APRIL 9-11, 2024

Hosted by

Colorado School of Mines

Golden, Colorado

America Makes

TRX

Technical Review & Exchange

www.americamakes.us

America Makes

America Makes is the nation's leading public-private partnership for additive manufacturing (AM) technology and education. America Makes members from industry, academia, government, workforce and economic development organizations, work together to accelerate the adoption of AM and the nation's global manufacturing competitiveness.

Founded in 2012 as the Department of Defense's national manufacturing innovation institute for AM and first of the Manufacturing USA network, America Makes is based in Youngstown, Ohio, and managed by the not-for-profit National Center for Defense Manufacturing and Machining (NCDMM).

Learn more at americamakes.us.

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DAY 1 @ THE ROSE	Venue Guest	VenueGuest
DAY 2/3 @ FRIEDHOFF HALL	Mines-Guest	(Not Needed)

Welcome to TRX!

The America Makes Technical Review and Exchange (TRX) is your opportunity to gather and discuss current Institute projects. During the event, you can expect to dive into a deeper level of technical information regarding each of the collaborative projects on the agenda.

There are 28 America Makes projects being presented over the next three days and attendees are encouraged to ask questions to gain a greater understanding of the research underway.

In addition to the project, we are excited to feature keynote speakers from the Colorado School of Mines, as well as insightful presentations from Ames National Laboratory, National Institute of Stardards and Technology, and the Department of Energy.

Enjoy your TRX experience in Golden, Colorado!

THANK YOU TO OUR HOSTS!

TRX@MINES – April 2024 by the numbers

America Makes
CORE
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CORE currently hosts over $350M in funded research along with related information as shared by our partners.

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CORE uses an advanced AI engine and natural language search tools to enhance the user experience. The tools consume the entirety of the material within the platform, returning search results that are highly relevant to the user's query.

The organization of the data provides a quick view of new and updated projects, as well as items recognized as important. This streamlined experience allows users to more rapidly identify relevant information, browse topics, and explore the body of knowledge.

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EXCLUSIVE ACCESS TO TRX CONTENT

TRX attendees can access the full content and project-related information presented at the event through the following links:

Two ways to access TRX content:

https://bit.ly/3wz0J42

Agenda subject to change without notice

TRX DAY 1 Tuesday, April 9, 2024

DAY 1

8:00	**Kickoff and Welcome** Brandon Ribic, America Makes
8:15	**Mines Welcome** Paul C. Johnson, President, Colorado School of Mines
8:30	**Interdisciplinary Research and Education in ADAPT at Mines** Joy Gockel, Colorado School of Mines
9:00	**Reliable Additive Manufacturing 1 Meter Tall (RAM1) (5526.001)** Alan Fung, Aerojet Rocketdyne
9:30	**Marotta – AM Phase 3, Application Development (5538)** Ross Brown, Marotta Controls
10:00	**Networking Break**
10:30	**Post-Processing Optimizing of Additive-Manufactured Nickel-Based Superalloys (5533)** Agustin Diaz, REM Surface Engineering
11:00	***Keynote:* Weldability of LPB-F Additive Manufactured Ni-base Superalloys** Zhenzhen Yu, Colorado School of Mines
11:30	**Improving LPBF Operational Qualification Through Software Automation (5567)** Alex Benham and Harshil Goel, Dyndrite
12:00	**Lunch/Networking Break**
1:00	**Methods and Approaches for Sustainable AM Operations (5567.001)** Mark Shaw, Wichita State University - National Institute for Aviation Research
1:30	**Accelerating Control and Certification: Enhancing Laser-PBF and Electron Beam-PBF Operation Quality via Real-time Analytics, Technological Integration, and Experimental Platforms for a Resilient Supply Chain (ACCELERATE) (5567.002)** Mohsen Taheri Andani, Texas A&M University
2:00	***Keynote:* Simplifying Post-Processing with Self-Terminating Etching Processes & Quench-Free Printing of Amorphous Metals Using Reactive Inks** Owen Hildreth, Colorado School of Mines
2:30	**Networking Break**
3:00	**Common AM Qualification Template (CAM-QT) (5550)** Bill Tredway, Applied Science & Technology Research Organization of America (ASTRO)
3:30	**Joint Metal Additive Database Definition (JMADD) (5511.001)** Neville Tay, Wichita State University - National Institute for Aviation Research
4:00	**Generation of Additive Material Allowables for Ti-6Al-4V (GAMAT) (5534.001)** Andrew Countryman, Boeing
4:30	**Day Closes; Open House Tours Available**

Agenda subject to change without notice

TRX DAY 2 Wednesday, April 10, 2024

DAY 2

8:00 **Day 2 Welcome**

8:20 ***Keynote:*** **Accelerating Alloy Development via Powder Synthesis and Advanced Manufacturing**
Ryan Ott, Ames National Laboratory (USDOE)

9:00 **Cold Metal Fusion Preliminary Research for Air Force Sustainment and Repair (5551)**
Michael Lander, The Ohio State University Center for Design Manufacturing Excellence

9:30 **Thin Wall Testing Methodology for High Temperature Materials (5560)**
Patrick Myers, GE Additive

10:00 **Networking Break**

10:30 **LIFT Award – DoD Manufacturing Innovation Institute, Cross Institute Collaborative Project: Digital Data Management for Transcribing Structural Part Performance Across Additive Manufacturing (AM) Platforms (1141)**
Alex Kitt, Edison Welding Institute (EWI); Daniel Reed, Digital Manufacturing and Cybersecurity Institute (MxD)

11:00 ***Keynote:*** **From Standards to Fundamental Research: NIST's Efforts to Expedite AM Adoption in Industry**
Callie Higgins, National Institute of Standards and Technology

11:30 **Innovations in Robotic Additive Manufacturing Process Planning (5555)**
Nathan Stranberg, Continuous Composites, Inc.

12:00 **Transitioning Best Practices and Technology Improvements for 3D Printed Molds/ Cores for Sand Castings (5554.001)**
Greg Colvin, Honeywell

12:30 **Lunch/Networking Break**

1:30 **AM Ceramic Shell Technology for Investment Casting (5554.002)**
Joseph Fritz, Investment Casting Institute

2:00 ***Keynote:*** **Metal AM at NIST Boulder – Enabling Use in Critical Applications**
Nik Hrabe, National Institute of Standards and Technology

2:30 **Maturation of Ceramic 3D Printed Shell-Based Investment Casting Foundry Capabilities of the 76th CMXG At Tinker AFB (5554.004)**
Suman Das, DDM Systems

3:00 **3D Ceramic Research & Extensive Application of Tools for Engineered Molds (3D CREATE) (5554.003)**
Randy Harris, Renaissance Services, Inc.

3:30 **Additive Manufacturing to Address Component Sourcing Gaps (5554.006)**
Kevin Orbine, Deloitte Consulting, LLP

4:00 **Student-led Tours of Mines**

5:00 **Reception held at the Geology Museum**

Agenda subject to change without notice

TRX DAY 3 Thursday, April 11, 2024

DAY 3

8:00 **Day 3 Welcome**

8:20 ***Keynote:* Strategic Priorities for Harsh Environment Materials**
Nick Lalena, Department of Energy, Advanced Materials & Manufacturing Technologies Office

9:00 **Techno-Economic Analysis to Bridge Casting and Forging Sourcing Gaps with AM (5554.007)**
Brady Williams, Wichita State University - National Institute for Aviation Research

9:30 **Pilot the Industrialization of AM Preforms to Expedite the Forging Process of Low Volume Forged Components (5554.005)**
Jay Desai, Cleveland State University

10:00 **Networking Break**

10:30 **DED Additive Manufacturing for Forging Die Repair (5554.008)**
Mayank Garg, Cleveland State University

11:00 **Delta Qual Team Red - Thorough Evaluation of AM with Rigorous Expertise and Data (5541)**
Matt Crill, The Barnes Global Advisors

11:30 **Delta Qualification Innovation (DQI) for Ti-6Al-4V Laser Powder Bed Fusion (5541)**
Kevin Chasse, Northrop Grumman

12:00 **Lunch/Networking Break**

1:00 **Boeing Baseline Delta Qualification Program (5541)**
Paul Wilson, Boeing

1:30 **Delta Qual Major: Rapid Qualification Pathway for Metal Additive Manufacturing Using PBF-L for Critical Applications (5541)**
Ben DiMarco, The Ohio State University Center for Design Manufacturing Excellence (on behalf of EOS)

2:00 **Delta Qual Major: Model Enabled Delta-Qual (MEDEL-QUAL) (5541)**
Josh Norman, Raytheon Technologies

2:30 **Delta Qual Major: Applying Machine Learning to Enable Effective Additive Manufacturing Process Qualification/Re-Qualification) (5541)**
Zach Simkin, Senvol

3:00 **Delta Qual Minor: Demonstration of Novel Methods for Effective AM Process Qualification/Re-Qualification (5541)**
Curtis Swift, Honeywell

3:30 **America Makes CORE Briefing**
Joe Veranese and Jason Saly, NCDMM

4:00 **America Makes Project Call Announcement**
John Martin, America Makes

4:30 **Close Out / Thank You**

SOLICITATION POLICY

In order to provide a distraction-free environment for our exhibitors, sponsors, attendees, and employees, we do not allow solicitation by unauthorized parties at our events. This policy includes, but is not limited to the following:

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- Exhibits or hospitality suites
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- Promotion of non-America Makes events
- Employment recruiting
- Distribution of printed or electronic marketing materials — you are encouraged to share business cards!

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America Makes is proud to partner with leading media organizations as they promote the advancement, adoption, and commercialization of additive manufacturing technologies.

Project Manager: Ed Nemeth

5526.001

Reliable Additive Manufacturing 1 Meter Tall (RAM 1)

PROBLEM

Complex internal flow paths have been a strong driver in the growth of metal additive manufacturing (AM), and specifically laser powder bed fusion (LPBF). As the flow paths become more complex and the parts grow in size, however, there are current technology limitations that hinder this growth. Specific shortcomings in the current implementation of LPBF include the inability to print low-angle overhangs without support; the dimensional accuracy and consistency of given geometries, especially in the case of thin walls and tall (i.e. long) builds; and the height of a part that can be built in a single print.

OBJECTIVE

This objective of this project is to address the shortcomings of LPBF in printing low-angle overhangs without support and the manufacturing of taller (up to 1 meter) AM parts in a thin-walled cylinder, leveraging both additive and traditional (welding) manufacturing of Inconel alloy 625 (IN625). Specifically this project seeks to develop and demonstrate low angle (< 45 degrees from the build plane) LPBF print capabilities in IN625; demonstrate the print of a tall (longer than 20 inches) thin-walled cylinder; and develop and demonstrate draft weld procedure specification for IN625 with associated initial mechanical evaluation.

TECHNICAL APPROACH

Aerojet Rocketdyne is leading the project which includes Velo3D. Aerojet Rocketdyne is designing geometry demonstration samples for fabrication and testing. The team plans to fabricate deliverable samples of IN625 components on a Velo3D Sapphire machine capable of printing 1 meter tall parts and post-process accordingly. They also plan to verify consistency of printed material with a pressure test of geometry demonstration samples. Finally, Aerojet Rocketdyne is performing welding trials and drafting the welding specification.

The focus of the project is on three main technical areas:

- Develop and demonstrate low angle printing down to zero degrees without the use of supports;
- Demonstrate printing tall, thin-walled cylinders longer than 20 inches; and
- Develop and demonstrate a draft weld procedure for IN625 with the mechanical evaluation of the weld.

PROJECT START DATE

October 2021

EXPECTED END DATE

March 2024

EXPECTED DELIVERABLES

- Thin-walled (0.1 inch) cylinder part-to-length to exceed 20 inches
- CAD model of demonstration samples
- Build layout for samples
- Pressure test data
- Welding trial data and copy of draft standard
- Raw data from testing of samples
- Draft weld procedure specification for IN625 and mechanical evaluation
- Draft design guidelines for Velo3D system
- Final project report

FUNDING

$1,125,680 total project budget

($975,680 public funding/$150,000 private funding)

PROJECT PARTICIPANTS

Project Principal:

Aerojet Rocketdyne

Project Participants:

Velo3D

Public Participants:

U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to: PROCESS

ASTM PROCESS CATEGORY
Powder Bed Fusion

EQUIPMENT
Velo3D Sapphire

MATERIAL
IN625

Project Manger: Ed Nemeth

5538

Marotta – AM Phase 3, Application Development

PROBLEM
Pressure boundary manifolds are an attractive part family for early additively manufactured (AM) qualification development as they are commonly used in complex, critical marine flow systems. Traditional manufacturing constraints, present when casting or machining manifolds, often result in overbuilt parts when it is cost-prohibitive to remove unnecessary material in areas between critical flow features. This unused design space is ideal for the implementation of Design for Additive Manufacturing (DfAM) techniques to reduce part weight and material for AM manifolds.

OBJECTIVE
The focus of this effort was to design and manufacture a powder bed fusion (PBF) replacement of an air-reducing manifold body. The goal was to investigate whether AM is a viable alternative with performance benefits and to propose an approach to qualification. Marotta Controls was considering both the qualification of the AM build in a setting emulating production and the qualification of the final product when compared to existing specification requirements.

TECHNICAL APPROACH
The technical approach began with evaluating the structure-borne noise attenuation capabilities of various lattice unit-cell structures with aim of identifying the optimal geometry for mass replacement in a traditionally manufactured manifold. The project team generated a first-article test procedure with appropriate witness coupons for qualification of the AM manifold body in a serial production setting. Topology optimization (volume removal) and lattice integration (volume replacement) were utilized to redesign the manifold body. Structural performance analysis based on the expected application loads and final manifold body design, as well as a thermal AM build analysis, are being performed to evaluate and address potential AM build issues. Witness coupons were constructed, post-processed, and machined to a condition suitable for materials testing. Nondestructive testing, physical inspection, and proof pressure testing were done on the AM manifold body.

ACCOMPLISHMENTS
This project furthered the case for expanding the Naval Sea Systems Command (NAVSEA) utilization of AM to produce and qualify air-reducing manifold components. A candidate manifold component that was traditionally machined from a solid billet was redesigned to be more optimal for AM. The design and AM build portion of the project integrated lattice structure design to reduce the legacy component's mass which also mitigated thermally-induced stress distortion during the AM build. This thermal stress distortion would have prevented the legacy component from building successfully using AM.

The Lattice Integrated Manifold (LIM) design was compared to the typical aerospace/space approach to AM manifold designs where absolute weight reduction is the driving factor for AM redesign. The additional material in the LIM design aided marine-type manifolds in additive manufacturability as determined by the successful printing of the complex AM components and relatively low degree of post-build distortion. The shock load resistance and noise performance were also aided by the integrated lattice. The LIM concept was easily applied using the design tools (nTopology) and processes developed during this project to transform manifolds as a part family into candidates for AM production.

Several other steps of the manufacturing process were also investigated including post-processing (chemical etching and abrasive flow machining), nondestructive examination (CT scanning) and manifold machining. Valuable lessons were learned at each step, including how to prepare the manifolds for the respective post-processing method and how best to utilize CT to inspect complex AM components like the LIM.

PROJECT END DATE
September 2023

DELIVERABLES
- First article testing procedure for the qualification of an AM manifold which proposes non-destructive, destructive, and witness coupon testing requirements.
- Report assessing the potential performance benefits and evaluation of the viability of using PBF to manufacture air-reducing manifold bodies.
- Final report

FUNDING
$1,800,000 total project budget

PROJECT PARTICIPANTS
Project Principal:
Marotta Controls

Project Participants:
NCDMM/America Makes
NAVSEA
StarHagen Aerospace Components, LLC

Public Participants:
U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to: DESIGN

ASTM PROCESS CATEGORY	EQUIPMENT	MATERIAL
Powder Bed Fusion	Velo3D Sapphire 1MZ	IN625

Project Manager: Litsa Rubino

5533

Post-Processing Optimizing of Additive-Manufactured Nickel-Based Superalloys

PROBLEM

To apply an optimized finishing technique composed of a chemical milling technology with a chemically accelerated vibratory finishing process to the interior surfaces of large-scale components, an apparatus sized to handle and rotate the component being treated must be used. The current prototype processing cell has a maximum component size capability of approximately 30 x 30 x 24-inch build volume and requires immersion of the part into a chemical bath. For large-scale additively manufactured Ni-based superalloy parts, the current build apparatus must be scaled and the component used as the processing vessel to contain the chemical bath. Up-scaling and redesigning of the processing cell are challenging due to capital expenditure and processing cost estimates.

OBJECTIVE

The goal of the project is to design, fabricate, and construct a scaled, rotatable processing apparatus and associated tooling to facilitate the application of a previously developed optimized finishing technique (OFT) to the interior surfaces of large-scale additively manufactured Ni-based superalloy parts supplied by Air Force Research Laboratory (AFRL) and National Aeronautics and Space Administration (NASA). The apparatus design must eliminate the need for chemical bath immersion by allowing for the large-scale component to act as a processing vessel to contain the required processing media.

TECHNICAL APPROACH

REM Surface Engineering is leading the effort which includes AFRL and NASA. A large-scale rotatable processing apparatus capable of handling Ni alloy-based aerospace components with dimensions not to exceed an outer diameter of 60 inches and a length of 72 inches is being designed, constructed, and installed. The large-scale component in conjunction with end cap tooling acts as the processing vessel to eliminate the need for chemical bath immersion and to enable the application of the OFT to the interior surfaces of the large-scale parts. The OFT, which combines a chemical milling technology with a chemically accelerated vibratory finishing process, is first being applied to a large-scale surrogate part to verify and optimize the large-scale process. Upon completion of the verification/optimization task, a 100K NASA rocket nozzle and an AFRL defined part of similar size and complexity are being treated with a special focus on the hotwall/inner diameter surfaces of the treated parts. After the project, the finished parts along with a final report detailing the development of the apparatus, the process used to apply the surface finishing, and final inspection of the AFRL treated parts are planned.

PROJECT START DATE

April 2022

EXPECTED END DATE

April 2024

EXPECTED DELIVERABLES

- Processed AFRL part with before and after inspection reports
- Final report detailing development of apparatus and process used to surface treat AFRL part

FUNDING

$168,035 total project budget

PROJECT PARTICIPANTS

Project Principal:

REM Surface Engineering

Project Participants:

Air Force Research Laboratory (AFLR)
National Aeronautics and Space Administration (NASA)

Public Participants:

U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to: PROCESS

ASTM PROCESS CATEGORY	EQUIPMENT	MATERIAL
Powder Bed Fusion, Directed Energy Deposition	N/A	Nickel-based Superalloys. IN625, IN718

Project Manager: Jason Thomas

5567

Improving LPBF Operational Qualification Through Software Automation

PROBLEM

Operational Qualification (OQ) is manual, slow, and expensive for all additive manufacturing (AM) users. It also requires extensive effort. OQ ties up AM machines, often for extended periods, that could otherwise be producing parts and adds significantly to part costs. OQ is error-prone, requiring substantial direct engineer and operator involvement, and builds in unwanted "human in loop" variation. OQ requires multiple materials and process development builds to ratify basic materials property performance and develop optimal parameters for a specific geometry before freezing the process. Too often, OQ results in locking the production process to a particular part revision and a given vendor's machine and even model type. Making a simple part change, upgrading a machine, or exploiting a productivity improvement, such as increasing layer thickness or print speed, all require a lengthy OQ to be rerun. Likewise, moving to a more productive multi-laser machine introduces new process variables like part stitching that will require new OQ. This hinders productivity. Finally at a wider level, while AM users often have machines that are nominally capable of making the same parts, it is usually too cost-prohibitive to conduct an OQ for the same part across different platforms. This stifles production flexibility and leaves machines dedicated to a few parts.

OBJECTIVE

This project aims to create a financial and productivity-focused qualification step change for AM. Combining Siemens production volumes, experience, and problems through an innovative software and deliverable platform with Dyndrite enables a variety of benefits for the mass production of AM parts. This project will balance time and cost savings against production expectations to deliver an OQ experience and capability for Siemens. The output will be a tool that will be validated and evidenced in its capability and support significant cost decreases and productivity increases in its deployment.

TECHNICAL APPROACH

The project will initially develop baseline capability, timings, and run process failure mode and effects analysis (PFMEA) trials to quantify and measure the process of a production part from design to shipping. This data is an essential key process parameter (KPP) for benchmarking. The following steps will focus on the following core attributes of AM production; each case will have a baseline process creation, test, and validation before optimization occurs:

1) Geometry feature detection and build suitability analysis; 2) Build design activities; 3) Support generation; 4) Serialization; 5) Additive computer-aided manufacturing (CAM) pre-process reporting; and 6) Slice and send to print.

At this stage, the build is fixed until a variable enters play for a change of build design, serial numbers, machines, and material. Dyndrite has the capability engine to then create an automated workflow which, when designed with extra steps at the part level, can allocate parameters to certain down skin geometry for maximizing surface quality, select and apply supports, nest, add serialization to all parts, and report the build CAM requirements from metadata before slicing and having the build prepared for any given machine in an automated and near-instant manner. To enable this, Dyndrite will create a Siemens Energy dedicated process route, and some AM validation will occur to iterate the specific needs for supports, parameters for down skins, and machine variability.

The collective output is a data-validated software toolkit to enable Siemens Energy to automate its build creation process and reporting with machine variability understood and neutralized via parameterization across laser powder bed fusion (LPBF) platforms. As the current process will be measured and quantified, the automated system can be compared directly. It is expected that the build preparation time, and therefore cost, will reduce by 50%.

PROJECT START DATE February 2024

EXPECTED END DATE February 2026

EXPECTED DELIVERABLES

- Automatic workflow for Siemens Energy gas turbine components from CAD to machine
- Process strategy to enable the production of features with an overhang up to 20 degrees and a general increase of down skin surfaces through automatic volume segmentation
- Automatic part labeling for recurring build jobs
- Documentation of assigned process parameters, (critical vectors, build time, cost information)
- Final report

FUNDING **$1,322,573 total project budget**
($866,123 public funding/$436,449 private funding)

PROJECT PARTICIPANTS

Project Principal: Dyndrite
Project Participants: Siemens Energy; ASTM International
Public Participants: U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to:

PROCESS

ASTM PROCESS CATEGORY	EQUIPMENT	MATERIAL
Powder Bed Fusion	EOS M290 / M400-4, Renishaw 500Q, SLM Solutions 280	Metals

Project Manager: Jason Thomas

5567.001

Methods and Approaches for Sustainable AM Operations

PROBLEM

Operation qualification (OQ) is a myriad of tasks that leads to process control documentation substantiated through characterization, analysis, and testing to confirm the process can deliver to material requirements. Specific barriers to rapid OQ to be addressed in this program include the lack of clear requirements and checklists for manufacturers of additively manufactured (AM) parts, lack of guidance and key process variable (KPV) relationships to OQ requirements, lack of OQ auditing and approval agencies, and lack of industry demonstration and acceptance of means of compliance to OQ.

OBJECTIVE

Wichita State University National Institute for Aviation Research (WSU NIAR) has composed a program that will establish a sustainable OQ process to be widely implemented within the organic and defense industrial bases (OIB and DIB). This will allow for a shorter and less costly process which will accelerate our nation's conversion from an AM capability to a capable AM manufacturing capacity. NIAR will deliver a public framework that outlines OQ requirements including material specifications, a published KPV window study to aid in material specification compliance, and an industry verification process.

TECHNICAL APPROACH

WSU NIAR will address four specific barriers to rapid OQ within the OIB and DIB. To overcome those barriers, an industry advisory board will assist by sharing lessons learned and guiding the work scope. To address the first barrier, "Lack of clear requirements and checklists for AM part manufacturers," WSU NIAR will partner with the Society of Automotive Engineers (SAE) International and National Aerospace and Defense Contractors Accreditation Program (Nadcap). This task will focus on integrating the OQ requirements detailed within AMS7032 and AMS7003 into its audit program or within Nadcap's existing AC7110/14 program. This will provide clear, standardized requirements and checklists for AM part suppliers to reference as they work to achieve an operationally qualified shop. Leveraging the guidance document and checklist developed in the preceding task, Nadcap will develop an accreditation specific to OQ for LPBFAM. This accreditation will address the "Lack of OQ auditing and approval agencies" and provide both industry and suppliers with an informed, trained, and experienced auditing and accreditation agency. To address the "Lack of clear guidance and KPV relationship to OQ requirements," NIAR will execute a window study analysis that compares the correlations, or lack thereof, between the "KPV required for LPBF Process" of AMS7003 and "LPBF process specification" as well as the material qualifications requirements listed within the appropriate material specifications of AMS7000. The final barrier this team will address is the "Lack of industry demonstration and acceptance of means compliance to OQ." This will be accomplished with the help of an ASTRO America-identified small to medium-sized business supplier (SMB), Sintavia. Sintavia will implement deliverables from phase one and prepare for an OQ audit by Nadcap and the National Center for Advanced Materials Performance (NCAMP) officials using the guidance documents generated under this scope of work.

PROJECT START DATE

February 2024

EXPECTED END DATE

February 2026

EXPECTED DELIVERABLES

- Material qualification window study procedure
- National Aerospace and Defense Contractors Accreditation Program audit plan
- OQ guidance document and checklist
- Final report including lessons learned

FUNDING

$738,663 total project budget
($344,741 public funding/$393,922 private funding)

PROJECT PARTICIPANTS

Project Principal:
Wichita State University National Institute for Aviation Research (WSU NIAR)

Project Participants:
Purdue University
REACT Lab Tinker Air Force Base

Public Participants:
U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to: PROCESS, VALUE CHAIN

ASTM PROCESS CATEGORY	EQUIPMENT	MATERIAL
Powder Bed Fusion	GE Additive M2 Series 5	Cobalt Chrome, IN718

Project Manager: Jason Thomas

5567.002

Accelerating Control and Certification: Enhancing Laser-PBF and Electron Beam-PBF Operation Quality via Real-time Analytics, Technological Integration, and Experimental Platforms for a Resilient Supply Chain (ACCELERATE)

PROBLEM

Metal additive manufacturing (AM) has revolutionized industrial sectors, notably aerospace applications, by enabling intricate and efficient production of customized metal components. However, the validation and qualification process, especially operational qualification (OQ), presents a significant challenge as it involves rigorous verification and validation of processes and procedures such as machine calibration, statistical validation via mechanical testing, process failure mode and effect analysis (PFMEA), powder feedstock control, facility and machine peripheral controls, software configuration and version control, operator training, and more. This complexity makes it both costly and time-intensive.

OBJECTIVE

The team aims to establish a reliable OQ framework for electron beam power bed fusion (E-PBF) and L-PBF, in line with the Air Force's specifications, DoD Instruction 5000.93. To achieve this, the action plan involves collecting and analyzing relevant OQ data, refining the OQ testing process, and setting up a data-driven framework for post-build sample analysis. This comprehensive approach should provide guidance and valuable insights to the Air Force, Air Force Research Laboratory (AFRL), and Department of Defense (DoD), to help make informed decisions and reduce time and money spent on OQ.

TECHNICAL APPROACH

Building on insights derived from data analysis and stake-holder engagement, the project team will construct a comprehensive OQ framework that addresses both E-PBF and L-PBF technologies. This framework is designed for compatibility and seamless integration across diverse platforms and brands. Beyond mere guidelines, it will encompass precise procedures and best practices for the OQ of platforms responsible for producing end components, particularly for Air Force hardware applications. Through the presentation of a well-structured methodology, the proposed OQ framework will facilitate a comprehensive assessment and validation of the reliability, safety, and performance of E-PBF and L-PBF systems. It will serve as an asset for industry adopters, regulatory agencies, and other relevant stakeholders. Ultimately, its accessibility will accelerate the adoption and widespread integration of E-PBF and L-PBF systems thereby enhancing the mission readiness for the Air Force and boosting the U.S. supply chain robustness.

PROJECT START DATE

March 2024

EXPECTED END DATE

March 2026

EXPECTED DELIVERABLES

- Development of a data-driven operational qualification (OQ) schema, addressing existing gaps and leveraging EOS experience and data for popular alloys
- Demonstration pathways to validate the qualification schema, involving different machine types, software versions, and operators
- Technology transition of qualification requirements and data to U.S. Air Force and supply chain partners
- Final written technical report and technical data package

FUNDING

$1,333,000 total project budget

($666,500 public funding/$666,500 private funding)

PROJECT PARTICIPANTS

Project Principal:

Texas A&M University (TAMU) Engineering Experiment Station (TEES)

Project Participants:

Addiguru
Beehive Industries
EOS
University of Michigan

Public Participants:

U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to: PROCESS

ASTM PROCESS CATEGORY	EQUIPMENT	MATERIAL
Powder Bed Fusion	EOS M290, EOS M300, EOS M400, Freemelt ONE Electron Beam, Freemelt e-MELT Electron Beam	Ti-6Al-V4 Grade 5

Program Manager: Mark Ray

5550

Common AM Qualification Template (CAM-QT)

PROBLEM

Qualification of additive manufacturing (AM) machines and materials is a major barrier for the broad adoption of AM. Generating the requisite data and models requires large investments of resources and time from small/medium businesses to produce a body of statistically significant data. This usually requires generating coupons under a controlled process, testing the coupons, and analyzing the resulting data. Moreover, part vendors are required to supply substantially different data to each original equipment manufacturer (OEM), even when using the same manufacturing process. The OEM supplier qualification process, the requirements that are often held as proprietary information, could benefit from common requirements across application sectors such as Engine, Structural, and Mechanical Subsystems.

OBJECTIVE

The objective of this project is to document the qualification requirements of in-service metal AM parts accepted by design authorities of three engine OEMs as part of their individual qualification/certification efforts.

TECHNICAL APPROACH

Advanced Science and Technology Research Organization of America (ASTRO America), the principal investigator (PI) for this project, will:

- Engage with key engine OEMs (GE Aerospace, Honeywell, Pratt & Whitney) to establish a plan and requirements for a common AM qualification template.
- Generate a detailed AM qualification template, based on Systems Engineering methodology, that defines requirements sufficient to meet OEM needs for Operational Qualification (OQ) and Installation Qualification (IQ).
- Work with the engine OEMs to identify a specific material/machine combination to demonstrate the common qualification template with analytic analysis conducted by ASTRO America.
- Review the analytic demonstration results with OEMs, the Government Advisory Team, and NCDMM/America Makes.

PROJECT START DATE

July 2023

EXPECTED END DATE

December 2024

EXPECTED DELIVERABLES

- Common Qualification Template for Operational Qualification (OQ) and Installation Qualification (IQ)
- Final Report

FUNDING

$1M total project budget

PROJECT PARTICIPANTS

Project Principal:

Advanced Science and Technology Research Organization of America (ASTRO America)

Project Participants:

NCDMM/America Makes
GE Aerospace
Honeywell
Pratt & Whitney

Public Participants:

U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to:

PROCESS

ASTM PROCESS CATEGORY	EQUIPMENT	MATERIAL
All Apply	All Apply	All Apply

Program Manager: Brian Schmidt

5511.001

Joint Metal Additive Database Definition (JMADD)

PROBLEM

A major factor driving complexity within additive manufacturing (AM) product qualification and technology adoption is a lack of industrially recognized materials data critical to product design cycles. At present, the absence of prevalent material allowable data requires substantial (usually >$1M and > 18 months) investment prior to any product manufacturing and testing. The material data and models necessary for common design practices require manufacturing, testing, and analysis of hundreds of test coupons using a controlled process. While there are proprietary AM design databases, these dispersed datasets don't offer the widespread understanding necessary to diminish barriers facing the AM supply chain and inhibit the technology's prevalence and use.

OBJECTIVE

The program addresses the lack of industrially recognized, statistically based bulk material allowables using an approach like those commonly utilized in commercial and military aerospace design. Statistically based, bulk material allowables will be delivered utilizing a qualified material and process while leveraging practices informed by government and public advisory groups and mirroring the Metallic Materials Properties Development and Standardization (MMPDS) allowables generation for cast and wrought metallic materials.

TECHNICAL APPROACH

The National Institute for Aviation Research (NIAR) is leading the effort which leverages expertise and resources at Boeing, Auburn University, and Battelle. The approach includes material and process qualification exercises necessary to establish material and process specifications and process control documentation prior to test coupon production. Upon qualification of the Ti-6Al-4V LPBF material and processes, the team will execute a site comparison analysis across multiple production sites at NIAR, Boeing, and Auburn University using various lots of powder feedstock material sourced from multiple suppliers (ATI, AP&C, and Tekna). Common build design factors such as layer timing, coupon spacing, and coupon orientation will be evaluated. Site and process qualification includes density, specific heat capacity, thermal diffusivity, coefficient of thermal expansion, tension, compression, shear, low cycle fatigue, fracture toughness, and hardness testing. T90 and T99 material allowables will be produced upon the conclusion of site qualification for tensile and fatigue properties. Data will be analyzed and procured in a manner in line with MMPDS and the National Center for Advanced Materials Performance (NCAMP) processes to deliver a set of public data which is industrially relevant and statistically substantiated for LPBF Ti-6Al-4V bulk material properties.

PROJECT START DATE

October 2020

EXPECTED END DATE

October 2024

EXPECTED DELIVERABLES

- Establish public steering committee and communication cadence with government technical team
- Establish a test matrix and test plan
- Identify and cite standards and material/process specifications to be leveraged by this program
- Define powder reuse strategy
- Statistically reduced data using one or more statistical methods B-basis allowables for Ti-6Al-4V
- Develop and publish A-basis allowables for Ti-6Al-4V
- Final project report including at a minimum: critical process parameters, lessons learned, standards used, and any deviations from those standards
- NCAMP material specification, including powder handling and characterization and powder reuse specification

FUNDING

$3.6M total project budget

($1.8M public funding/$1.8M private funding)

PROJECT PARTICIPANTS

Project Principal:

National Institute of Aeronautics Research (NIAR)

Project Participants:

The Boeing Company
Auburn University
Battelle

Public Participants: U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to:

MATERIAL

ASTM PROCESS CATEGORY	EQUIPMENT	MATERIAL
Powder Bed Fusion	EOS-M290	Ti-6Al-4V Powder

Program Manager: Mark Ray

5534.001

Generation of Additive Material Allowables for Ti-6Al-4V (GAMAT)

PROBLEM

One of the most significant gaps to the approval of additively manufactured (AM) parts is a lack of widely accepted and available design data for use by engineers and designers. Generating the requisite data and models requires a significant investment of resources and time to produce statistically significant data, which involves creating test coupons under a controlled process, and performing testing and analysis of the resulting data. While there are some existing proprietary AM design databases, there is currently a very limited amount of publicly available industry or government-accepted standard design data for AM processes and materials. This data is needed across the government and industry to accelerate the broader adoption of AM.

OBJECTIVE

The purpose of the project is to develop a systematic approach to the generation of statistically based bulk material properties for Ti-6Al-4V via laser powder feed directed energy deposition (L-DED), which helps address the gap within the defense and commercial industry in design allowables for the L-DED process. Another goal is to provide a framework for attaining allowables for future alloys utilizing the L-DED process. Boeing is eager to further establish the foundation of AM and the available design data for AM materials/processes to accelerate the adoption of AM as a repeatable, robust method to fabricate flight-worthy parts.

TECHNICAL APPROACH

Leveraging the capabilities of each strategic partner, the first task consists of a comprehensive study of the L-DED process and the characterization of all necessary data to support the generation of bulk metallic material property data that can be reliably replicated. Utilizing the lessons learned from the first task, RPMI and Boeing are constructing a process control document (PCD) that includes the machine operation procedures and key process variable tolerances. The PCD is being developed in conformance with AMS7010A to enhance the transition into publicly accessible availability. Boeing and the team will develop and demonstrate a workflow that addresses Metallic Materials Properties Development and Standardization (MMPDS) allowables generation guidelines to deliver statistically relevant material allowables for L-DED Ti-6Al-4V tensile, compression, shear, bearing, and fatigue properties. The test matrix includes consideration for the relevance and design of test specimen blank preform extraction plans and includes multiple coupon orientations. Production of material will occur using multiple (5) AM machines with feedstock from two powder suppliers.

PROJECT START DATE
September 2022

EXPECTED END DATE
March 2025

EXPECTED DELIVERABLES

- DED process KPV tolerances
- Powder variability data
- Heat treatment sensitivity data
- NDE inspection data
- Mechanical test data
- C/D-basis allowables generation
- Process control documentation
- Data package for MMPDS submission
- Draft AMS specification for material
- Final report

FUNDING

$4,952,000 total project budget
($4M public funding/$952,000 private funding)

PROJECT PARTICIPANTS

Project Principal:
The Boeing Company

Project Participants:
NCDMM/America Make
National Institute for Aviation Research (NIAR)
The University of Texas at El Paso (UTEP)
Auburn University
Edison Welding Institute (EWI)
RPM Innovations (RPMI)
American Society for Testing and Materials (ASTM)

Public Participants:
U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to: MATERIAL

ASTM PROCESS CATEGORY	EQUIPMENT	MATERIAL
Directed Energy Deposition	RPMI 557 DED Machine; RPMI 222 DED Machine	Ti-6Al-4V Powder

Project Manager: Adam Chakot

5551

Cold Metal Fusion Preliminary Research for Air Force Sustainment and Repair

PROBLEM

The Department of Defense (DoD) industrial base continues to adopt advanced manufacturing technologies that enhance the readiness and effectiveness of the United States military. Adoption of additive manufacturing (AM) is creating new opportunities to provide advanced technical solutions to the warfighter. However, material qualification, material cost, and overall process efficiencies are limiting broader implementation of AM. Cold metal fusion can provide a more efficient and cost-effective solution to support the warfighter, but limited testing of this emerging process exists. Further testing is necessary to prove the process and inform the larger DoD industrial base.

OBJECTIVE

The project objective is to develop and demonstrate a cold metal fusion process through manufacturing and testing three Ti-6Al-4V material manufacturing builds.

TECHNICAL APPROACH

To investigate and evaluate cold metal fusion, the research team led by The Ohio State University (OSU) Center for Design Manufacturing Excellence (CDME), will perform four separate tasks.

Task 1 involves commissioning the EOS P110 while concurrently drafting a 10-page technology overview to be submitted at the end of the project. Further, the team will compare the productivity and design criteria to those of similar modalities (laser powder bed fusion, directed energy deposition, binder jet, etc.).

Task 2 involves creating three manufacturing builds from Ti-6Al-4V material, verifying machine parameters, and assessing part performance. The first build specimen will be geared toward parameter development and the second build specimen will consist of mechanical test specimens (tensile and fatigue). The OSU CDME and Tinker Air Force Base (AFB) REACT Laboratory will collaborate to determine a demonstration component to use as the third test specimen.

Task 3 will focus on measuring the green and final part densities, conducting tensile testing, and performing basic material characterization to assess the mechanical properties of the produced parts.

Task 4 involves consolidating all the findings from the previous tasks into a comprehensive final report. The final report will serve as a valuable resource for the DoD and its supply chain, providing them with insights into the feasibility and potential of cold metal fusion technology.

PROJECT START DATE

July 2023

EXPECTED END DATE

April 2024

EXPECTED DELIVERABLES

- Technology overview summary
- Conduct three manufacturing builds including test specimen for evaluation
- Part Densities (Green and Final), Tensile (12 specimen minimum), Fatigue (5 specimen minimum), and Witness Coupon Microstructure from each build
- Technical report and presentation at a public forum

FUNDING

$225,000 total project budget

PROJECT PARTICIPANTS

Project Principal:

The Ohio State University Center for Design and Manufacturing Excellence (CDME)

Project Participants:

NCDMM/America Makes
Headmade Materials
EOS
Air Force Research Laboratory (AFRL)
Air Force Sustainment Center

Public Participants:

U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to:

PROCESS

ASTM PROCESS CATEGORY	EQUIPMENT	MATERIAL
Powder Bed Fusion	EOS P110	Ti-6Al-4V

Project Manager: Jeff Verkleeren

5560

Thin Wall Testing Methodology for High Temperature Materials

PROBLEM
The development of processes and material properties for additively manufactured (AM) parts is a significant challenge for the United States Air Force (USAF), particularly when thin wall features are desired. The inherent surface texture from the laser powder bed fusion (LPBF) processes are known to yield deviations in load-bearing surfaces when compared to nominal computer-aided design (CAD). The organic industrial base (OIB) needs cobalt-chromium (CoCr) process data to expand LPBF capabilities and enable solutions for applications containing thin wall conditions. Additionally, engineering and sustainment teams depend on AM testing projects such as thin wall testing to support tactical and operational readiness.

OBJECTIVE
This material testing program seeks to expand the USAF CoCr material property dataset by characterizing material behavior in thin wall as-printed features. Defining the material allowables for these features is necessary to design and qualify parts with thin walls. This project demonstrates a methodology for characterizing thin wall features of additively produced material and defining the material allowables. Ultimately, the development of standard design allowables enables the design and certification of additively produced materials. This method allows for decreased development times and faster design iterations.

TECHNICAL APPROACH
Pedigree of the manufactured LPBF material will align with the existing USAF CoCr material dataset. The existing USAF material dataset characterized bulk material defined by wall thicknesses equal to or greater than 0.075 inch. GE Additive plans to print and characterize LPBF CoCr specimens with wall thicknesses less than 0.075 inch. Characterization will include low cycle fatigue testing to determine the impact on fatigue with decreasing wall thicknesses. In addition to varying the wall thickness, GE Additive intends to encompass multiple test temperatures aligned with the existing USAF material dataset.

PROJECT START DATE
December 2023

EXPECTED END DATE
April 2025

EXPECTED DELIVERABLES
- Cobalt-chromium thin wall fatigue test results
- Final project report

FUNDING
$260,425 total project budget

PROJECT PARTICIPANTS
Project Principal:
GE Additive

Project Participants:
NCDMM/America Makes

Public Participants:
U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to:

PROCESS

ASTM PROCESS CATEGORY	EQUIPMENT	MATERIAL
Powder Bed Fusion	GE Concept Laser M2 S4+ Machine	Cobalt-chromium (CoCr)

Project Manager: Ed Nemeth

1141

LIFT Award – DoD Manufacturing Innovation Institute, Cross Institute Collaborative Project: Digital Data Management for Transcribing Structural Part Performance Across Additive Manufacturing Platforms

PROBLEM

The Army developed the process for additively manufacturing and post processing ramjet projectile inlet nozzles and nickel rotating bands. To scale production, a method is needed to ensure the as-built quality of these components when produced on different AM build platforms. Current approaches for process qualification, also known as system equivalence, require many coupons and parts to be built and tested. This often costs upwards of $1M and can take up to six months.

OBJECTIVE

The goal of this multi-year, long term project was to qualify structural parts for use directly from the manufacturing process without a nondestructive evaluation or lot acceptance testing step. This effort focused on understanding the primary factors influencing product quality and how they can be captured in the digital build log during manufacturing. The team utilized existing data from America Makes, LIFT, and MxD, and determined minimum data needs to ensure interoperability of the framework across various platforms.

TECHNICAL APPROACH

The team used several methods to drive activities throughout the project. The first step was to improve upon the advanced manufacturing qualification and certification approaches developed for additive manufacturing by the Army and extending to other forms of advanced manufacturing needed to produce a system. Another was to review existing data sets and define the minimum data requirements that would enable verification and/or validation of a data set. The team also conducted roadmap modeling and predictive analytics to communicate AM design, material, process, and part performance data across platforms. With these approaches in mind, the team established preliminary training for utilization of data sets and established a secure data transfer portal.

ACCOMPLISHMENTS

This project achieved a proof of concept that equipment health monitoring can be used to establish effective quality envelopes. Although the proof of concept targeted a conservative use case, which included a production relevant variation in gas flow and laser quality, conservative coupon geometries (15 mm diameter cylinders), a well-controlled material (IN718 built on an EOS M290 with EOS provided process parameters), and use of HIP to eliminate defects, the results showed that the use of an equipment health-based quality envelope could improve Low Cycle Fatigue (LCF).

Several technical elements were leveraged to accomplish goals:

- Planned, executed, and reported on three-day workshop titled "Data Enabled AM Process Qualification Workshop"
- Identified primary data elements that were important to accelerating AM process qualification.
- Directly measured subsystem performance across the build envelope using the EWI gas flow measurement rig and laser pin hole measurement system
- Repeatably varied equipment health performance on a single system to represent a production- relevant range of AM equipment variability
- The use of Bayesian optimization and FEA simulation to design coupons with thermal history variation
- A design of experiments that allowed a wide range of effects to be studied in an efficient way
- The use of descriptive, diagnostic, predictive, and prescriptive analytics to quantify the effects of variability on material properties

PROJECT END DATE
February 2024

EXPECTED DELIVERABLES

- Workshop summary reports
- Digital build log/sample parts
- Test data report
- Final report

FUNDING
$882,469 total project budget

PROJECT PARTICIPANTS

Project Principal:
American Lightweight Materials Manufacturing Innovation Institute (ALMMII) – aka LIFT

Project Participants: NCDMM/America Makes; Digital Manufacturing and Cybersecurity Institute (MxD); Edison Welding Institute (EWI)

Public Participants: U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to: PROCESS

ASTM PROCESS CATEGORY	EQUIPMENT	MATERIAL
Powder Bed Fusion	EOS M290	IN718

Project Manager: Adam Chakot

5555

Innovations in Robotic Additive Manufacturing Process Planning

PROBLEM

In the continuous fiber 3D printing industry, there is a gap in printability between the part geometries that can be designed and those currently produced by state-of-the-art continuous fiber printers. Specifically, steered continuous fiber (SCF) toolpath planning software lags physical SCF printing capability. To date, there is no slicing or toolpathing software available that enables a designer to efficiently specify SCF within complex and highly-curved 3D geometries to achieve fiber orientation parity with finite element analysis (FEA) load simulation guidance.

OBJECTIVE

The objective of this project is to develop a user interface and toolpathing approach that is fully 3D-centric. This will include a variable slicing perspective and a library of intelligent toolpath replication algorithms. The end result will be a collection of functional building blocks that designers can use to efficiently define fiber pathways. Additionally, the project will establish downstream interoperability with industry finite element analysis software.

TECHNICAL APPROACH

Continuous Composites, Inc. (CCI) CF3D® Toolpathing Studio software will be leveraged to provide an application codebase and 3D slicing surface computer-aided design (CAD) models imported by the designer. CCI engineers will develop new SCF toolpathing algorithms and then test the functionality of each algorithm through a sample part. Toolpathed parts will be exported to a CF3D printing platform digital twin on the Siemens Run My Virtual Machine simulator for confirmation. Once the functionality is confirmed, C++ programming language algorithms and capability demonstrating visuals and files will be delivered. To achieve downstream interoperability of SCF software and FEA, CCI will work with two FEA vendors to develop a standard for multi-fiber, multi-material SCF toolpath data. This standard will be free of motion data and include a translation utility to import data into the vendors' standards. The downstream interoperability of FEA will be improved by developing a toolpath data standard and a post-trim model reconciliation algorithm to account for expected post-machining of the print.

PROJECT START DATE

August 2023

EXPECTED END DATE

July 2025

EXPECTED DELIVERABLES

- Data management plan
- Transition and commercialization plan
- Slicing, regioning, replication, wrapping, and toolpath algorithms
- Presentation at two public forums
- Final project report

FUNDING

$1,527,415 total project budget

($794,284 public funding/$561,116 private funding)

PROJECT PARTICIPANTS

Project Principal:

Continuous Composites, LLC

Project Participants:

Air Force Research Laboratory (AFRL)

Public Participants:

U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to:

DESIGN

ASTM PROCESS CATEGORY
Material Extrusion

EQUIPMENT
3D Steered Continuous Composite Fiber Manufacturing Printers

MATERIAL
Polymer and Ceramic Composites

Project Manager: Litsa Rubino

5554.001

Transitioning Best Practices and Technology Improvements for 3D Printed Molds/Cores for Sand Castings

PROBLEM

Honeywell is currently exploring the application of additively manufactured (AM) sand molds to produce gearbox housings, covers, and inlet housings for the Chinook Helicopter T55-714C engine. Challenges related to the quality of parts produced using AM sand molds are impeding the use of this technology. The final cast parts often fall short of acceptable standards due to issues related to surface roughness, dimensional accuracy, and porosity resulting from outgassing of the mold during the casting process. The subpar quality of these components necessitates additional rework cycles, causing delays in receipt of initial castings. The challenges faced by Honeywell mirror the broader issues faced by the domestic sand-casting industry, explaining the limited integration of AM-printed sand molds in their processes.

OBJECTIVE

The primary objective is to improve the casting quality of parts produced with AM sand molds by evaluating and implementing measures to improve surface roughness, minimize dimensional variations, and reduce porosity caused by outgassing of the sand mold. The project team plans to disseminate best practices and technological advancements established through training and presentations at industry-wide conferences to foster widespread adoption of AM sand molds within the casting industry.

TECHNICAL APPROACH

The technical approach begins with the baseline process confirmation task where Honeywell, ExOne, Hoosier Pattern, Ohio Aluminum, and Chicago Magnesium will baseline current state-of-the-art processing parameters for AM sand molds and cores. During this task, quality characteristics of the cast parts are being evaluated and documented relative to part design requirements.

Following baseline confirmation, the project team is evaluating technology improvements that address identified quality gaps. Options include mold/core orientation during build, layer thickness, and sand particle size distribution to enhance surface finish. Coatings applied to AM sand molds and cores are also under consideration to alleviate stair-step effects and other surface roughness issues. To reduce outgassing, methods such as pre-burning out the cores prior to casting, reducing the amount of binder used, altering binder composition, and evaluating different venting options are being investigated.

On completion of the technology improvement tasks, a combination of options is being collectively evaluated by the project team through casting trials utilizing the recommended improved AM molds/cores to determine if project objectives are achieved.

As a final task, the American Foundry Society (AFS) is slated to conduct outreach and identify educational opportunities to the domestic casting industry to share established best practices.

PROJECT START DATE

October 2023

EXPECTED END DATE

October 2025

EXPECTED DELIVERABLES

- Final written report summarizing micro-structural and dimensional characterizations of parts produced with enhanced sand printing technologies as compared to baseline parts produced with current sand printing technology.
- Training material and courses directed towards the domestic sand-casting industry to promote best practices/methods to improve the quality of cast parts produced with sand-printed molds and cores.
- Presentations at industry events detailing technology improvements and best practice recommendations.

FUNDING

$3,352,660 total project budget

($1,902,160 public funding/$1,450,500 private funding)

PROJECT PARTICIPANTS

Project Principal:

Honeywell

Project Participants: NCDMM/America Makes, Ohio Aluminum, Chicago Magnesium, ExOne Company, Hoosier Pattern, American Foundry Society (AFS)

Public Participants:

U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to:

PROCESS

ASTM PROCESS CATEGORY	EQUIPMENT	MATERIAL
Binder Jetting	N/A	N/A

Project Manager: Litsa Rubino

5554.002

AM Ceramic Shell Technology for Investment Casting

PROBLEM

Manufacturing lead times of legacy military investment cast components are excessively long. The use of additive manufacturing (AM) technologies to produce the ceramic shells used in investment casting can offset the multi-step process required to produce traditional shells. However, the benefits of AM ceramic shells are not widely recognized, nor widely accepted by domestic foundries creating a need to develop and demonstrate how AM may offer improvements in productivity, lead time, yield, and cost for the manufacturing of ceramic shells for investment casting applications.

OBJECTIVE

The project aims to develop an AM shell-building process for producing investment cast parts that conform to military quality standards and achieve Technology Readiness Level (TRL) and Manufacturing Readiness Level (MRL) 7 requirements. The incorporation of AM-manufactured shells streamlines the investment cast process, significantly reducing cycle times by eliminating the traditional steps of pattern manufacture, mold setup, and dipping operations.

TECHNICAL APPROACH

To assess and refine the AM shell-building process, the project is divided into four campaigns focused on two casting geometries. Three service bureaus produce ceramic shells and supply them to eight different foundries where parts are cast based on the foundries' respective metal expertise.

Campaign I focuses on analyzing ceramic material properties, comparing AM to dipped ceramic coupons based on the modulus of rupture (MOR), compression, and heat transfer. The primary objective is to ensure mold integrity for safe foundry use and establish a baseline for subsequent evaluations. In Campaign II, the emphasis shifts to instrumenting molds for in-process data collection during foundry operations. Data gathered here concentrates on the dimensional performance of the cast parts and establishes metallurgical baselines, providing input for early simulation models.

Campaign III further refines data collection, extending metallurgical analysis to include test bars from castings made with gating in place. This phase further introduces evaluations on nickel alloys cast under vacuum. Finally, Campaign IV entails a comprehensive examination of cast parts through full non-destructive testing (NDT) per AMS2175A standards. This campaign aims to ensure the validation and reliability of the entire AM shell-building process.

Upon completion of the project activity, an analysis of the benefits, impact, and trade-offs observed will be reviewed and documented to ensure successful integration into the defense industrial base.

PROJECT START DATE

October 2023

EXPECTED END DATE

October 2025

EXPECTED DELIVERABLES

- Final report detailing shell-building systems that meet Technology Readiness Level (TRL) and Manufacturing Readiness Level (MRL) Level 7.
  - Report shall include manufacturing cost, production lead time, and cycle time benefits achieved.
  - The technical performance of the shell building system and resulting castings will be reviewed.
- AM-produced ceramic shell and related cast samples that meet AMS2175A Grade C specifications.
- Technical update presentations at America Makes, Investment Casting Institute events, and others
- Economic model for AM printed shells

FUNDING

$2,999,921 total project budget

($1,999,947 public funding/$999,974 private funding)

PROJECT PARTICIPANTS

Project Principal: Investment Casting Institute (ICI)

Project Participants: NCDMM/America Makes; Concurrent Resources; Foundry Support Operations

Foundries: Barron Industries; Bescast, Inc.; Kovatch Castings, Inc.; Metaltek International; O'Fallon Casting; Signicast Investment Castings; Shellcast, Inc.; SeaCast, Inc.

Service Bureaus: Intrepid Automation; Product Development & Analysis, LLC; Rangeview, Inc.; Tethon 3D

Universities: Alfred University; Missouri University of Science & Technology; Pennsylvania State University; University of Arizona

Public Participants:

U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to:

PROCESS

ASTM PROCESS CATEGORY	EQUIPMENT	MATERIAL
Vat Photopolymerization	N/A	Ceramics

Project Manager: Litsa Rubino

5554.004

Maturation of Ceramic 3D Printed Shell-Based Investment Casting Foundry Capabilities of the 76th CMXG at Tinker AFB

PROBLEM

The 76th CMXG at Tinker Air Force Base (AFB) needs replacement parts for the B-2 Spirit Bomber, C-5 Galaxy, and A-10 Thunderbolt II aircrafts since commercial suppliers currently do not exist. Producers of traditional investment castings typically perform approximately 12 major process steps to complete a production part. Each step of production creates the potential for defects, rework, and scrap contributing to longer lead times, higher part costs, and additional energy usage. Legacy methods for creating tools from wax and ceramic are complex, labor-intensive, and susceptible to dimensional distortion. The material variability of wax, the reliance on complex injection molding processes, and the manual assembly techniques to create castable shells contribute to casting lead times of 12 months or more. Ceramic 3D printing has the potential to decrease investment casting lead times through the reduction of up-front traditional processing steps from seven steps to one.

OBJECTIVE

The objective of this project is to mature the ceramic 3D printing capabilities of the 76th CMXG at Tinker AFB from a Technology Readiness Level (TRL) and Manufacturing Readiness Level (MRL) of seven to nine. The increased readiness level enables onsite casting, provides sustaining engineering opportunities, and maximizes the probability of producing high-quality castings that conform to AMS-2175 Class I Grade A requirements.

TECHNICAL APPROACH

DDM Systems, Inc., (DDM) will partner with the 76th CMXG casting foundry at Tinker AFB to develop a comprehensive program to mature and transition Large Area Maskless Photopolymerization (LAMP) ceramic 3D printing technology for the rapid, low-volume production of investment castings. Leveraging DDM's ceramic 3D printing capabilities for investment casting shells with the latest casting modeling tools, the project will accelerate the path to obtain critical parts necessary for sustaining aircraft readiness. The project team and industry professionals will collaborate to develop a rigorous development plan that guides this project through detailing shell design, shell optimization, and ceramic 3D printing innovations to significantly reduce casting lead times. Simplification of front-end casting processes using LAMP ceramic 3D printing eliminates many of the traditional processing steps needed to build cores and shells. One component will be selected from each aircraft program (B-2 Spirit Bomber, C-5 Galaxy, and A-10 Thunderbolt II) to undergo demonstration of on-demand investment casting using LAMP ceramic 3D printing technology and inspection results will be evaluated for acceptability.

PROJECT START DATE

October 2023

EXPECTED END DATE

January 2026

EXPECTED DELIVERABLES

- Ceramic shell design files
- Ceramic shell slice image stacks
- Presentations shared at MMX and TRX events
- Final report

FUNDING

$1,868,331 total project budget

($1,245,554 public funding/$622,777 private funding)

PROJECT PARTICIPANTS

Project Principal:

DDM Systems, Inc.

Project Participants:

NCDMM/America Makes
76th CMXG at Tinker Air Force Base
Air Force Sustainment Center
Mueller Additive Manufacturing Solutions

Public Participants:

U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to: PROCESS

ASTM PROCESS CATEGORY	EQUIPMENT	MATERIAL
Vat Photopolymerization	DDM Systems' CPT6060 Ceramic 3D Printer	Ceramics

Project Manager: Amanda Young

5554.003

3D Ceramic Research and Extensive Application of Tools for Engineered Molds (3D CREATE)

PROBLEM
The U.S. Air Force requires parts that can be delivered rapidly, affordably, and in small quantities to support legacy systems with part shortages and new system development. However, making complex tools for casting applications is not cost-effective for producing small batches of parts. Similarly, producing small quantities of parts using metal additive manufacturing (AM) is not cost-effective due to the high qualification costs for material and process changes. Furthermore, a lack of industry awareness and roadblocks within ceramic molding hinders acceptance among design engineering and foundries and remains a barrier to wider AM tooling adoption.

OBJECTIVE
Renaissance Services, Inc. (RSI) has identified five technical focus areas to address the success factors for ceramic AM. The first focus area is a better surface finish for AM ceramic tooling, providing an improved surface finish for castings. The second area is AM ceramics' in-process inspection to reduce cycle times and cost. The third topic is enhanced ceramic AM mold assembly for complex castings and improved casting yields. The fourth area is reducing trial and error in the AM mold gating design to minimize cycle time and cost. Lastly, RSI will concentrate on the ease of core removal for integral and core molds, enabling castings to replace fabricated parts.

TECHNICAL APPROACH
As part of the approach for 3D CREATE, the RSI project team and industry professionals will collaborate on a plan for business drivers for new and legacy cast parts and will present ceramic AM opportunities from the five technical focus areas. Each area will assist with the development of news parts versus those used for legacy part sustainment.

Aspen Technology will provide consulting on the five main objective areas. RSI engineers will manufacture ceramic samples and molds and apply the various post-processes and profilometer measurements. The University of Northern Iowa will supply sample castings for evaluating the results of this technical development. The Ohio State University will improve ceramic core removal from aluminum castings. Product Development & Analysis will perform mold casting simulations. The five foundry partners will demonstrate the results for a range of castings produced from nickel, aluminum, and steel. As part of the America Makes effort, the RSI team will leverage outreach to the casting and aerospace industries to share and promote results from 3D CREATE.

PROJECT START DATE
September 2023

EXPECTED END DATE
December 2025

EXPECTED DELIVERABLES
- Feasibility and development reports
- Material properties and validations reports
- Demonstration castings
- Monthly presentations with industry partners
- TRX presentation
- Final report

FUNDING
$2,980,583 total project budget
($1,987,055 public funding/$999,528 private funding)

PROJECT PARTICIPANTS
Project Principal:
Renaissance Services, Inc. (RSI)

Project Participants:
Aspen Technology, LLC
Product Development & Analysis (PDA), LLC
University of Northern Iowa
The Ohio State University
Bescast, Inc.
Chicago Magnesium
HTCI Co.
Kovatch Castings, Inc.

Public Participants:
U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to: PROCESS

ASTM PROCESS CATEGORY	EQUIPMENT	MATERIAL
Vat Photopolymerization	N/A	Ceramic Oxide Powders

Project Manager: Litsa Rubino

5554.006

Additive Manufacturing to Address Component Sourcing Gaps

PROBLEM

Limited exploration of the economics of using additive manufacturing (AM) techniques in the production of cast and forged parts have mostly resulted in art-of-the-possible demonstrators without an adequate assessment of the economic tradeoffs. A repeatable and reusable method to evaluate the tradeoff between traditional casting and forging processes and AM techniques quickly and reliably is needed to determine when AM is suitable for use in the casting and forging supply chains.

OBJECTIVE

The objective of this program is to develop a validated, modular, techno-economic framework adaptable to various metal AM modalities with the goal of assessing the feasibility of using AM to “bridge” casting and forging supply chain gaps. The framework guides decisions for when to deploy AM to address gaps in component sourcing, considering aspects spanning the value chain. Specific objectives include the development of a tool to assess process viability with ability to match viable processes with potential suppliers and visualize cost and time tradeoffs across technologies and sources.

TECHNICAL APPROACH

The technical approach constructs and validates a matrixed, modular framework comprised of three primary pillars: technology, production, and economics. Each pillar serves a key function in defining when (economics), where (production), and how (technology) to viably implement “bridge” components using AM.

The technology pillar focuses on identifying a viable AM process for a given part. To build this capability, key metal AM modalities will be identified, and representative test cases employed to enable a comparison of component characteristics against AM process flows.

The production pillar creates a structured set of AM supplier attributes, including capabilities and certifications. When combined with output from the technology pillar, this information enables visibility to potential sourcing pathways by mapping candidate processes with features of candidate suppliers.

The economics pillar enables a time and cost-based view of candidate sourcing pathways. These two factors support a “cost of time” analysis, enabling visibility into potential inflection points where one pathway may be preferable over another.

Integration of the technology, production and economics pillars finalizes the techno-economic framework and allows the processing of representative test cases to complete the validation phase of the activity.

PROJECT START DATE

August 2023

EXPECTED END DATE

May 2024

EXPECTED DELIVERABLES

- Techno-eeconomic framework and associated software tool
- Final report

FUNDING

$3,236,840 total project budget

($500,000 public funding, $2,736,840 private funding)

PROJECT PARTICIPANTS

Project Principal:

Deloitte Consulting, LLC

Project Participants:

NCDMM/America Makes

Public Participants:

U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to: VALUE CHAIN

ASTM PROCESS CATEGORY	EQUIPMENT	MATERIAL
Powder Bed Fusion, Directed Energy Deposition	N/A	N/A

Project Manager: Nick Leone

5554.007

Techno-Economic Analysis to Bridge Casting and Forging Sourcing Gaps with AM

PROBLEM

There are instances where additive manufacturing (AM) can serve as a method to bridge gaps in component sourcing for casting and forging applications. However, these applications and opportunities lack definition and understanding. In addition, the economics of technology transition from casting and forging to AM have often failed to demonstrate a comprehensive return on investment (ROI) at the macro-economic level. To truly understand the economics of transitioning from casting and forging to AM, a techno-economic analysis (TEA) framework is required. A preliminary analysis of product types, considerations, and acceptance standards in concert with an AM technology/manufacturing readiness assessment is needed to develop such a framework.

OBJECTIVE

The objective of this project is to create a tool that provides a TEA framework for when, where, and how to utilize AM technologies to bridge gaps in component sourcing. This tool will cover four metal AM modalities: Laser powder bed fusion (PBF-LB), laser and electron beam directed energy deposition (DED), wire arc additive manufacturing (WAAM), and additive friction stir deposition (AFSD). The tool should provide insight as to why traditional cost models show that AM is more expensive than traditional castings and forgings and whether this will continue to be true as the AM industry matures.

TECHNICAL APPROACH

Wichita State University National Institute for Aviation Research (WSU NIAR) will create a TEA framework to enable the application of four additive manufacturing modalities to bridge the current casting and forging manufacturing methods.

Work will be divided into three sequential milestone efforts: research, gap analysis, and recommendations. These work streams will in turn focus on three topic areas – TEA, technical AM, and the sourcing process – to ensure the delivered framework can be leveraged across the sustainment lifecycle process. Throughout the project, an advisory board composed of government agencies and industry stakeholders with expertise in the above three focus areas will provide input.

During the research phase, WSU NIAR will seek, review, and compare existing AM cost tools including recommendations from the advisory board. These models will then undergo a gap analysis focusing on their accuracy within techno-economic viability, technical AM precision, and sourcing application. The final phase of the program will be the creation of a TEA framework that provides the tools needed to make informed decisions concerning all relevant factors.

PROJECT START DATE

November 2023

EXPECTED END DATE

August 2025

EXPECTED DELIVERABLES

- Four Modality AM cost model including techno-economic analysis
- Final report

FUNDING

$384,611 total project budget

($246,524 public funding/$138,087 private funding)

PROJECT PARTICIPANTS

Project Principal:

Wichita State University National Institute for Aviation Research (WSU NIAR)

Project Participants:

Valdos Consulting, LLC

Public Participants:

U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to: VALUE CHAIN

ASTM PROCESS CATEGORY
Powder Bed Fusion, Directed Energy Deposition, Sheet Lamination

EQUIPMENT
N/A

MATERIAL
Metals

Project Manager: Litsa Rubino

5554.005

Pilot the Industrialization of AM Preforms to Expedite the Forging Process of Low Volume Forged Components

PROBLEM

Producing low-volume, forged components, often required by the Department of Defense (DoD), involves significant tooling costs and extended lead times. The prolonged lead times stem from the intricate forging process, which requires a considerable number (two to seven or more) of pre-forming steps to achieve highly complex designs that meet stringent strain requirements. In addition, the machining and heat treating of the tooling to achieve the final forged part add additional time and expense.

OBJECTIVE

The project aims to assess the feasibility of employing additive manufacturing (AM) techniques to streamline the production of low-volume forgings. The project involves investigating the properties, viability, efficiency, cost-effectiveness, lead times, and other advantages associated with AM preforms. The goal is to promote the adoption of AM preforms, resulting in shorter lead times and improved performance in forging operations. Additionally, the project seeks to offer guidance to forging professionals, allowing them to make informed decisions regarding selecting and effectively utilizing AM-produced preforms in their processes.

TECHNICAL APPROACH

Cleveland State University, Wright State University, and the Forging Industry Association (FIA) are collaborating with forgers (Cleveland Drop Forge and SIFCO) and other DOD stakeholders to identify suitable forgings for investigation. Upon identification, FasTech and Georgia Southern University are employing three AM processes to fabricate preform material coupons, subjecting them to nondestructive investigation (NDI), microstructural studies, and compression tests. The data obtained from these tests inform simulation studies, which will establish requirements for the preforms used in the forging process.

In the forging and characterization phase of the project, finished forgings are being produced from AM preforms using finisher dies. Mechanical testing and microstructural analysis of the resulting forgings provide insights into the internal structure and composition achieved. NDI evaluations identify defects and structural integrity, allowing correlation to forged part performance. A comparison between parts produced via an AM preform forging process and conventionally forged parts is being conducted with preform quality, material efficiency, and cost-effectiveness being evaluated. The findings guide the establishment of recommended requirements and benchmarks with plans to address scalability, reproducibility, and industrial feasibility of the AM processes. Criteria are also developed for selecting appropriate preform design and AM fabrication methods.

PROJECT START DATE

October 2023

EXPECTED END DATE

October 2025

EXPECTED DELIVERABLES

- Interim report detailing AM processing variables and resulting performance evaluations for SS316L
- Interim report detailing AM processing variable and resulting performance evaluations for Inconel 718
- Benchmarking of tensile properties of AM forged SS316 to traditional forged part
- Benchmarking of tensile properties of AM forged Inconel 718 to traditional forged part
- NDT procedures/results for AM forged SS316

FUNDING

$2,959,856 total project budget

($1,835,781 public funding/$1,124,075 private funding)

PROJECT PARTICIPANTS

Project Principal:

Cleveland State University

Project Participants:

NCDMM/America Makes; Wright State University; Georgia Southern University; FasTech, LLC; Forging Industry Association (FIA); Canton Drop Forge; SIFCO Industries

Public Participants:

U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to: DESIGN

ASTM PROCESS CATEGORY	EQUIPMENT	MATERIAL
Binder Jetting, Powder Bed Fusion, Directed Energy Deposition	N/A	SS316L, IN718

Project Manager: Litsa Rubino

5554.008

DED Additive Manufacturing for Forging Die Repair

PROBLEM

Forming dies plays a crucial role in forging operations, impacting overall manufacturing expenses, productivity, quality, and the lead time of the final forged part. Traditional welding die repair methods can pose challenges like material compatibility issues, extended post-repair machining cycles, and risk of heat-affected zone (HAZ) formation, affecting the quality and reliability of the repaired die. Additive manufacturing (AM) technologies, such as directed energy deposition (DED), can offer an efficient, cost-effective method for die repair. However, there is an ongoing need to better understand the DED process from the standpoint of material properties, design methodologies, and manufacturing procedures to ensure optimal performance for dies repaired with AM technologies.

OBJECTIVE

The objective is to comprehensively assess the effectiveness and efficiency of DED methods in repairing forging dies. This involves advancing proficiency in DED processes through practical manufacturing demonstrations, robust qualification initiatives, effective characterization methods, and dependable modeling and simulation tools.

Additionally, the project aims to develop efficient DED process parameters tailored to the die repair conditions relevant to the selected material. Further objectives include the development of annealing treatments to ensure the durability and efficiency of the repaired dies. Lastly, the goal is to integrate DED processes to refurbish large, heavy, or complex forging dies.

TECHNICAL APPROACH

The approach begins with selecting alloys for die repair, considering mechanical properties, material availability, and compatibility with H13 tool steel. Additionally, plans involve developing annealing or tempering treatments to ensure consistent mechanical properties and reduce internal stresses, enhancing the overall performance and durability of the repaired dies.

Following alloy selection, the project shifts to testing and characterizing the repair alloys post-deposition, evaluating mechanical properties and microstructure for optimized behavior and durability in the finished die.

The project then focuses on repairing tooling through DED. Validation of the optimal DED method and repair alloy through testing ensures precise restoration of the forging die's functionality and integrity. This includes checking result repeatability, comparing deposition times with conventional methods, and exploring post-processing treatments for potential cost savings and productivity improvements.

Lastly, the repaired die is returned to production, and its ability to forge numerous parts without additional repairs is monitored. The ongoing assessment aims to compile best practices for repairing forging dies using DED-deposited alloys, providing valuable insights and recommendations to America Makes members and forging professionals.

PROJECT START DATE October 2023

EXPECTED END DATE October 2025

EXPECTED DELIVERABLES

- Written documentation of the selection and evaluation of alloys to determine capability of DED processes to repair forging dies. Annealing and tempering treatment requirements to ensure performance and durability of the forging dies to also be reported.
- Written report to document mechanical and micro-structural testing and characterization of repair alloys.
- Written report detailing the measurement and characterization of the tooling repairs performed through DED deposition in conjunction with selected repair alloys.
- Final report and presentation at national meetings/conferences detailing performance evaluations of repaired dies in forging production to assess the effectiveness of repairs and associated KPPs.
- Published manual and corresponding workshops to compile and disseminate best practices for AM repair of forging dies to the forging community.

FUNDING

$1,276,679 total project budget
($750,000 public funding/$526,679 private funding)

PROJECT PARTICIPANTS

Project Principal: Cleveland State University

Project Participants: NCDMM/America Makes; Canton Drop Forge; Absolute Welding & Machining; Forging Industry Association (FIA); FasTech, LLC

Public Participants: U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to: VALUE CHAIN, DESIGN

ASTM PROCESS CATEGORY
Directed Energy Deposition

EQUIPMENT
N/A

MATERIAL
H13 Tool Steel, Maraging Steel, Martensitic Steel

Program Manager: Mark Ray

5541

Delta Qual Team Red - Thorough Evaluation of AM with Rigorous Expertise and Data

PROBLEM

Additive manufacturing (AM) machines and materials qualification are major barriers to broad AM adoption. Generating the requisite data and models requires significant resources to produce statistically significant data. This qualification process requires generating test coupons under a controlled process and testing and analysis of the resulting data. These processes are then "frozen" with no changes to key process variables allowed. Standard-based guidance does not exist for requirements when a process change is needed. This greatly inhibits the agility of AM processes to respond to changes in the technology or supply base, allowing only one path to implement change to a qualified process — a total requalification, which may cost more than $3M per machine/material combination and take several years.

OBJECTIVE

This project will demonstrate the ability to rapidly and affordably update and/or establish a qualified AM process that can allow for changes in key AM process, post-processing, and/or material feedstock variables.

TECHNICAL APPROACH

Under this project, Team Red, The Barnes Global Advisors (TBGA), will research, map, document, and analyze AM qualification approaches, including relevant material/process specifications, and develop a conservative (nearly start from scratch) baseline for comparison. The team will review and evaluate the demonstration projects, identify both positive and negative lessons learned, and rate them against the key performance parameters (KPPs), and the baseline test matrix and plan. Following the evaluation activities, Team Red will complete its analyses and document its final recommendations. Any recommendations will be communicated to the America Makes Technology Roadmaps team for consideration in future activities.

PROJECT START DATE

September 2023

EXPECTED END DATE

September 2025

EXPECTED DELIVERABLES

- Cite standards and material/process specifications to be leveraged by this program
- Draft language for including process change in standards
- Consolidated and curated list of lessons learned, key recommendations, and draft language for standards organizations to consider
- Final report

FUNDING

$826,993 total project budget

($400,000 public funding/$426,993 private funding)

PROJECT PARTICIPANTS

Project Principal:

Team Red, The Barnes Global Advisors (TBGA)

Project Participants:

BlueForge Alliance
Carnegie-Mellon University
Federal Aviation Administration
NASA
Sandia National Laboratories
SAE International

Public Participants:

U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to: PROCESS

ASTM PROCESS CATEGORY	EQUIPMENT	MATERIAL
Powder Bed Fusion	Laser Powder Bed Fusion Printing	Ti-6Al-4V

Program Manager: Mark Ray

5541

Delta Qualification Innovation (DQI) for Ti-6Al-4V Laser Powder Bed Fusion

PROBLEM

Additive manufacturing (AM) machines and materials qualification are major barriers to broad AM adoption. Generating the requisite data and models requires significant resources to produce statistically significant data. This qualification process requires generating test coupons under a controlled process and testing and analysis of the resulting data. These processes are then "frozen" with no changes to key process variables allowed. Standard-based guidance does not exist for requirements when a process change is needed. This greatly inhibits the agility of AM processes to respond to changes in the technology or supply base, allowing only one path to implement change to a qualified process — a total requalification, which may cost more than $3M per machine/material combination and take several years.

OBJECTIVE

This project will demonstrate a delta qualification approach for statistical equivalency of static allowable data and develop a statistical database and framework that provides A/B basis allowables. Specimens will be fabricated at a new supplier through the application of a geometry-driven approach that leverages existing Joint Metal Additive Database Definition (JMADD) data.

TECHNICAL APPROACH

Northrop Grumman Corporation (NGC) will develop material and process specifications and a process control document leveraging its previous data. The delta qualification build layout and test matrix will then be generated to guide test sample builds. These builds will be fabricated on an EOS M290 machine at Oerlikon and Castheon. Major process and parameter changes will be incorporated into the test matrix. All build samples will be tested and characterized. Finally, the data collected will be used to generate A/B basis allowables and actively maintained via a data management plan.

PROJECT START DATE

May 2023

EXPECTED END DATE

May 2025

EXPECTED DELIVERABLES

- Conventional test matrix and test plan
- Cite standards and material/process specifications used on project
- Powder reuse strategy
- Statistically based mechanical property curve (B-basis)
- Final report

FUNDING

$1,397,073 total project budget
($900,000 public funding/$497,073 private funding)

PROJECT PARTICIPANTS

Project Principal:
Northrop Grumman Corporation (NGC)

Project Participants:
3Degrees
Castheon
National Institute for Aviation Research (NIAR)
Oerlikon
Pinnacle X-Ray Solutions

Public Participants:
U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to: PROCESS

ASTM PROCESS CATEGORY	EQUIPMENT	MATERIAL
Powder Bed Fusion	N/A	N/A

Program Manager: Mark Ray

5541

Boeing Baseline Delta Qualification Program

PROBLEM

Additive manufacturing (AM) machines and materials qualification are major barriers to broad AM adoption. Generating the requisite data and models requires significant resources to produce statistically significant data. This qualification process requires generating test coupons under a controlled process and testing and analysis of the resulting data. These processes are then "frozen" with no changes to key process variables allowed. Standard-based guidance does not exist for requirements when a process change is needed. This greatly inhibits the agility of AM processes to respond to changes in the technology or supply base, allowing only one path to implement change to a qualified process — a total requalification, which may cost more than $3M per machine/material combination and take several years.

OBJECTIVE

The primary objective of this project is to establish a baseline for the effort needed to qualify a machine at a vendor for laser powder bed fusion (LPBF), and then demonstrate the process required to bridge this qualification to a different machine.

An additional goal of the project is to qualify two vendors to produce aerospace-quality parts from Ti-6Al-4V based on an accepted industry specification. This will allow Boeing, the Air Force, and any other organization to use these vendors to produce parts.

TECHNICAL APPROACH

Building on their knowledge and experience with the EOS M290, Boeing will establish a Process Control Document (PCD) to conduct Installation Qualification (IQ) Operational Qualification (OQ), and Material Qualification (MQ) for an M290 located at Beehive Industries. These qualification activities will follow the Aerospace Material Specification (AMS)7032 framework and the process control approach defined in AMS7003A.

Boeing will then apply the same qualification methodology to a Renishaw 500Q at Innovative 3D. Due to the differences in machine design, including the differing number of lasers, this machine will require more initial analysis for IQ and OQ.

Upon completion of this project, there will be clear documentation regarding the methods for qualifying a vendor to an industry specification for producing Ti-6Al-4V material using LBPF. There will also be documentation regarding the effort required to qualify a vendor for a different machine (bridge qualification) that is not well-known to the original equipment manufacturer (Boeing). This documentation will be provided to other organizations that will be working concurrently to develop innovative methods to reduce the level of effort required to conduct a bridge qualification.

PROJECT START DATE

May 2023

EXPECTED END DATE

May 2025

EXPECTED DELIVERABLES

- Conventional test matrix and test plan
- Cite standards and material/process specifications used on project
- Powder reuse strategy
- Statistically based mechanical property curve (B-basis)
- Final report

FUNDING

$1,333,164 total project budget

($880,442 public funding/$452,722 private funding)

PROJECT PARTICIPANTS

Project Principal:

The Boeing Company

Project Participants:

Beehive Industries

Innovative 3D

Public Participants:

U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to:

PROCESS

ASTM PROCESS CATEGORY	EQUIPMENT	MATERIAL
Powder Bed Fusion	EOS M290, Renishaw 500Q	Ti-6Al-4V

Program Manager: Mark Ray

5541

Delta Qual Major: Rapid Qualification Pathway for Metal Additive Manufacturing Using PBF-L for Critical Applications

PROBLEM

Additive manufacturing (AM) machines and materials qualification are major barriers to broad AM adoption. Generating the requisite data and models requires significant resources to produce statistically significant data. This qualification process requires generating test coupons under a controlled process and testing and analysis of the resulting data. These processes are then "frozen" with no changes to key process variables allowed. Standard-based guidance does not exist for requirements when a process change is needed. This greatly inhibits the agility of AM processes to respond to changes in the technology or supply base, allowing only one path to implement change to a qualified process — a total requalification, which may cost more than $3M per machine/material combination and take several years.

OBJECTIVE

Develop a rapid qualification framework for metal AM laser powder bed fusion (PBF-L) processes that can be achieved with a data-driven solution to minimize the reliance on costly and time-consuming post-build testing.

TECHNICAL APPROACH

This project will be executed using a data-driven framework, integration of key stakeholders, and the utilization of advanced technologies. The project will be organized into seven tasks that cover various aspects of the qualification process for metal additive structures: data collection, advanced sensing and data fusion, qualification framework, manufacturing and testing, demonstration component and process verification, workforce development and mobilization of rapid qualification, and data management. Each task will have specific deliverables and milestones, ensuring a systematic and well-coordinated approach to achieve the project objectives.

PROJECT START DATE

October 2023

EXPECTED END DATE

July 2025

EXPECTED DELIVERABLES

- Conventional test matrix and test plan
- Cite standards and material/process specifications used on project
- Powder reuse strategy
- Statistically based mechanical property curve (B-basis)
- Final report

FUNDING

$1,050,000 total project budget
($700,000 public funding/$350,000 private funding)

PROJECT PARTICIPANTS

Project Principal:
EOS North America

Project Participants:
3Degrees
Addiguru
NSL Analytical
The Ohio State University Center for Design and Manufacturing Excellence (CDME)
Tinker Air Force Base

Public Participants:
U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to: PROCESS

ASTM PROCESS CATEGORY	EQUIPMENT	MATERIAL
Powder Bed Fusion	EOS M290	Ti-6Al-4V

Program Manager: Mark Ray

5541

Delta Qual Major: Model Enabled Delta-Qual (MEDEL-QUAL)

PROBLEM
Additive manufacturing (AM) machines and materials qualification are major barriers to broad AM adoption. Generating the requisite data and models requires significant resources to produce statistically significant data. This qualification process requires generating test coupons under a controlled process and testing and analysis of the resulting data. These processes are then "frozen" with no changes to key process variables allowed. Standard-based guidance does not exist for requirements when a process change is needed. This greatly inhibits the agility of AM processes to respond to changes in the technology or supply base, allowing only one path to implement change to a qualified process — a total requalification, which may cost more than $3M per machine/material combination and take several years.

OBJECTIVE
The MEDEL-QUAL team will develop and demonstrate a delta qualification methodology that utilizes advanced empirical, analytical, and numerical tools to model the process-microstructure-property relationships of Ti-6Al-4V additively built material to an SLM280 machine against a baseline material data set generated under Joint Metal Additive Database Definition (JMADD) on EOS M290 machines. Additionally, the proposed program will utilize the resulting data sets to validate the use of Integrated Computational Materials Engineering (ICME) tools to reduce the time required to generate fatigue allowables by 75%.

TECHNICAL APPROACH
RTX Technologies Research Center (RTRC) will generate an Initial Experimentation (IE) test plan and build-to-print Ti-6Al-4V specimens using an SLM 280 machine. Mechanical properties from these builds will be analyzed to develop an initial process-structure-property model for the subsequent delta qualification builds. The mechanical analysis of the IE builds will assist in defining the optimum machine parameters for the delta qualification test plan. RTRC will produce up to 120 Ti-6Al-4V specimens built in accordance with the test plan and then complete mechanical property testing and Scanning Electron Microscopy (SEM) fractography to generate mechanical property curves consistent with a statistically based mechanical properties curve (B-Basis). Results from the delta qualification will be compared against the baseline JMADD results to determine equivalency.

PROJECT START DATE
October 2023

EXPECTED END DATE
June 2025

EXPECTED DELIVERABLES
- Conventional test matrix and test plan
- Standards and material/process specifications used on project
- Powder reuse strategy
- Statistically based mechanical property curve (B-basis)
- Final report

FUNDING
$1,294,849 total project budget
($700,000 public funding/$594,849 private funding)

PROJECT PARTICIPANTS
Project Principal:
RTX Technology Research Center (RTRC)

Project Participants:
Collins Applied Research & Technology
Colorado School of Mines
Hexagon Manufacturing Intelligence
Sentient Science

Public Participants:
U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to: PROCESS

ASTM PROCESS CATEGORY	EQUIPMENT	MATERIAL
Powder Bed Fusion	SLM280	Ti-6Al-4V

Program Manager: Mark Ray

5541

Delta Qual Major: Applying Machine Learning to Enable Effective Additive Manufacturing Process Qualification/Re-Qualification

PROBLEM

Additive manufacturing (AM) machines and materials qualification are major barriers to broad AM adoption. Generating the requisite data and models requires significant resources to produce statistically significant data. This qualification process requires generating test coupons under a controlled process and testing and analysis of the resulting data. These processes are then "frozen" with no changes to key process variables allowed. There is no standard-based guidance for what is required when a change to the process is needed. This greatly inhibits the agility of AM processes to respond to changes in the technology or supply base, allowing only one path to implement change to a qualified process — a total requalification, which may cost more than $3M per machine / material combination and take several years.

OBJECTIVE

This project will demonstrate an approach to AM allowables and delta qualifications that leverages AM's digital nature with machine learning (ML). ML has successfully demonstrated effectiveness across other industries for its flexibility and capacity to withstand AM process changes (e.g. changing AM material or machine), making this approach ideal for long-term sustainment.

TECHNICAL APPROACH

Senvol will complete three significant tasks: generating data, analyzing the data using the ML approach, and conducting validation builds to confirm equivalency to achieve a minimum equivalence to the Joint Metal Additive Definition Database (JMADD) program material baseline. Project training data will be generated through two separate builds on an EOS M400-1 machine, followed by mechanical testing of the specimens. Once data is collected, Senvol will use its ML software to quantify the relationship between machine parameters and mechanical performance to calculate machine learning allowables. Specifically, Senvol will develop one machine parameter set for the EOS M400-1 that will meet all baseline JMADD mechanical performance requirements and calculate the B-Basis machine learning allowable for each mechanical property target using the model generated by the machine learning software. Lastly, the Senvol team will create additional builds on the EOS M400-1 using the machine parameters developed in the previous task to evaluate the mechanical results of those builds using the AMS 7032, National Institute for Aviation Research (NIAR), and National Center for Advanced Materials Performance (NCAMP) qualification approaches to determine equivalence to the baseline JMADD data set.

PROJECT START DATE

October 2023

EXPECTED END DATE

July 2025

EXPECTED DELIVERABLES

- Conventional test matrix and test plan
- Cite standards and material/process specifications used on project
- Powder reuse strategy
- Statistically-based mechanical property curve (B-basis)
- Final report

FUNDING

$1,159,666 total project budget
($699,986 public funding/$459,681 private funding)

PROJECT PARTICIPANTS

Project Principal:
Senvol

Project Participants:
3Degrees
AoZora Additive
ATI
Battelle
The Boeing Company
Element
National Institute for Aviation Research (NIAR)
Pilgrim Consulting

Public Participants:
U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to: PROCESS

ASTM PROCESS CATEGORY	EQUIPMENT	MATERIAL
Powder Bed Fusion	EOS M400-1	Ti-6Al-4V

Program Manager: Mark Ray

5541

Delta Qual Minor: Demonstration of Novel Methods for Effective Additive Manufacturing Process Qualification/Re-Qualification

PROBLEM

Additive manufacturing (AM) machines and materials qualification are major barriers to broad AM adoption. Generating the requisite data and models requires significant resources to produce statistically significant data. This qualification process requires generating test coupons under a controlled process and testing and analysis of the resulting data. These processes are then "frozen" with no changes to key process variables allowed. Standard-based guidance does not exist for requirements when a process change is needed. This greatly inhibits the agility of AM processes to respond to changes in the technology or supply base, allowing only one path to implement change to a qualified process — a total requalification, which may cost more than $3M per machine/material combination and take several years.

OBJECTIVE

The objective of this project is to develop an effective, streamlined process for requalifying laser powder bed fusion (LPBF) Ti-6Al-4V and any components manufactured from this material after the equipment has undergone a minor software change.

TECHNICAL APPROACH

Honeywell will review its current machine qualification plan for opportunities to significantly reduce the number of tests necessary to requalify a machine after a minor software change. This review will inform the development of a delta qualification test plan and associated build layout. Honeywell will then complete a baseline qualification per its standard baseline qualification process to allow for subsequent comparison to a reduced delta qualification. Once the baseline qualification process is complete, Honeywell will complete the reduced qualification test plan and builds developed for a minor software change. Mechanical property results from the test plan will be compared to the baseline qualification process and Joint Metal Additive Database Definition (JMADD) mechanical property results to determine equivalency. Finally, a candidate machine will receive an approved minor software update and the reduced qualification will be repeated. Mechanical property results will be compared to the previously acquired mechanical property results on the project and if all results align, the reduced qualification test plan will be considered acceptable for use.

PROJECT START DATE

September 2023

EXPECTED END DATE

June 2025

EXPECTED DELIVERABLES

- Conventional test matrix and test plan
- Standards and material/process specifications used on project
- Powder reuse strategy
- Statistically based mechanical property curve (B-basis)
- Final report

FUNDING

$727,825 total project budget
($341,815 public funding/$386,010 private funding)

PROJECT PARTICIPANTS

Project Principal:
Honeywell

Public Participants:
U.S. Department of Defense

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to: PROCESS

ASTM PROCESS CATEGORY
Powder Bed Fusion

EQUIPMENT
SLM280

MATERIAL
Ti-6Al-4V

NOTES

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