Review. [orl.gov/blog/eess-review/mdf-new-large-area-multi-material-printer-advance-research](orl.gov/blog/eess-review/mdf-new-large-area-multi-material-printer-advance-research)


5 Instagram. [instagram.com/p/BXYgMtwgTPi/](instagram.com/p/BXYgMtwgTPi/)
BAAM System Demonstrates Potential for Innovation Across Multiple Industries

Oak Ridge National Laboratory in partnership with various industry partners and the U.S. Navy

Diversity of 3D-printing projects shows promise for revolutionizing the manufacture of transportation and construction machinery.

Innovation

Upon unveiling the novel large-scale 3D printer that enabled faster printing of larger objects with advanced materials, the Big-Area Additive Manufacturing (BAAM) has shown the range of innovative products it can fabricate. Thus far it has printed automobiles (e.g., Shelby Cobra, Strati, the body of a military jeep), a house, a submarine, a mold for a wind turbine blade, a boat hull mold, and a trim tool used in manufacturing wing tips for Boeing’s 777X. These AM products used composite printing technologies to show the possibilities that AM technologies unlock.

Outcomes

Technology Advancement

These projects demonstrate the possibility to create customized vehicles and heavy machinery while saving time and money, a great benefit to the U.S. Navy in particular. In addition, these innovative designs and applications show the diversity of uses for AM products in residential, military, and construction industries. Exemplifying the versatility of the technology, the excavator project used a variety of 3D printing materials and processes, showing the seamless integration of AM parts into a large, working machine.1,2

Impact

In the case of 3D-printed submarines and watercraft, AM technology reduces the number of parts and cost compared to traditional manufacturing. The full-scale 210-square foot home and vehicle – both printed at ORNL’s Manufacturing Demonstration Facility – and excavator integrate industrial components that involve complex shapes and patterns. These research projects provide solutions on a small scale, which will translate to significant reductions in energy use and corresponding increases in cost savings when ramped up to a national or global level.1,5

Timeline

January 2015: ORNL conceptualizes new 3D-printed demonstration machine1

April 2015: Early production on the house and vehicle begins utilizing AM2

September 2015: Integrated home and vehicle energy system unveiled at EERE Industry Day at ORNL3

August 2016: Project partners began work on the 3D-printed submersible at a two-week rapid prototyping event4

March 2017: Excavator is showcased at the International Fluid Power Expo5

1 DOE. energy.gov/eere/articles/navy-partnership-goes-new-depths-first-3d-printed-submersible

2 ORNL. ornl.gov/sci/manufacturing/projectame/

3 ORNL. https://web.ornl.gov/sci/eere/amie/

4 U.S. Navy. navy.mil/submit/display.asp?story_id=101537

5 3D Printing Industry. 3dprintingindustry.com/news/project-ame-3d-printed-excavator-showcased-las-vegas-107482/
**Large Scale Metal Printing Opens Doors for Localized Manufacturing**

Oak Ridge National Laboratory in partnership with America Makes, Lincoln Electric and Wolf Robotics

*Bringing advantages of AM to large, structural metal components for applications such as tooling, vessels, construction and more.*

**Innovation**

After several technological breakthroughs in the area of large-scale polymer deposition, Oak Ridge National Laboratory (ORNL) teamed up with Lincoln Electric and Wolf Robotics to bring advantages of AM to large, structural metal components for the tool and die sector as well as construction and automotive applications.

**Outcomes**

**Technology Advancement**

Wolf Robotics, Lincoln Electric and ORNL partnered to develop the materials and processes necessary to manufacture large (over 100 cubic feet) metallic structures at high deposition rates (>10 lbs/hr). Preliminary modeling efforts, validated through thermal imaging and neutron scattering, helped enable the development of new materials and controls that provided a pathway to the rapid production of large-scale metal structures. Current efforts are expanding to multi-material and hybrid additive/subtractive processes.

**Impact**

ORNL showcased the impact of this system by fabricating the arm of a mini excavator at CONEXPO 2017, a construction expo with over 130,000 attendees. The excavator arm was fabricated from mild steel weld wire on the Wolf platform in about 5 days and illustrates how this novel system can be used to create single components with complex geometries. Specifically, it showcases the ability to embed hydraulic channels within the print.

Recently, ORNL showcased the capabilities of the large-scale metal additive manufacturing by printing a new die every day that was machined, hard faced, and used to fabricate parts at the International Manufacturing Technology Show (IMTS) 2018. Whirlpool manufactured over 70,000 refrigerators using a 3D printed metal stamping die.

*The 3D printed excavator] will be a platform to demonstrate how the latest innovations and applied technologies are changing the future of the construction industry.*

John Rozum, IFPE Show Director

**Timeline**

- **August 2016:** ORNL installs Lincoln Electric/Wolf Robotics MIG welder in high bay
- **March 2017:** ORNL presents 3D printed excavator at CONEXPO
- **December 2017:** Development of thermal mechanical models to predict distortion and thermal history of large-scale steel structures
- **August 2018:** ORNL demonstrates ability to print multi-materials using Wolf platform
- **September 2018:** The team illustrates the concept of “Die in a Day” at IMTS 2018
New Generation of Miniaturized, High-Efficiency Heat Exchangers

DOE Building Technologies Office in partnership with the University of Maryland and 3D Systems

Printing a heat exchanger as a single, continuous piece allows novel designs at greater manufacturing efficiencies, with important implications for commercial products.

Innovation

Tube-fin heat exchangers have historically offered relatively high efficiency at low manufacturing cost—effectively constraining exploration of highly efficient alternative designs that would be too expensive to mass produce. 3D printing significantly accelerates the design-to-production process for complex heat exchangers, lowers production costs, and permits non-conventional shapes that can improve performance. Researchers at the University of Maryland’s Center for Environmental Energy Engineering (CEEE) were able to design and manufacture an innovative heat exchanger in just weeks instead of months.¹

Outcomes

Technology Advancement

Over the course of the project, CEEE researchers designed, prototyped, and additively manufactured a novel 1kW miniaturized air-to-refrigerant heat exchanger prototype that reduces energy losses by 20% relative to existing technologies and weighs 20% less. Compared to current advanced heat exchangers, it can also be manufactured much more quickly. A 10kW prototype was also fabricated and tested as part of this project.²³

Impact

Heat exchangers are crucial components in residential and commercial heat pump systems (e.g., HVAC and refrigeration) that consume nearly 7 quadrillion Btu in the United States each year. The widespread commercial deployment of low-cost, high-efficiency heat exchangers can help to dramatically reduce this energy consumption and associated emissions. On a global scale, heat exchange is a multi-billion-dollar industry, impacting everything from consumer goods to automotive and aerospace engineering. As a result, improving the efficiency of a heat exchanger can improve the performance of a broad range of products.¹

²University of Maryland. cee.umd.edu/news/news_story.php?id=9709
³DOE Building Technologies Office. energy.gov/sites/prod/files/2016/04/f30/312103_Radermark_040616-1505.pdf

“・The prototypes take much less time to build, enabling us to do test designs much earlier and more often during research.”²

Dr. Vikrant Aute, CEEE Researcher

Timeline

March 2014: Heat exchanger design optimization completed³
June 2015: UMD researchers complete fabrication and testing of 1kW prototype high-efficiency heat exchanger³
January 2016: Project team completes fabrication and testing of 10 kW prototype as part of the same project³
Enabling Efficient Additive Manufacturing of Titanium Alloys

Ames Laboratory

Close-coupled high pressure gas atomization enabled by the “hot shot” pour tube energy-efficiently converts molten titanium into uniform fine spherical powders for use in manufacturing a broad range of products.

Innovation

Standard gas atomization methods for titanium (Ti) produce a wide range of sizes of spherical powder and only small yields of useful powders (diameters less than 45μm) resulting in extremely expensive fine powders of Ti-based alloys. The more efficient and uniform process of close-coupled gas atomization is needed, but required the design of a new modular pour tube heater to allow superheating of the Ti-alloy melt prior to immediate supersonic (cold) gas impingement, creating the best atomization conditions for the formation of high yields of fine spherical powders.¹

Outcomes

Technology Advancement

Given the rapid progress in 3D printing and additive manufacturing technology, ready access to affordable custom metal powders is likely to expedite further advancements in these energy-efficient production processes. Ti metal powders produced using this close-coupled gas atomization process open new possibilities for low-cost, high-volume additive manufacturing. This includes new opportunities in industrial, automotive, aerospace, and medical markets to revisit materials that industry and researchers had previously deemed too hard to work with.²

Impact

According to the Powder Metallurgy Review (August 2017), the Ti atomization process developed at Ames Laboratory may be 10 times more efficient than traditional powder-making methods and could lower manufacturing costs by 80%.⁴ The Lab has acquired at least 16 patents for the process over the last two decades. In 2014, spin-off company Iowa Powder Atomization Technologies (IPAT) was acquired by Praxair, which now exclusively licenses Ames Laboratory’s Ti atomization patents.²

Timeline

Summer 2011: Iowa Powder Atomization Technologies (IPAT) spin-off company established to exclusively license Ames’ Ti atomization patents⁵

Summer 2014: Praxair, Inc. – a Fortune 250 company – acquires IPAT

December 2015: Praxair Inc., in partnership with Ames Laboratory, begins large-scale production of Ti powder for use in AM and metal injection molding³

September 2017: Ames Laboratory’s “hot shot” pour tube wins the 2017 Excellence in Technology Transfer Award⁴

“This method enables us to revisit materials that have been around a long time, give them a second chance, and find new potential applications for them.”

Dr. Iver Anderson  
Senior Metallurgist, Ames

² Science News: sciencedaily.com/releases/2017/01/170112113847.htm
³ World Industrial Reporter: worldindustrialreporter.com/praxair-market-ames-labs-titanium-powder-additive-manufacturing/
⁵ DOE: energy.gov/articles/iowa-start-may-be-america-s-next-top-energy-innovator

energy.gov/technologytransitions March 2019
3D Direct Ink Writing with Graphene Aerogels

Lawrence Livermore National Laboratory in partnership with Virginia Polytechnic University

Novel process produces complex objects from a high-performing material for tailored applications in energy storage, aerospace, and other industries.

Innovation

Aerogel is a synthetic, porous, ultralight material formed by replacing the liquid component of a gel with a gas. Graphene aerogel, one of the least-dense solids in existence, is ideal for energy storage applications because of its high surface area, strength, and excellent mechanical properties, including high thermal and electric conductivity. Previous efforts to produce bulk graphene aerogels yielded only 2D sheets or basic structures with largely random pore structures, thwarting efforts to optimize the material’s useful properties. Researchers have now successfully used an AM technique (direct ink writing) to create microlattices and other intricate structures for making graphene-based aerogels, opening a range of potential applications for this unique material.1,2,3

Outcomes

Technology Advancement

Researchers combined an aqueous graphene oxide (GO) suspension and silica filler to form a highly viscous ink, which can be extruded through a micronozzle to print a 3D structure.1 After using ultrasound to break the GO hydrogel, researchers then added light-sensitive polymers and applied projection micro-stereolithography to create the desired solid 3D structures. The 3D structures were then heated to burn off the polymers and fuse the layers together. The resulting graphene aerogel structures were an order of magnitude finer resolution than ever before achieved (10 μm versus 100 μm).3

Impact

The ability to create graphene aerogels with tailored 3D macro-architectures paves the way to optimize key properties of graphene. Graphene aerogels are promising for applications in the automotive, aerospace, energy storage, chemicals, and nanoelectronics industries. Graphene aerogel microlattices could also find uses as thermal insulators, shock absorbers, battery electrodes, pressure sensors, and catalyst supports.1,3,4

"This development should open up the design space for using aerogels in novel and creative applications” 1

Marcus Worsley
Engineer, LLNL

Timeline

April 2015: Project research is published in the journal, Nature Communications4

August 2018: Virginia Tech publishes article in Nature reporting on its work with LLNL.4 Key findings are also published in Materials Horizons.5

1 LLNL. llnl.gov/news/3d-printed-aerogels-improve-energy-storage
2 Graphene-Info. graphene-info.com/graphene-aerogel
3 Virginia Tech. vtnews.vt.edu/articles/2018/08/engineering-3dprinted-graphene.html
4 Nature Communications. nature.com/articles/ncomms7962
5 Materials Horizons. pubs.rsc.org/en/content/articlehtml/2018/mh/c8mh00668g
Additive Manufacturing of Precast Concrete Molds for Construction Applications

Oak Ridge National Laboratory in partnership with Gate Precast and Precast/Prestressed Concrete Institute

Demonstrating how additively manufactured precast concrete molds outperform conventional molds.

Innovation

Polymer composite AM has reached new heights in recent years with the development of large-scale systems such as the Big Area Additive Manufacturing (BAAM) system and the Wide and High Additive Manufacturing (WHAM) machine. Oak Ridge National Laboratory (ORNL) has also made significant advances in working with industry to develop polymer chemistries for pellet feedstock material for use on these large-scale systems. To date, ORNL has successfully printed over 70 various fiber-reinforced polymers.

Outcomes

Technology Advancement

One of these materials, 20% carbon fiber-reinforced acrylonitrile butadiene styrene (CF-ABS) was used to 3D-print precast concrete molds to refurbish the façade of the Domino Sugar Building in Brooklyn, New York. ORNL, Gate Precast (a supplier of precast structural and architectural concrete), and the Precast/Prestressed Concrete Institute (PCI) demonstrated the feasibility of using the BAAM system to manufacture this tooling.

Impact

Conventionally manufacturing the molds is a slow and expensive process with a shrinking workforce. The 3D-printed molds have been successfully used for 190 pours while still being usable – traditionally manufactured molds can only be used for 20 to 30 pours. In addition, the 3D-printed mold can provide the durability to complete precast concrete test samples with the required accuracy of less than 0.05 inch surface defects.

Timeline

Summer 2015: ORNL and PCI initiate collaboration on advancing precast construction

July 2016: Additive Engineering Solutions becomes a service bureau and purchases a BAAM system after interacting with ORNL, provides support to precast concrete project

July 2017: ORNL and Gate Precast design, manufacture, and evaluate 3D-printed mold prototypes

August 2017: ORNL and Gate Precast begin production of molds and precast façade components

"Additive manufacturing allows you to redesign things in ways we’ve never done before.”

Dr. Lonnie Love, Corporate Research Fellow, ORNL

3D printed precast concrete mold (9’ long x 5.5’ wide) printed on the BAAM system at ORNL’s Manufacturing Demonstration Facility.

Photo: ORNL

energy.gov/technologytransitions

March 2019
X-Rays Help Identify and Avoid Flaws in Laser Metal Deposition

SLAC National Accelerator Laboratory in partnership with Lawrence Livermore National Laboratory and Ames Laboratory

X-ray studies improve manufacturing of specialized metal parts for the aerospace, automotive, and health care industries

Innovation

Metal 3D printing can occasionally produce pits or weak spots if the metal cools and hardens unevenly as successive layers are deposited. Researchers at Stanford’s Synchrotron Radiation Lightsource (SSRL) are working with Ames Laboratory and Lawrence Livermore National Laboratory experts to analyze every aspect of the process using X-rays and other tools. The aim is to find methods to eliminate pits, control the microstructure, and manufacture strong metal parts. The research uses two types of X-rays. One studies the formation of layers at a micron level, while the other analyzes how particles change from solid to liquid and back again under the laser’s path.

Outcomes

Technology Advancement

To date, researchers have investigated lasers hitting standing layers of metal powder. Next, they will investigate an approach called directed energy deposition (DED) in which a laser beam melts metal powder or wire as it is being laid down. DED enables the creation of more complex geometric forms, which would be especially useful in making repairs.

Next steps also include the incorporation of a high-speed camera into the experimental setup to document the manufacturing process. Researchers will then correlate the detailed photographic images with the X-rays to develop a clearer understanding of DED build-chamber behavior.

Impact

Avoiding flaws in 3D-printed metal parts will help manufacturers more efficiently build more reliable parts on the spot. The need for vigorous qualification would diminish, and manufacturing costs could decrease. The project can lead to an improved understanding of the laser fusion process and help to build industry confidence in metal 3D printing of critical parts for automotive and aerospace applications.

“We are providing the fundamental physics research that will help us identify which aspects of metal 3D printing are important.”

Chris Tassone, Staff Scientist, SSRL

Timeline

January 2018: Initial studies of the laser deposition process in making metal parts at SLAC’s Stanford Synchrotron Radiation Lightsource (SSRL)

May 2018: The Review of Scientific Instruments publishes paper on the research and names it an “Editor’s Pick.”

1 SLAC. slac.stanford.edu/news/2018-01-30-slac-scientists-investigate-how-metal-3-d-printing-can-avoid-producing-flawed-parts


3 LLNL. llnl.gov/news/llnl-researchers-use-x-ray-imaging-experiments-probe-metal-3d-printing-process

energy.gov/technologytransitions March 2019
Additive Manufacturing of High Temperature Alloys for Energy Applications

Oak Ridge National Laboratory in partnership with Brayton Energy

Using AM to deposit complex, near net shape energy components of high temperature materials previously considered unweldable.

Innovation

Powder bed deposition AM techniques are useful for manufacturing commercial components, but are limited by the number of materials available for use in AM systems, especially for high temperature applications such as those used in the energy sector. Oak Ridge National Laboratory (ORNL) has made significant advances in developing high-temperature alloys using laser and electron beam melting (EBM). Developments in scan strategy, modeling of thermal histories of the deposited part, and in situ non-destructive evaluation techniques have enabled the fabrication of crack-free nickel (Ni) superalloy and refractory metal components.

Outcomes

Technology Advancement

ORNL has worked on the commercial deployment of Ni-based superalloy inconel 718 (IN718), as well as other Ni-based superalloy materials such as inconel 625, HastelloyX, and Haynes 282. More recently, ORNL has used unique EBM scan strategies based on input from simulation tools to deposit crack-free IN738 and MarM-247 in complex geometries; these alloys have traditionally been unweldable. The scan strategies developed by ORNL minimize the thermal gradients that lead to cracking, allowing for the deposition of a wider range of geometries from these advantageous materials.1,2

Impact

ORNL worked with Arcam to deploy IN718 – companies printing IN718 are likely using process parameters developed by ORNL. High temperature materials developments have led to successful deposition of MarM-247 and IN738, two high temperature materials previously considered unweldable. ORNL’s various high temperature materials projects – enabling applications for gas turbines and fuel nozzle burners, among others – have enabled benefits such as higher operating temperatures, improvements in efficiency for energy generation, and lower NOx emissions.1,2

Timeline

July 2012: ORNL initiates CRADA with Arcam to develop process parameters for IN718 on Arcam’s EBM system

June 2014: Arcam launches IN718 for 3D printing off of ORNL process parameters

January 2015: Honeywell becomes the first company to use EBM to produce an aerospace component from IN718

May 2017: ORNL prints crack-free MarM-247 simple geometries

November 2017: ORNL and ECM Technologies complete trials on improving surface finish of IN738 using EBM

December 2017: GE acquires Arcam for $750 million

May 2018: ORNL completes 3D-printed crack free turbine blade using IN738


3 Arcam Press Release. arcam.com/ge-increases-its-shareholding-in-arcam-to-more-than-90-per-cent/
3D Printing Aerospace-Grade Carbon Fiber

Lawrence Livermore National Laboratory

3D printing of aerospace-grade carbon fiber composites enables greater control and optimization of this lightweight yet stronger-than-steel material.

Innovation

Lawrence Livermore National Laboratory (LLNL) researchers have found a way to successfully 3D print aerospace-grade carbon fiber composites (CFCs). These strong, lightweight, conductive, and temperature-resistant composites are restricted in applications today due to their high cost to manufacture, shape limitations (i.e., flat or cylindrical), and variable reliability in service. Now, with a modified form of 3D printing called direct ink writing (DIW), researchers are able to build complex shapes and rapidly cure the material to provide valuable mechanical properties.1,2

Outcomes

Technology Advancement

During DIW, a small nozzle extrudes custom carbon fiber-filled ink and lays it down precisely within a 3D build space to construct complex shapes.2 With a patented new chemistry, the material cures in seconds instead of hours.1 Running on LLNL’s supercomputers, computational models are able to simulate thousands of carbon fibers as they emerge from the nozzle. These models can help determine the best fiber lengths and alignments to optimize material properties and performance in finished parts.2 Products with closely aligned microfibers may use two-thirds less carbon fiber and outperform CFC materials produced by other methods.1

Impact

LLNL researchers have entered discussions with commercial, aerospace, and defense partners to advance the development of this technology.1 Future applications could include high-performance airplane wings, insulation for satellite components, and wearables that can draw heat from the body.1,2

Researchers believe parallelization of the process, using multiple print heads and advanced curing protocols, would allow larger, more complex parts to be produced in reasonable timeframes. If industrial partnerships are forged, these goals may be met within a three-to-five-year timeframe.2

“The mantra is ‘if you could make every-thing out of carbon fiber, you would’ — it’s potentially the ultimate material. It’s been waiting in the wings for years because it’s so difficult to make into complex shapes. But with 3D printing, you could potentially make anything out of carbon fiber.”

James Lewicki, Scientist, LLNL

Timeline

March 2017: Scientific Reports publishes research on 3D-printed carbon fiber1

July 2017: Researchers are in discussion with possible partners to advance the development of 3D-printed carbon fiber composites.2

1 LLNL. llnl.gov/news/3d-printing-high-performance-carbon-fiber


energy.gov/technologytransitions March 2019
3D Printing Enables Development of Cost-Effective Robotics

Sandia National Laboratories in partnership with Stanford University and LUNAR

Use of AM components in robotics can lead to significant cost savings.

Innovation

Dexterous robotic hands are expensive and can cost hundreds of thousands of dollars due to the cost of components, challenging assembly procedures, and relatively small scale of their manufacture. In a project funded by the U.S. Department of Defense’s Defense Advanced Research Projects Agency (DARPA), Sandia National Laboratories (SNL) collaborated with LUNAR and Stanford University to develop a dexterous robotic hand that would cost significantly less than traditional robotic hands.¹,²

Outcomes

Technology Advancement

AM played two key roles in the development of the hand. In the design and prototype stages, it allowed parts to be quickly fabricated and tested, facilitating rapid design iterations. Approximately 50% of the Sandia Hand components are 3D printed. In addition, due to the anthropomorphic design of the hand, many of the parts have complex geometries which are difficult to manufacture using traditional methods. The use of 3D printing technology permitted the hand – including components of the fingers – to be fabricated at a substantially lower price using a laser powder bed AM process.

The Sandia Hand consists of a frame that supports a set of identical finger modules that magnetically attach and detach from the hand frame. The finger modules consist of several sensor systems that enable the hand to perform complex manipulation tasks and is supported by several imaging systems to increase function and performance.¹

Impact

The hand addresses challenges that have prevented widespread adoption of other robotic hands, such as cost, durability, dexterity, and modularity. 3D printing was a key enabler in cost-effective creation of the hand. Major cost reductions were achieved through a combination of inexpensive components, simplified assembly and maintenance procedures, and additive manufacturing methods.¹


“The Sandia Hand has 12 degrees of freedom, and is estimated to retail for about $800 per degree of freedom — $10,000 total — in low-volume production. This 90 percent cost reduction is really a breakthrough.”

Curt Salisbury
Researcher, SNL

Timeline

2010: DARPA’s Autonomous Robotic Manipulation (ARM) Program commences²

2011: The Sandia Hand, along with two other project teams, passes critical design review²

2012: Sandia Hand is developed and completes a full evaluation²
Developing a New Qualification Framework for Additive Manufacturing

Oak Ridge National Laboratory in partnership with the U.S. Air Force, other government agencies, and industry

Utilizing advanced characterization and data analytics to address challenges and cost barriers associated with adopting AM parts for transportation, defense, and energy applications.

Innovation

Although AM technologies have demonstrated the ability to fabricate complex products, few are currently being used in production environments due to the challenges and costs associated with the certification and qualification of parts and components. AM presents the advantage of building objects one element at a time. Developing technologies that can monitor, understand, and control AM processes can advance the industry toward certifying every single element independently and then merging this information to certify the final component.

Outcomes

Technology Advancement

In order to establish a new AM certification platform, Oak Ridge National Laboratory (ORNL) developed new methods of information gathering and built software to analyze and visualize the quality of the additive component. Both hardware and software tools have been created to enable a data rich environment, capturing information from every stage of the production chain. ORNL then partnered with the U.S. Air Force using a data analytics framework (Dream3D) to visualize, analyze, optimize, simulate, and interpret the data. Since then, various data analysis and visualization software has been developed to analyze anomalies such as porosity, cracking, and microstructure evolution and link them with process variability. Artificial intelligence and machine learning software have been developed to minimize computational processing requirements and provide new tools to aid in predicting performance of AM components.¹,²

Impact

Leveraging the AM database and various analytical tools, ORNL is working to develop a digital twin for each part fabricated which contains the relevant information toward certification. Projects in nuclear, fossil energy, and energy efficiency are using these new tools.


Timeline

April 2016: ORNL initiates a data analytics framework effort for certification and qualification of AM.

December 2017: ORNL completes project with Honeywell on residual stress determination of direct metal laser sintered inconel specimens and parts

June 2018: ORNL completes a collaboration with Rolls Royce to understand part-to-part variability during directed energy deposition processes using in situ and ex situ process characterization

Spring 2018: ORNL initiates projects with BWXT to use the digital qualification framework to evaluate components for the nuclear industry

---

1,2 energy.gov/technologytransitions March 2019
3D Printing Metal Parts Faster than Ever

Lawrence Livermore National Laboratory

A technology originally developed to smooth out and pattern laser beams can be used to 3D print metal objects faster than ever before.

Innovation

Lawrence Livermore National Laboratory (LLNL) scientists have developed a new metal 3D printing process called Diode-based Additive Manufacturing (DiAM) which uses arrays of laser diodes, a Q-switched laser and a specialized laser modulator developed for LLNL’s National Ignition Facility to flash print an entire layer of metal powder at a time, as opposed to other powder-based laser systems.

The result is that large metal objects could be printed in a fraction of the time compared to metal 3D printers on the market today, expanding possibilities for industries requiring larger metal parts, such as aerospace and automotive. The speed and degree of design flexibility afforded with the DiAM method is potentially “far beyond” that of current powder-bed fusion-based systems.¹

Outcomes

Technology Advancement

The benefit of the DiAM process is the implementation of a customized laser modulator called an Optically Addressable Light Valve (OALV), which contains a liquid crystal cell and photoconductive crystal in series. Much like a liquid crystal-based projector, the OALV is used to dynamically sculpt the high-power laser light according to pre-programmed layer-by-layer images. Unlike a conventional liquid crystal projector, the OALV is un-pixelated and can handle high laser powers.¹

Impact

In 2016, Lawrence Livermore National Security (LLNS) LLC licensed patents for the system to Seurat Technologies, a startup company that envisions bringing an industrial metal printer to market with unparalleled speed and resolution. The Department of Energy awarded a grant to Seurat under the HPC4Manufacturing (HPCMfg) program in August of 2018 that will allow the company to use high-speed video, material analysis and multiphysics modeling performed at LLNL to optimize the printer. Seurat also closed a $13.5 million Series A round of funding in 2018 led by venture capitalist firm True Ventures that will be used to accelerate commercialization of the technology.

Timeline

2016: LLNS licenses patents for Diode-based Additive Manufacturing (DiAM) technology to Seurat Technologies

October 2017: Optics Express publishes research on DiAM

January 2018: Seurat closes $13.5 million Series A round of funding to accelerate commercialization of technology

August 2018: U.S. Department of Energy awards grant to Seurat Technologies under HPC4Manufacturing program allowing company to work with LLNL to optimize industrial metal printer
