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CENTER FOR AGILE AND ADAPTIVE ADDITIVE MANUFACTURING
Fostering innovative industry-academia-government partnerships through science and engineering of agile and adaptive additive manufacturing

CAAAM
Reaching for a star

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UNT’s Center for Agile and Adaptive Additive Manufacturing (CAAAM) was launched in 2019, thanks to a $10 million appropriation by the Texas Legislature that helped to fund the center’s nearly $6 million in new custom-built equipment. In 2021, the Texas legislature renewed CAAAM’s funding through 2023 with an additional $10 million — a reaffirmation of the center’s importance in positioning Texas as a leader in additive manufacturing innovation and workforce development.

While the industry is rapidly moving forward, additive manufacturing is a long way from becoming a commercially viable tool for widespread industrial applications due to a lack of thorough understanding among researchers and industry leaders of the science and engineering of materials from micro-to-multiscale properties. This includes physics-based processes and science and engineering approaches such as fusion-based, solid-state, mixed-phase and surface engineering-based additive manufacturing.

Many innovations now are feasible through CAAAM’s synergistic approach involving computational processes, materials modeling and in-situ and ex-situ process, materials analysis/diagnostics along with data and decision sciences and machine learning sciences. The center is poised to forge innovative interdisciplinary collaborations across a multitude of science and engineering aspects of additive manufacturing including cybersecurity, data and decision sciences, complex logistics and supply chain, and high-performance computing. Additionally, the center will work to address acute shortages in the manufacturing workforce by empowering companies to embark on additive manufacturing innovation and create industry-research partnerships with regional and multinational manufacturing industries and their partners to meet the needs of public, private, federal and defense industry domains. These partnerships ultimately will lead to technology development and commercialization opportunities. Finally, CAAAM’s educational unit, the Institute for Transformative Education in Additive Manufacturing (ITEAM), focuses on developing a truly comprehensive and integrated education and training program in additive manufacturing. The emphasis is on the underlying scientific principles behind each of the additive manufacturing (AM) processes and detailed and robust characterization of the microstructure/nanostructure and resulting properties.

Through support from partnerships and the State of Texas, CAAAM is positioned to build and support next-generation manufacturing expertise to lead U.S. global competitiveness and forge the way toward creating the future of manufacturing innovation and success. We look forward to you joining us in making this vision a reality!

Sincerely,

Narendra Dahotre

FROM OUR ASSOCIATE VICE PRESIDENT

MISSION
To serve as a catalyst in fostering innovative industry-academia-government partnerships through science and engineering of agile and adaptive additive manufacturing

GOALS
Support and strengthen interdisciplinary collaborations in science and engineering of materials
Enable the 21st century data-capable workforce that supports U.S. leadership in additive manufacturing
Serve as model for incubating new centers of excellence and to strengthen research and academic excellence in support of UNT’s pursuit of National Research University status

TIMELINE
» 2006 LENS system: the first 3D printing of metals system in North Texas
» 2008 U.S. Air Force Research Lab funds novel composites program at UNT
» 2010 Additive, Subtractive Manufacturing Lab at UNT; metals, ceramics, composites
» 2011 First center for Friction Stir Processing in Texas
» 2012 Federal government establishes National Additive Manufacturing Institute, AMERICA MAKES
» 2016 International Journal of Additive & Subtractive Manufacturing, Narendra Dahotre, editor-in-chief
» 2018 Additive Manufacturing Lab at UNT
» 2019 CAAAM is established with funding from Texas Legislature
» 2021 Texas Legislature renews CAAAM’s funding through 2023
WHO WE ARE

ADDITIVE MANUFACTURING IS A RAPIDLY DEVELOPING TECHNOLOGY that builds complex and near-net shape 3D objects through the successive layering of materials. These objects can be of almost any shape or geometry and are produced in an agile and adaptive manner through the use of laser technology. Because of its unprecedented efficiency, limitless applications, and a transformational shift in design, manufacturing and supply approaches, industry will increasingly turn to additive manufacturing technology to produce stronger and more efficient materials.

The center is working to forge innovative interdisciplinary collaborations across a multitude of fields, including cybersecurity, data and decision sciences, complex logistics and supply chain, and high-performance computing. CAAAM empowers companies to embark on additive manufacturing innovation and create industry-research partnerships with regional and multinational manufacturing industries and their partners to meet the needs of public, private, federal and defense industries. These partnerships ultimately will lead to technology development and commercialization opportunities.

CAAAM researchers have multiple funded research programs on additive manufacturing related activities from the Army Research Laboratory, the U.S. Air Force Office of Scientific Research and the Australian Institute for Robotic Orthopedics, as well as the U.S. additive manufacturing industry. Also, faculty from UNT, as well as UNT’s Health Science Center, are working regularly on multiple funded research grants from the National Institutes of Health. The pioneering work by UNT faculty has resulted in multiple patents and patent applications and development of technologies that are licensed to the biomedical sector. They also pioneered laser-based manufacturing of biomedical devices. UNT established the first university-based comprehensive and centralized Additive Manufacturing Facility in the North Texas region, bringing together multiple additive manufacturing platforms of laser powder bed fusion and directed energy deposition systems.

WATCH A VIDEO TO LEARN MORE ABOUT CAAAM.
OPTOMEC LENS CS-250
The LENS CS-250 System is the latest model to come out of Optomec Inc. Featuring four powder hoppers, this machine can be used to make compositionally and functionally gradient materials. This machine also comes with a 5-axis system that creates complex shapes and also performs repairs on existing parts. A 1KW nLight laser system can be used to print highly reflective materials like copper and its alloys.

HYBRID MANUFACTURING AMBIT™
This machine combines both the additive and subtractive part of manufacturing in one system. It can be used to deposit metal from 0.5 to 3mm+ (~0.02” to .12”) bead-width. Additional types of laser processing are supported by the Series 7 powers for drilling, ablating and finishing metal.
SOLID STATE PROCESSING

MELD B8
The MELD B8 is a solid-state processor, meaning materials do not reach melting point temperatures while in use. It offers a wide range of capabilities, including additive manufacturing, coating applications, component repair, metal joining, and custom metal alloy and metal matrix composite billet and part fabrication.

BINDING JETTING

EXONE INNOVENT+
Binder jetting uses a binder to make, cure and sinter 3D-printed parts. The machine is easy to use and features state-of-the-art recoating technology, allowing for the widest range of materials to be printed while producing the most consistent and uniform print bed. It prints the widest range of standard metal injection molding (MIM), powders, metal, ceramic, composite and other powder materials.

PRECISION MICRODISPENSING SYSTEM

NSCRYPT 3DN
The 3Dn Series is a gantry-based, high-precision motion platform running nScrip Machine Tool Software for exceptional control. For example, the user can configure the system with multiple micro-dispensing tool heads (gizmos) or multiple heads of different functionality, such as material extrusion, micro-milling, or pick and place. Other options include sintering, heating, UV curing, mapping and machine vision.

FUSED DEPOSITION MODELING

ZORTRAX M200+, MAKERBOT METHOD X, FORMLABS FORM 3+, MARKFORGED ONYX
Our small-sized printers are used for both classroom and polymer-based research. Materials vary from ABS to PC-ISO.

POWDER PROCESSING AND ANALYSIS

TEKNA TEKSPHERO-15
Spheroidization System TekSphero-15 is a plasma treatment system uniquely designed to manufacture and process metal and ceramic powder that enables the design and prototyping of new materials for additive manufacturing. This unit is equipped with a spheroidization reactor and a nanoreactor to produce powder with a particle-sized distribution from nano to micro scales. The lab-scale design of this unit allows for rapid turnarounds of experimental and computational materials design.

ANCILLARY EQUIPMENT

MELD B8
The MELD B8 is a solid-state processor, meaning materials do not reach melting point temperatures while in use. It offers a wide range of capabilities, including additive manufacturing, coating applications, component repair, metal joining, and custom metal alloy and metal matrix composite billet and part fabrication.

POWDER PROCESSING
- Powder sieves
- Powder analysis

POST PROCESSING
- Hot isostatic press
- Sintering furnace

IN-SITU CHARACTERIZATION
- Renishaw Virsa Raman spectroscopy
- In-situ emission spectroscopy system

MECHANICAL CHARACTERIZATION
- Instron 8872
- Nanovea CB500 MicroIndenter
- KLA iMicro NanoIndenter
- Kammrath-Weiss, 5KN tensile module attached with MZ.ZDi tension/compression gripper

OTHERS
- Lakeshore 8600 Series vibrating sample magnetometer
CAAAM RESEARCH THRUST AREAS

RESEARCH EFFORTS ARE BASED ON THE FOLLOWING UNIFYING ASPECTS:

- Developing a fundamental understanding of the science underlying categories of the different AM processes
- Developing a fundamental understanding of the impact of the AM process on the microstructure, nanosctructure and resulting properties of the material
- Employing the understanding gained to optimize composition and process parameters to develop a new generation of AM-processed alloys and composites
- Addressing and integrating logistics and supply-chain management, cybersecurity, data-decision sciences and analytics-related issues

Science and Engineering of AM Processes

Fundamental Understanding of the AM Process
- Fundamentals of laser-materials interactions
- In-situ monitoring and diagnostics of process
- Multi-physics process modeling

New Alloys, Composites
- Computational alloy design for AM, thermodynamic and kinetic modeling
- Structural
- Functional
- Composites, hybrid materials
- Compositionally, functionally graded

Logistics and Supply Chain
- Decentralized manufacturing structures with reduced inventories
- AM-based shift in the traditional operational, process, and business models for logistics and supply chain influence of AM technologies on improving value delivery for products within existing supply chains

3D Characterization
- X-ray tomography, microscopy
- Serial-sectioning and 3D reconstruction based on optical microscopy
- Serial-sectioning and 3D reconstruction using focused ion beam, scanning electron microscopy
- 3D tomography using transmission electron microscopy
- Atom-probe tomography

Cybersecurity
- Hardware security
- Design and verification framework for digital components
- Machine learning and predicative models
- Blockchain security

Data, Decision Sciences and Analytics
- Optimized manufacturing processes
- Intelligent predictive maintenance
- Accurate real-time detection
- Precise in-situ monitoring
- Precise ex-situ process and material evaluations

THE WAY FORWARD
CAAAM faculty members have been awarded nearly $2.4 million in externally funded research grants from agencies such as the National Science Foundation, U.S. Department of Energy, U.S. Department of Defense, U.S. Army Research Laboratory and the U.S. Air Force Office of Scientific Research, and have applied for research proposals totaling nearly $17.5 million. As a result, the center is poised to pave the way forward for the future of manufacturing success and to address workforce shortages.
ACCORDING TO A HOMELAND SECURITY ADVISORY COUNCIL 2020 REPORT, 3D PRINTING IS ONE OF THE SIX EMERGING TECHNOLOGIES WITH DEVELOPING RECOMMENDATIONS. FURTHERMORE, 3D PRINTERS WILL BE USED FOR CRITICAL APPLICATIONS SUCH AS HEALTH CARE AND TRANSPORTATION, AND MAY HAVE SIGNIFICANT IMPLICATIONS FOR PUBLIC SAFETY ISSUES SUCH AS CYBERATTACKS.

The council emphasizes multiple threat use cases such as sabotage of the critical parts in printing and concealment of illicit objects, to name just a few. In particular, 3D printed parts can be sabotaged by malicious modifications in the model files by introducing concealed flaws that may not be easily identifiable. In addition to the sabotage of the design, it is also possible for hackers to infect 3D printers with malicious code, either directly or more likely via the controlling computer. Even though the original print design may be safe and reliable, the end-product could be critically compromised.

To combat these issues, UNT computer science and engineering researchers Kirill Mozorov and Cihan Tunc are working with CAAAM to identify the attack vectors in 3D printing environments and to understand how they can affect the final printed product. Their main focus is to counter the malicious activities that target 3D printers.

"By studying the threat model and introducing the defense mechanisms and mitigation solutions, we’ll be able to integrate cybersecurity measures such as intrusion detection with material science methodologies for printed product diagnostics," Tunc says.

LOOKING TO LEVERAGE UNT’S EXISTING STRENGTHS IN DATA ANALYTICS, CAAAM RESEARCHERS HAVE PARTNERED WITH SONG FU, PROFESSOR AND ASSOCIATE CHAIR FOR RESEARCH AND OPERATIONS IN THE DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING, TO HELP ACCELERATE RESEARCH EFFORTS.

Fu and his research team model the manufacturing process using UNT’s high-performance computing capabilities to run simulations to test for AM process outcomes, such as melt pool geometry, porosity, and as-built microstructure, modeling AM processes and finding parameters for optimal processes. They also develop machine learning and deep learning methods to examine different parameters in the manufacturing process to create computer models that can be used in a wide range of manufacturing applications, including aerospace.

Fu says their results will help manufacturers down the road to determine what materials to use without having to do their own simulations. "We’re working to improve speed, feasibility and accuracy to allow additive manufacturing to be implemented in more industry settings — making it more agile and adaptive," Fu says.
SOLID-STATE PROCESSING

ONE KEY NEW PIECE OF TECHNOLOGY IN CAAAM IS THE MELD — A PATENTED ADDITIVE FRICTION STIR DEPOSITION (AFSD) TECHNOLOGY — THAT CAN PRINT MUCH FASTER AND PRODUCE VERY LARGE COMPONENTS. THIS NEXT-GEN PRINTER USES METAL BARS RATHER THAN THE POWDER-BASED FUSION EQUIPMENT THAT HAS BEEN USED FOR SEVERAL YEARS.

AFSD is a solid-state AM process where a metal feedstock or metal powder consolidate is fed through the AFSD tool. The feedstock is plasticized by friction stir heating and the plasticized material gets extruded beneath the tool that is sheared and additively deposited during tool traverse to obtain a near-to-final geometry. In a solid-state AM process, the material doesn’t melt. Instead, metal is built up using other mechanisms like friction, pressure, and velocity. These processes involve little to no heat that means little to no residual stress created in the part.

Rajiv Mishra, University Distinguished Research Professor of materials science and engineering, and other researchers in UNT’s Advanced Materials and Manufacturing Processes Institute are using state-of-the-art CAAAM to design new alloys for aerospace and research how the process affects existing materials. “3D printing through additive friction stir deposition has opened up whole areas of innovation due to the ability to build one-piece components with new advanced materials that are stronger and more efficient to produce,” Mishra says.

DIRECTED ENERGY DEPOSITION AND LASER POWDER BED FUSION

RAJARSHI BANERJEE, REGENTS PROFESSOR OF MATERIALS SCIENCE AND ENGINEERING, HAS EARNED MORE THAN $10 MILLION IN RESEARCH FUNDING DURING HIS TENURE AT UNT. HIS LATEST WORK INVOLVES EXPLORATION OF HYBRID ALLOYS AND FUNCTIONALLY GRADED ALLOYS FOR BALLISTIC APPLICATIONS.

For Banerjee, whose research focuses on lightweight metallic materials, high-temperature alloys, and high entropy alloys for aerospace, biomedical, and energy related applications — access to the state of art equipment in CAAAM has been key in improving the mechanical performance of the alloys. The instruments that he and his team utilize in their research include Optomec LENS Directed Energy Deposition systems and Trumpf TruPrint Laser Powder Bed Fusion systems.

“The big challenge for many metallic materials is how to make them high-strength while still maintaining their deformability”, says Banerjee, who is recognized as a pioneer in the additive manufacturing of materials at UNT and also is credited with playing a substantial role in the development of CAAAM. Together with Narendra Dahotre, Banerjee has made big improvements in understanding the fundamental science behind the additive manufacturing technology, which subsequently improve the performance of these alloys.
CAAAM EDUCATIONAL WING

Institute for Transformative Education in Additive Manufacturing

CAAAM’s educational wing focuses on developing a truly comprehensive and integrated educational and training program in additive manufacturing. The emphasis is on the underlying scientific principles behind each category of AM processes and detailed and robust characterization of the microstructure, nanostructure and resulting properties. The AM curricula also includes integration of data and decision sciences, artificial intelligence, cybersecurity, supply-chain logistics and high-performance computing.

THRUST AREAS
- Process Engineering
- Materials Science & Engineering
- In-situ Diagnostics
- Computational Modeling
- Novel Materials & Composites

AUXILIARY AREAS
- Data & Decision Sciences
- Cybersecurity & Informatics
- Supply-Chain Logistics
- High-Performance Computing

EDUCATIONAL PROGRAMS
Education, training and research programs:
- University faculty and research staff
- Guest lecturers from industry, national labs and other universities
- In-person certificate program: two semesters and an eight-week internship
- Fully online certificate program option
- Online and traditional master’s and Ph.D. programs
- Research and development projects

Our programs offer something for everyone:
- Traditional university academic curricula — classroom and online courses
- Laboratories
- Senior design projects
- Master’s and Ph.D.-level projects in AM
- Specialized programs for community colleges
- Certificate courses for workforce training and industrial resiliency

TRAINING TOMORROW’S WORKFORCE
Additive manufacturing will revolutionize many industries and require a workforce trained in the engineering and technical skills of this emerging area. CAAAM’s Institute for Transformative Education in Additive Manufacturing (ITEAM) focuses on education and workforce development.

“Our goal is not only research, but also education — creating the workforce for the next generation,” says Narendra Dahotre, founding leader and associate vice president of CAAAM.

WATCH A VIDEO TO LEARN MORE ABOUT ITEAM.
HECTOR SILLER, ASSISTANT PROFESSOR OF MECHANICAL ENGINEERING, IS WORKING TO DEVELOP MEDICAL IMPLANTS AND DRONES THROUGH DIGITAL MANUFACTURING.

“These are two dissimilar fields,” he says. “But what they have in common is that they require the use of lightweight structures that can only be made by additive manufacturing.”

Together with his research group, Siller is using three different programs in CAAAM: Hybrid Manufacturing (Directed Energy Deposition), Laser Powder Bed Fusion (L-PBF) and Structural Design Optimization. In Hybrid Manufacturing, the aim is to study surface integrity, process monitoring, process life cycle and the use of multisensory approaches for process optimization. The integration between additive and subtractive manufacturing is relevant to accelerate the adoption of hybrid processes when making products like conformal molds, large aerospace precision parts and lightweight mobility systems.

Sillers’ work with CAAAM also involves structural design optimization and is aimed to investigate how topology optimization — the use of meta-material properties and lattice-based optimization — can be used in light-weighting, sound mitigation and energy-absorption applications such as in drone components, medical devices or in soft actuators for robotic devices.

IN-SITU DIAGNOSTICS

IN-SITU MONITORING OF THE AM/3D PRINTING PROCESS IS A CRITICAL CAPABILITY GAP NEEDED FOR REAL-TIME PROCESS CONTROLS AND STANDARDIZATION AND CERTIFICATION OF AM/3D PRINTED COMPONENTS.

Researchers in CAAAM, including Nigel Shepherd, associate professor of materials science and engineering, and Andrey Voevodin, professor of materials science and engineering, are addressing this important technological gap by developing non-invasive spectroscopic methods for in-situ composition analysis and monitoring using Optical Emission Spectroscopy (OES), Laser Induced Breakdown Spectroscopy (LIBS) and Raman spectoscopies.

Integration of these in-situ techniques facilitates the understanding of the AM/3D printing process dependent thermokinetic effects on compositional variation and microstructural evolution in real time of the component being fabricated. This understanding, when correlated and verified with ex-situ characterization, will iteratively guide synthesis and processing optimization, and facilitate development of the processing rules that govern the design of microstructure, macrostructure and multiple properties of the components. As a result, performance uncertainties will be reduced and the processes will achieve quality assurance, standardization and certification. “The ultimate goal of our work is to reduce performance uncertainties and achieve quality assurance,” Shepherd says.
SUPPLY CHAIN LOGISTICS

WHILE ADDITIVE MANUFACTURING HAS MANY ADVANTAGES — THE ABILITY TO MANUFACTURE ONE-OFF DESIGNS, USE ADVANCED MATERIALS, MANUFACTURE WITHOUT WASTE AND CREATE ONE-PIECE PARTS WITH ALMOST LIMITLESS POSSIBILITIES OF COMPLEX DESIGN — MUCH NEEDS TO BE RE-ENVISIONED, SUCH AS WITH THE SUPPLY CHAIN PROCESS.

Ph.D. candidate Himali Patil and assistant professor Suman Niranjan in the Department of Logistics and Operations Management are studying the logistics of additive manufacturing spare parts, from automotive to appliances. In the not-too-distant future, service or repair companies could actually print small spare parts in their service vehicles or locally, as long as they have the designs. Patil is collecting data from manufacturers to look at what additive manufacturing of metal parts would be practical, feasible and economically viable.

“Additive manufacturing of spare parts could be a revolution,” says Arunachalam Narayanan, associate professor of information technology and decision sciences. “It’s not that the technology is not good. It’s just that people have not studied it, and there’s not enough trust in the process. CAAAM is helping to understand these things so the industry can move forward.”

POLYMERS

XIAO LI, ASSISTANT PROFESSOR OF MATERIALS SCIENCE AND ENGINEERING, IS RESEARCHING THE POLYMERS LIQUID CRYSTAL ELASTOMERS, WHICH ARE USED IN APPLICATIONS SUCH AS SOFT ROBOTS, ARTIFICIAL MUSCLES, SENSORS AND ALSO AEROSPACE SYSTEMS.

Li and her group use CAAAM to create 3D-printed, hierarchical, porous structures using these liquid crystal elastomers. The idea of using porous structures is unique and hasn’t been fully developed, but Li believes they have great promise.

The liquid crystal elastomers with hierarchical nano-/micro-porous structure will significantly advance multi-function, multi-responsiveness of the materials and enable the design of micro-actuators — microscopic servomechanism that supplies and transmits a measured amount of energy to operate another mechanism or system — and wearable devices that are smaller in size, lighter and lower energy consumption. “The foundations established here will support the realization of advanced smart materials concepts and adaptive, multi-functional materials that dynamically respond to their environment,” Li says.
CAAAM is working with numerous external partners to help advance engineering research, development and innovation, and workforce training.

- **ASTM International**, standards development on various aspects of additive manufacturing
- **Air Force Research Laboratory**, manufacturing technology development
- **Hybrid Manufacturing Technologies**, development of hybrid (additive + subtractive) manufacturing
- **TRUMPF GmbH**, process design and development
- **Pratt & Whitney**, development of new and repair applications using additive manufacturing
- **ATI Metals**, powder development
- **Tosoh SMD Inc.**, development of non-traditional/non-commercial metal powder development as precursor material in additive manufacturing printing
- **Boeing**, enabling cradle-to-cradle manufacturing through friction stir additive deposition of metallic materials as a breakthrough technology for converting the recycled titanium chips into products
- **Altair Engineering**, software development in additive manufacturing
- **Cook Children’s Medical Center**, additive manufacturing for clinical application
- **Stratasys Inc.**, material characterization of 3D-printed biomaterials
- **Bio X Cell**, cellular printer for printing of biological and cellular materials
- **MELD**, friction stir based solid-state additive manufacturing
- **H.C. Starck**, powder development
- **National Center for Defense Manufacturing and Machining, IUCRC engagement with SHAP3D; potential to increase industry-research partnerships and educational engagement opportunities through ITTEAM
- **Army Research Laboratory**, new alloy development for ballistic applications

“CAAAM has very impressive facilities and comprehensive capabilities. We look forward to our continued collaboration with UNT.”
— Kerri McGrory, Project Engineer at Pratt & Whitney

“We are very excited by the number of facilities, and the deep and frontier research CAAAM can perform.”
— Qiaofu Zhang, Senior Materials Design Engineer at Questek Innovations LLC

CAAAM’s workforce development goes beyond training students to use the new technology. The center is taking a holistic approach to additive manufacturing, not just in the areas of materials science and processing methods, but looking at everything from sustainability to data science.

“3D printing is not typically associated with all of the topics we are addressing — but is associated with mainstream technology,” says Rajarshi Banerjee, Regents Professor and director of UNT’s Materials Research Facility at CAAAM. “In the future, all these aspects of 3D printing will be interconnected, and that’s what CAAAM is all about.”