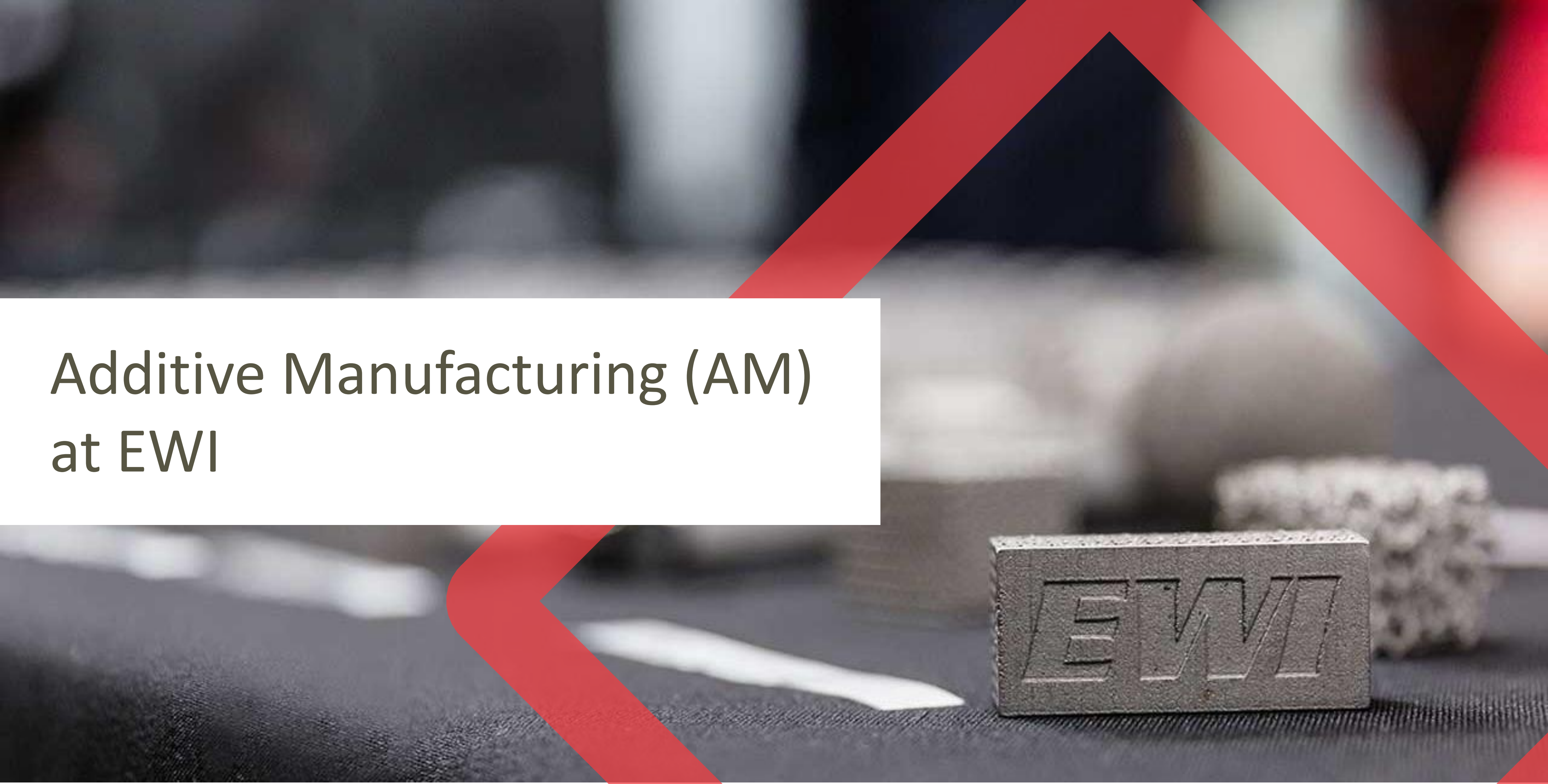
Additive Manufacturing (AM) at EWI

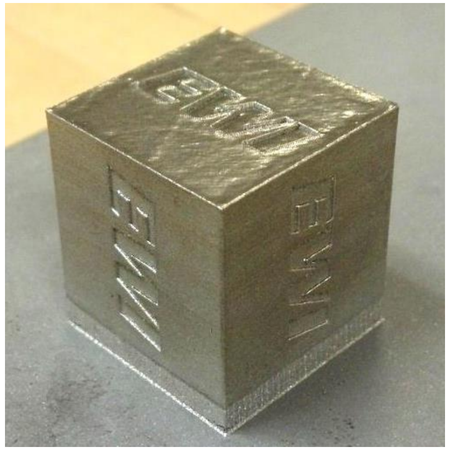


EWI®
We Manufacture Innovation

Why is EWI interested in AM?

1-inch L-PBF Cube

675 feet of weld
(Audi R8)

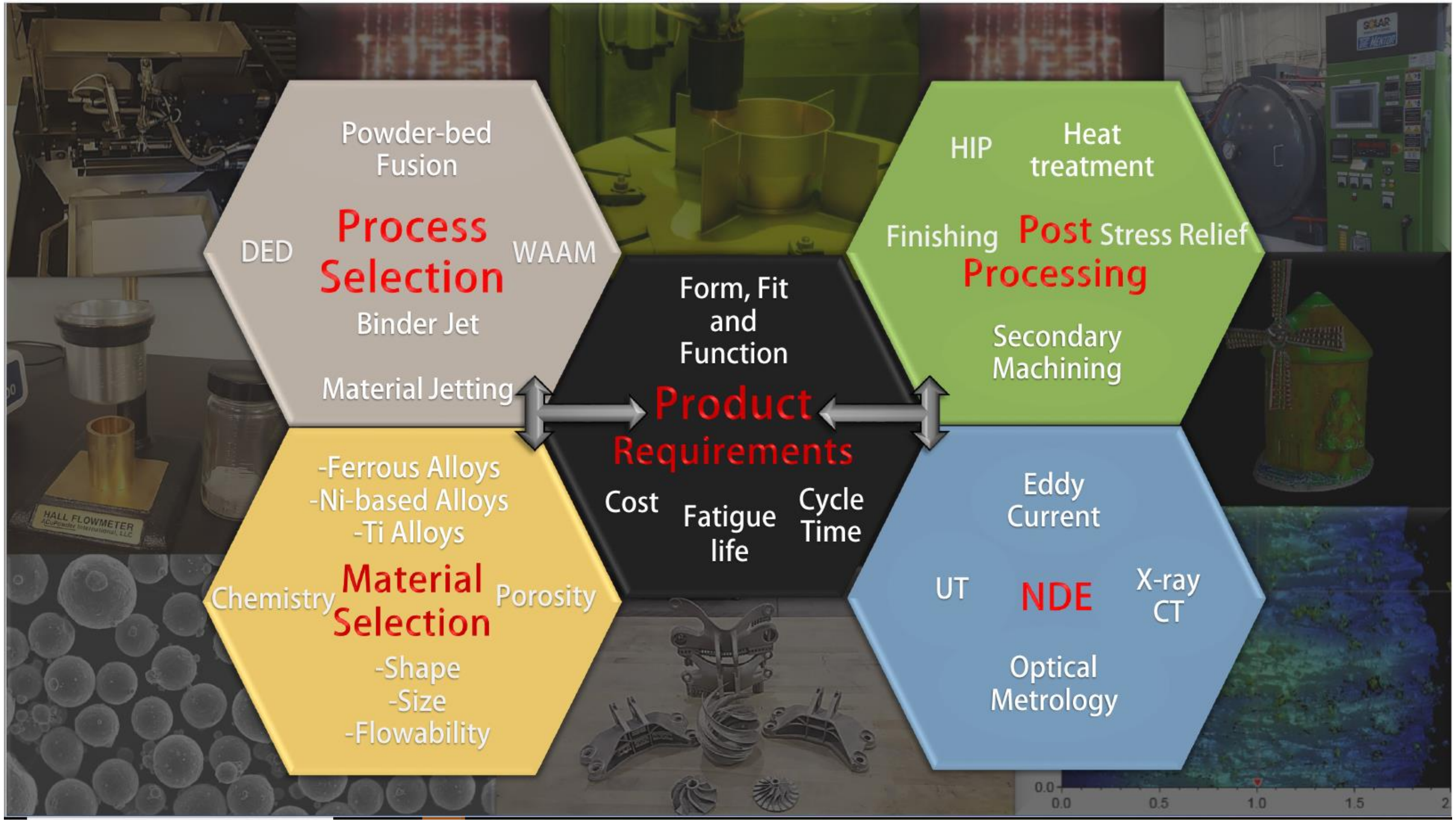


5 miles of weld

3,400 feet of weld

Additive manufacturing is materials joining over and over again!

AM Process Development



Expertise Across the Value Chain

+ Post-Processing

MATERIALS

Competency:
- Weldability
- Heat treatment
- Material processing
- Powder characterization
- Powder recycling
- Powder spheriodization
- Functionally gradient components
- Microstructure

AM DESIGN

Competency:
- Build layout, orientation, and supports
- Identification of AM prospect parts
- Design optimization for AM
- Multi-axis toolpath generation
- AM process simulation

PROCESSING

Competency:
- Material process parameter development
- Application-based process selection
- Large scale AM
- Surface finish optimization
- Scan strategies
- Material property database generation

QUALITY CNTL.

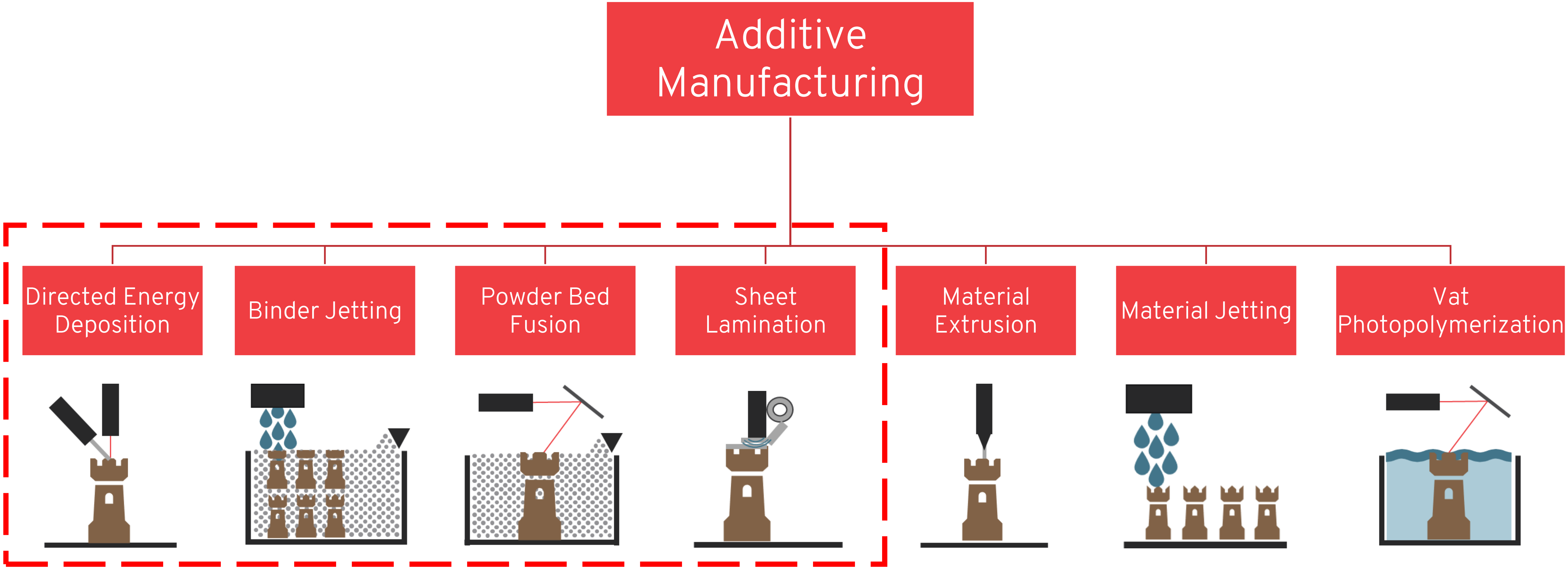
Competency:
- In-process monitoring
- Surface characterization
- Eddy current
- Phased-array UT
- X-ray CT
- Dimensional metrology

EWI's Approach to AM Applications

TRL/MRL 1 -2	**Select Application**	Learn about AM Process Capabilities, Economics, & Key Considerations	Select application candidates	Create hardware development strategies
TRL/MRL 2 - 3	**Prove Feasibility**	Learn AM design and materials considerations	Conduct initial design & analysis	Prove Feasibility
TRL/MRL 4 - 6	**Mature & Develop**	Learn AM production & qualification considerations	Test full scale prototypes at component & system levels	Begin transition out of the lab into a production environment
TRL/MRL 7 - 9	**Qualify & Produce**	Freeze component designs and process	Establish production process control	Document everything

EWI® We Manufacture Innovation

Seven Broad Modalities of AM (for now)



We Manufacture Innovation

AM technologies at EWI

- **Build Envelope:** 250×250×325 mm
- **Material Capability:**
  - Alloy steels (4140, 17-4PH)
  - Ni alloys (Haynes 282, Inco 625, Inco 718)
  - Cobalt Alloys (CoCrMo, Haynes 188)
  - Aluminum (AlSi10Mg, A205)
  - Titanium (Ti64)
  - Stainless steels (316, 420, 2205)
  - Refractory metals (Zr, W, Mo)
- **Capabilities:**
  - Production Relevant 400W laser system
  - EOSTATE MeltPool & Exposur

LB-PBF: EOS M290

- **Build Envelope:** 125×125×50 mm
- **Material Capability:**
  - All metal powder
- **Capabilities:**
  - Fully programmable 700W laser system
  - Customizable optics table and build chamber for sensor implementation
  - Open access to laser path planning, recoater motor & scanner galvanometer I/O
  - Preheated platform (up to 500°C)

LB-PBF: Open Architecture System

- **Build Envelope:** 250×250×380 mm
- **Material Capability:**
  - Stainless steel (316L)
  - Ni alloys (Inco 718)
  - Ti64, TiAl
  - Magnesium
  - CoCrMo
- **Capabilities:**
  - Production Relevant Electron Beam System
  - High Temp Vacuum Chamber for processing solidification crack prone alloys

EB-PBF: Arcam A2X

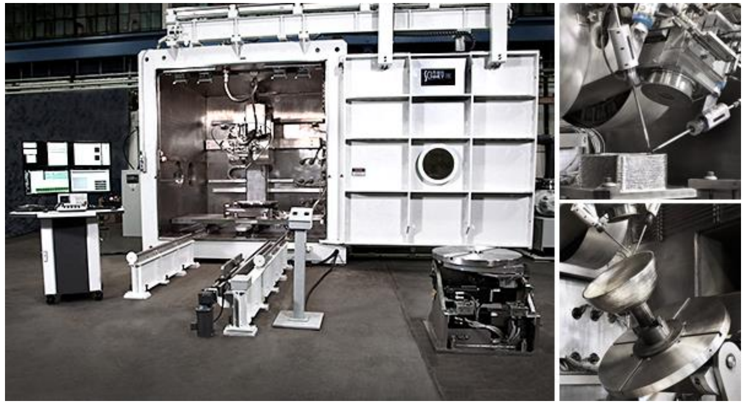
AM technologies at EWI

- **Build Envelope:**
  - 160*65*65 mm
- **Materials:**
  - Metals
  - ceramics
  - glass
  - Sand castings

Binder Jetting: ExOne Innovent+

- **Build Envelope:**
  - 5’*5’*7’
- **Materials:**
  - Metals
- **Capabilities:**
  - 5-axis capabilities

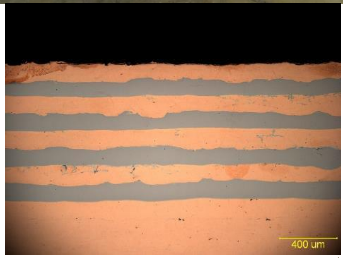
Laser Powder DED: RPMi 557XR



- **Build Envelope:**
  - 70”*47”*63”
- **Materials:**
  - Metals
- **Capabilities:**
  - multi-axis capabilities
  - Closed loop control

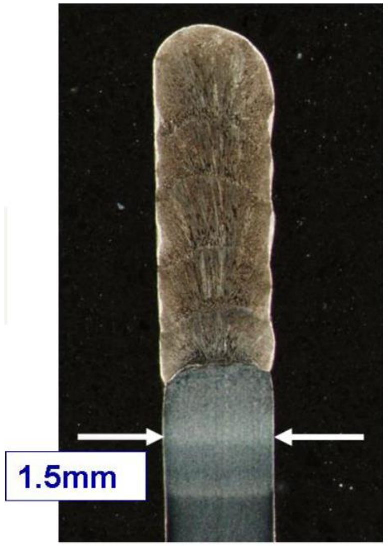
E-Beam Wire DED: Sciaky EBAM 110

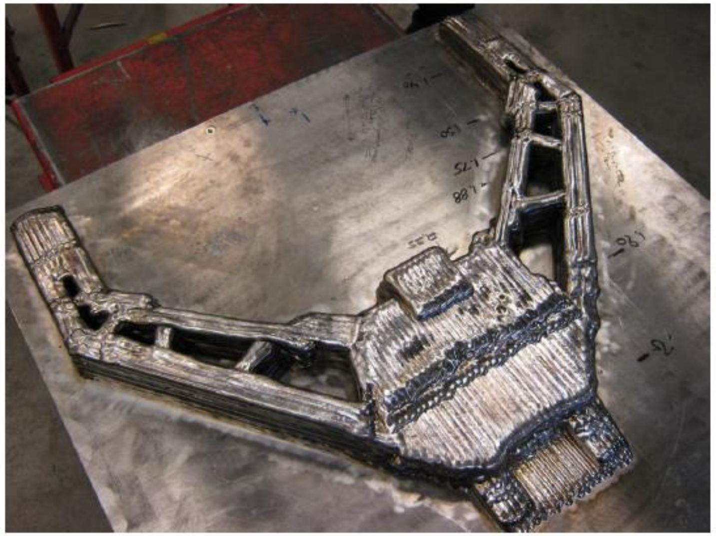
AM technologies at EWI



- **Build Envelope:**
  - 6’x6’x3’ with hybrid CNC
- **Materials:**
  - Metals incl. Al, Cu, SS, Zr, Ta, Ni
- **Capabilities**
  - Solid state, room temperature
  - Enables multi-material-system, embedded electronics

Ultrasonic AM: Fabrisonic Sheet Lamination

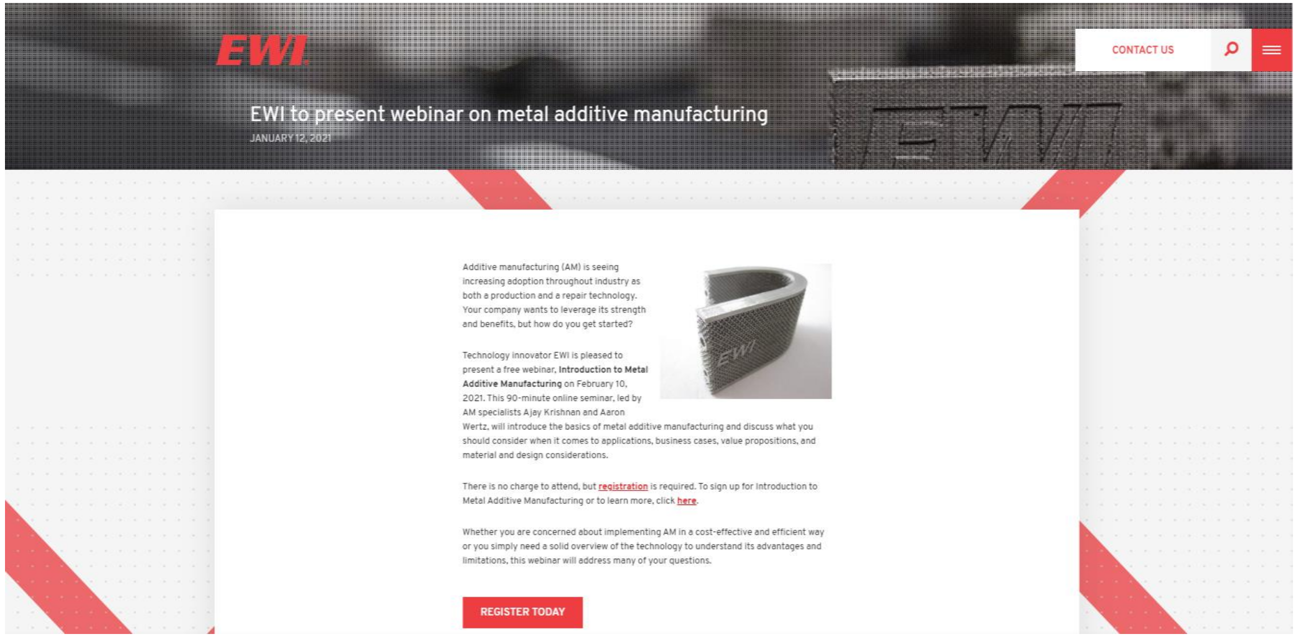


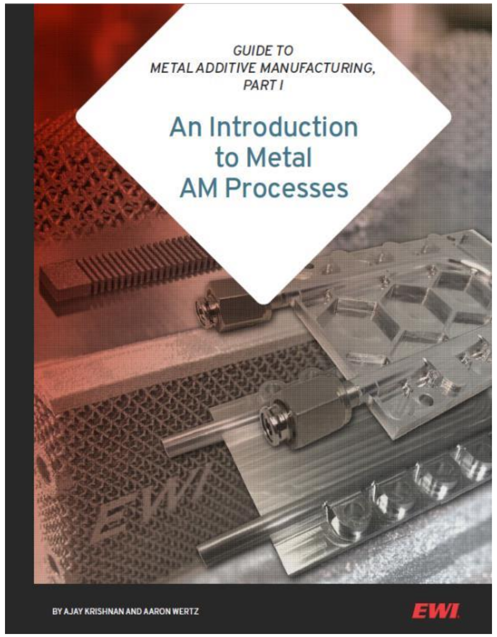


- **Build Envelope:**
  - Open cells with many options and configurations available
- **Materials:**
  - Any weldable metal wire
- **Capabilities**
  - Energy source equipment readily available
  - Core process is well understood
  - Feedstock Availability
  - High Deposition speeds

Robotic Laser and Arc DED AM: Multiple Systems

Check out our “Introduction to Metal AM” Content



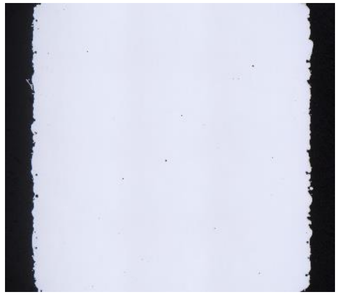


Available on-demand

Download Today!

AM Parameter & Process Development

Printing Trials

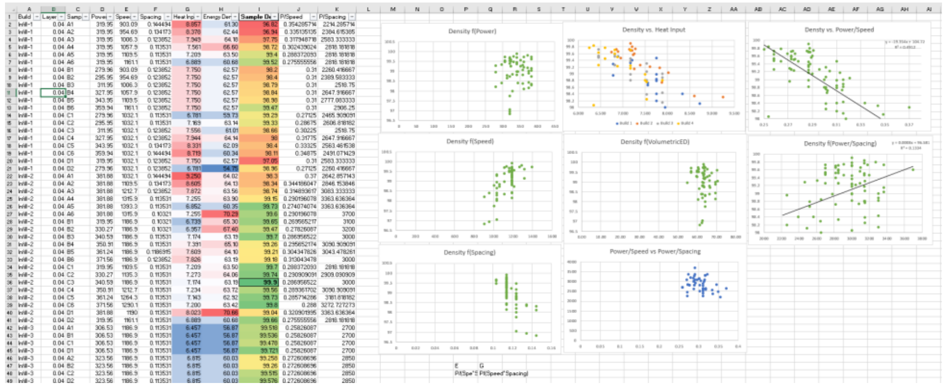


Microstructural Evaluation

Downselection of Parameters

Mechanical Testing

Iteration



Design of Experiments

AM Project Examples

New Material for New Application

Objective:

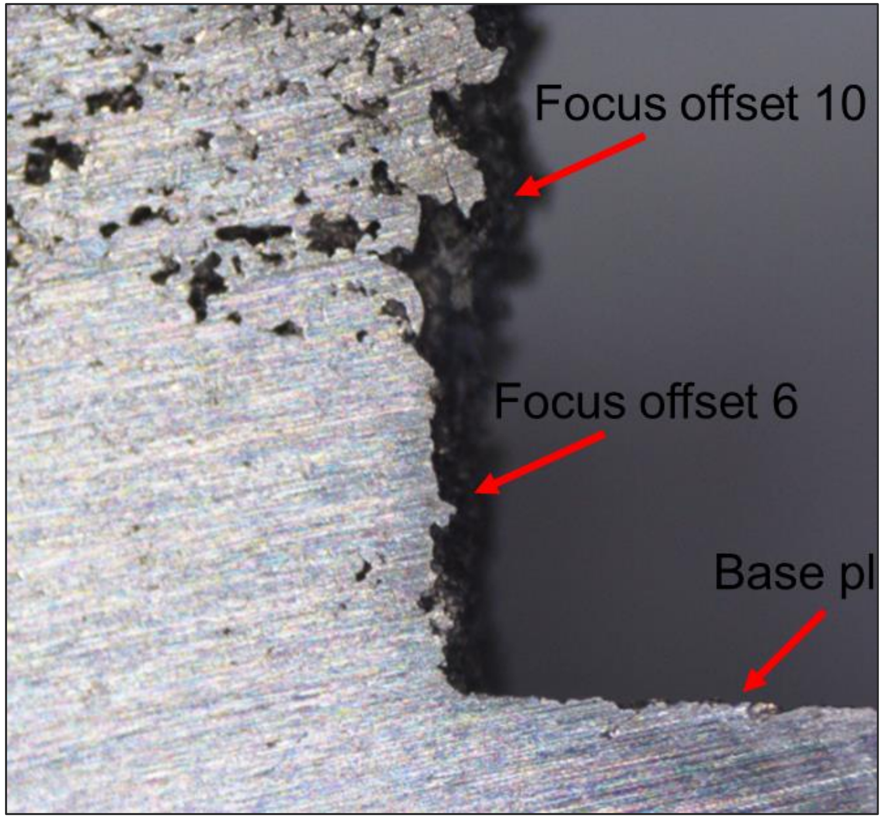
- Enable custom, additively manufactured, medical implant

Solution:

- Developed process parameters on Arcam for *high thermal conductivity material*
- Built test parts
- Validated quality met customer specification

Outcome:

- Customer performing ex-situ testing
- Customer setting plan for clinical trials



Process development for complex geometries

Objective:

- Evaluate the feasibility of conventionally built part through large scale AM

Solution:

- Redesigned part to make it AM friendly
- Determined parameters to successfully build part
- Developed a roadmap to take part to production

Outcome:

- Prototype part built

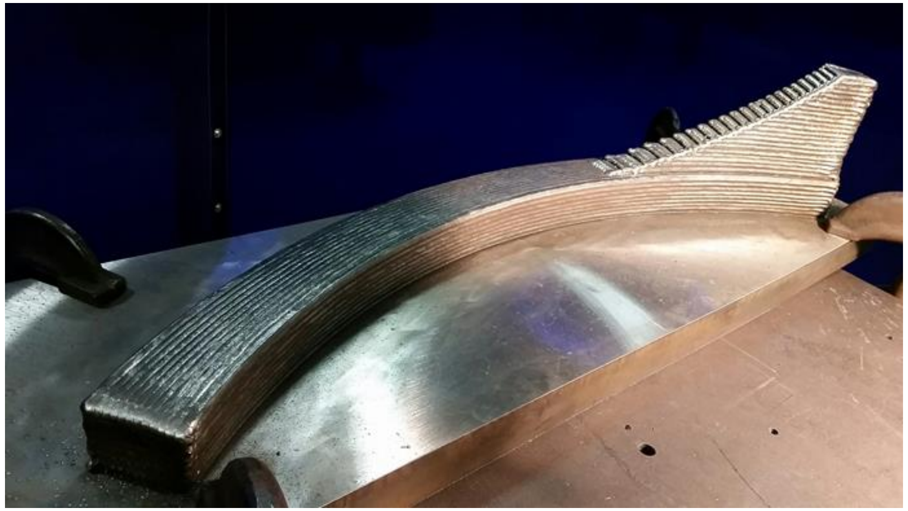
MOOG

Ti64 demo build of a secondary payload adapter

Video laser powder DED

https://youtu.be/XHepzLJqMy0

Application of robotic Arc based DED



Objective:

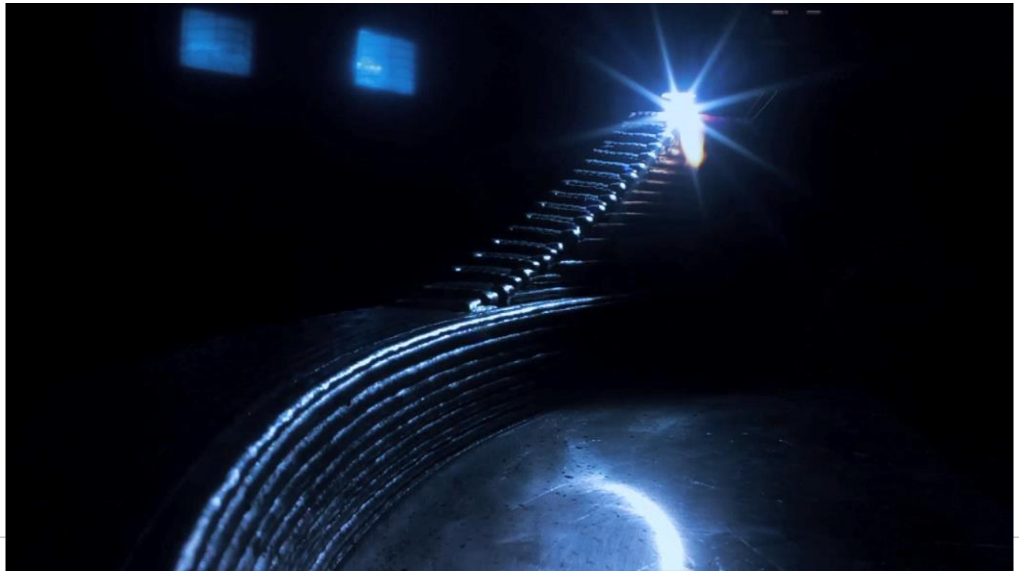
- Evaluate the feasibility GMA-DED to build 308 stainless components

Solution:

- Part built with 3/8” extra width on each side to allow for edge variation
- 0.5” added to ends

Outcome:

- Billet/casting required to machine ≥ 8” x 8” x 42”
- Process results in an 85% reduction in material required
- “Production” build time:
  - Arc-on time: 15 hours
  - Inter-layer cleaning time: 2 hours



Roughness Optimization for AM Product Improvement

Objective:

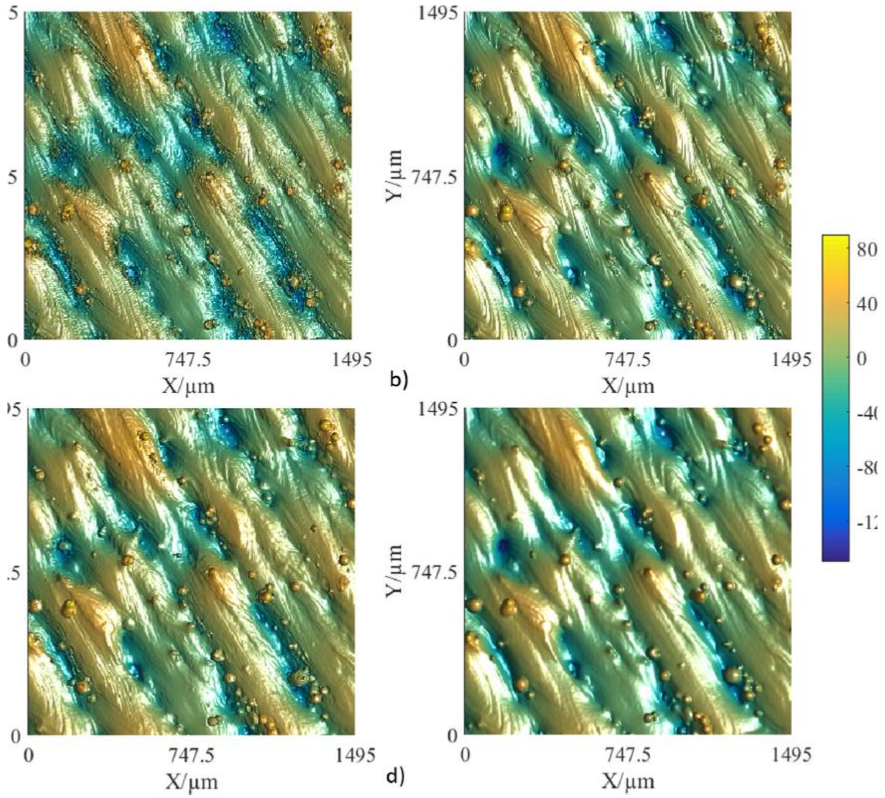
- Improve performance of in-development additively manufactured component by optimizing roughness

Solution:

- Identified metrics and measurement solutions for optimization and quality control
- Optimized surface roughness on critical surfaces to improve fatigue life and fluid flow

Outcome:

- Customer qualifying parts manufactured using new parameters



Example: Comparison of Methods to Measure Roughness

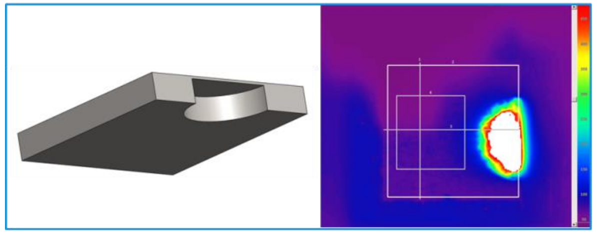
N. Senin et al. Meas. Sci. Technol. 28 (2017) 095003

In-process monitoring for AM

America Makes

- In Process Sensing for L-PBF
  - Developed and built a sensor test bed
  - Developing in process monitoring baselines for LPF
  - Investigate integration issues on EOS M280
- In Process Sensing for L-DED
  - Leading in process sensing task for L-DED repair applications
  - Developing methods to quantify powder flow rate in process.

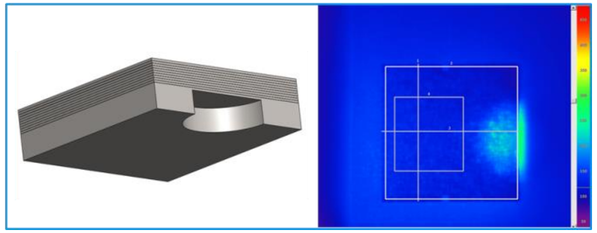
Global Thermal Imaging Pyrometer



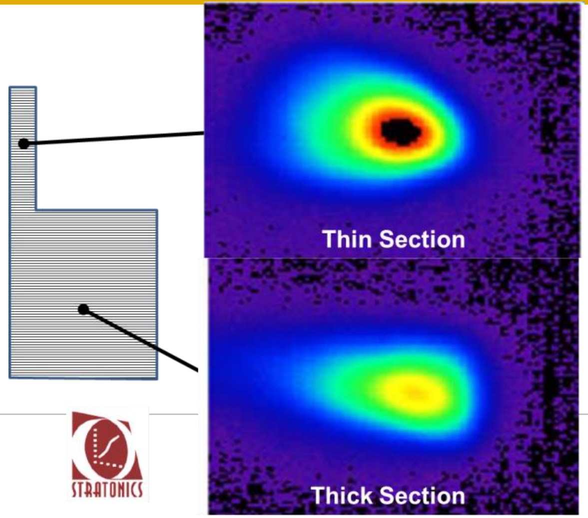
STRATONICS

Layer 1

Layer 10



Local Thermal Imaging Pyrometer



STRATONICS

Global Laser Scan and Imaging

Laser Scanned Data

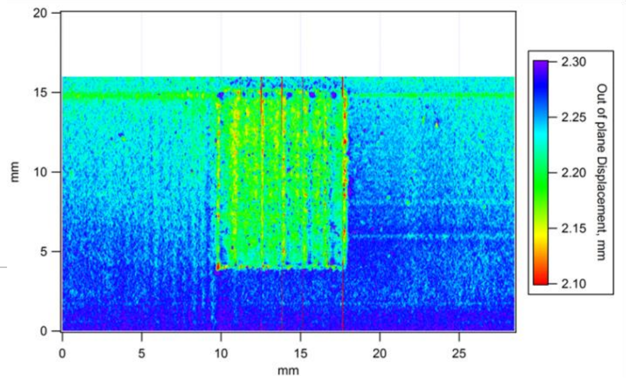
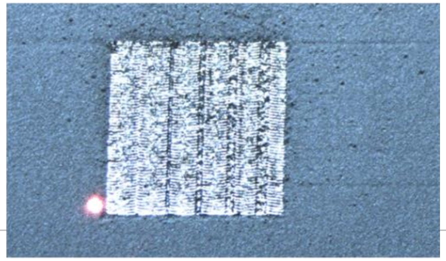


Image Scan



EWI® We Manufacture Innovation

21

Optimizing Powder for AM/Recyclability

Objective:

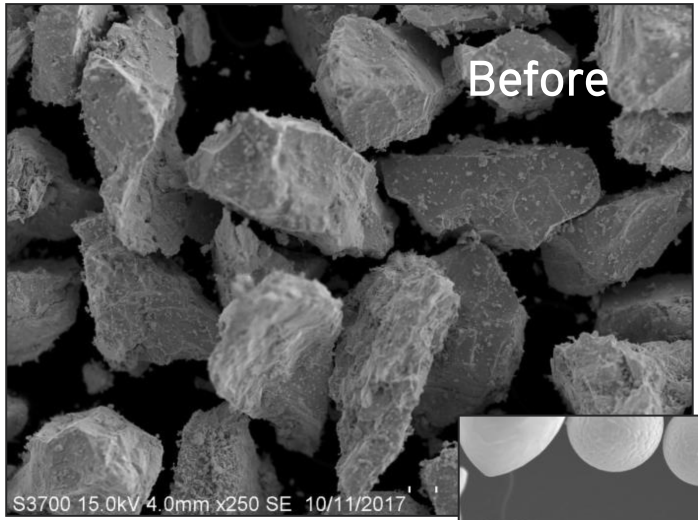
Process non spherical powder into powder that can be sold for AM

Solution:

- Sieve into batches appropriate for AM process.
- Select plasma parameters on Tek-15 for:
    - High spherical yield for flowability
    - Removal of powder porosity
    - Reduced O, N, and H content
- Provide cost evaluation on solution.

Outcome:

- Customer investing in processing equipment.
- Extending research efforts into AM process parameter development.



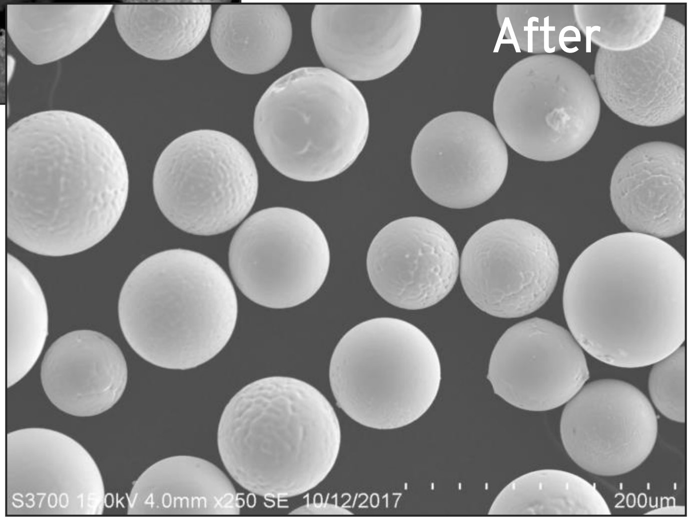


***Image:** 250x magnification - Before and After plasma processing. (Particle size: 75-105µm)*

AM at EWI

EWI advances AM at three scales:

1. **Confidential Customer Projects:** EWI confidentially solves individual companies metal AM challenges.
2. **Consortia:** Since 2009 EWI's Additive Manufacturing Consortia (AMC) has provided:
    - Pre-competitive R&D
    - Quarterly meetings to network and stay in touch with the latest and greatest
3. **Standards:** Founding partner of the ASTM AM Center of Excellence which performs and streamlines the research needed for standards development.

Additive Manufacturing Consortium

EWI®
We Manufacture Innovation

Additive Manufacturing Consortium

Mission: Accelerate and advance the manufacturing readiness of additive manufacturing technologies

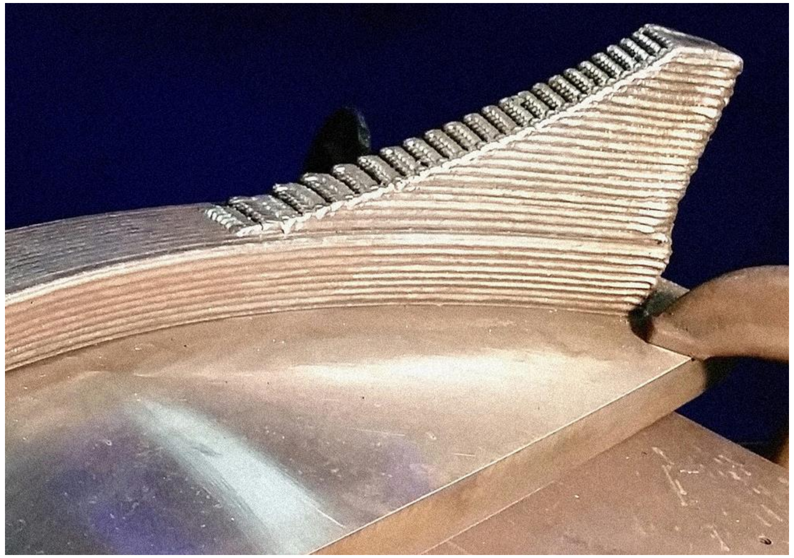
- Goals:
  - Platform for *collaboration* across global industry, academia and government entities.
  - Execute group sponsored projects focused on addressing *pre-competitive* AM challenges
  - *Partner* on government funding opportunities
  - *Forum* for discussion/shaping AM roadmaps

EWI
We Manufacture Innovation

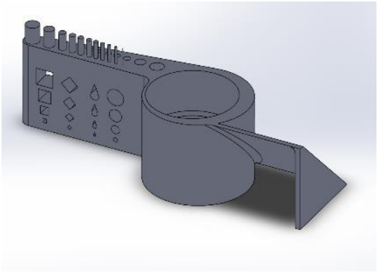
AMC Project Portfolio

Total current project portfolio is:

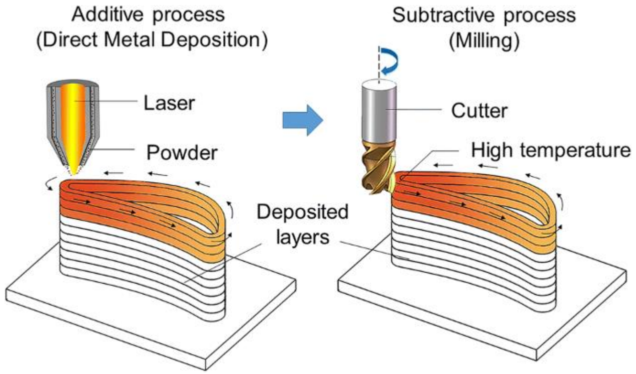
- +$4.5M in past project work
- Over $2M cash/in-kind per year of project work
- Currently 5 -8 projects/year



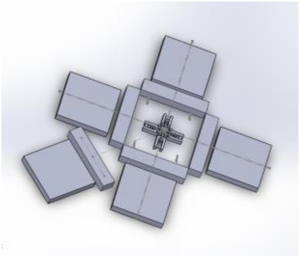
2021 AMC Projects



- **Phase 3 – Continuation of evaluating new AM technologies**
  - Continuing researching new AM technologies, obtaining samples for testing and surveys on the technologies



- **Assessment of new AM technologies - Hybrid**
  - Adopting the survey and part from new AM technologies project to cover hybrid systems (ie: additive & subtractive in same system)



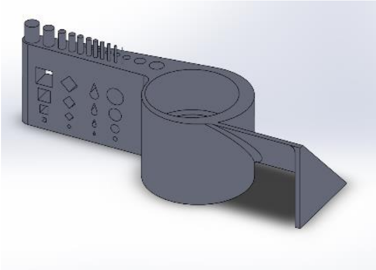
- **Investigation into multi-laser systems**
  - Completing fatigue on Ti-64 samples from last year's project and duplicating last year's project for AlSi10Mg material build from various quad laser systems (EOS, SLM, Renishaw)

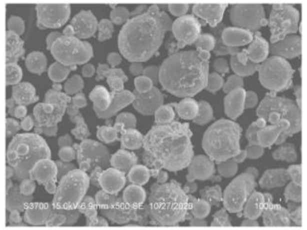
2021 AMC Projects

- **Materials Testing in AM – Does your coupon size, shape & surface condition matter?**
  - Studying the effect of coupon size & shape on properties. Determining optimum coupon sizes

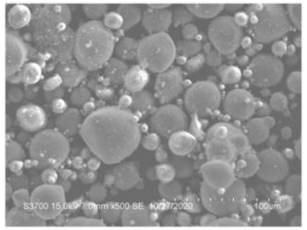
- **Deeper Dive into LPBF Process restarts**
  - Study of what is really happening at microstructure level when a process restarts and determining effects of restarts.

2020 AMC Projects

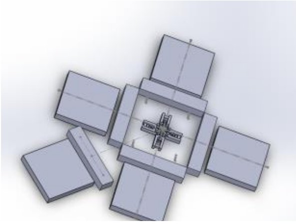


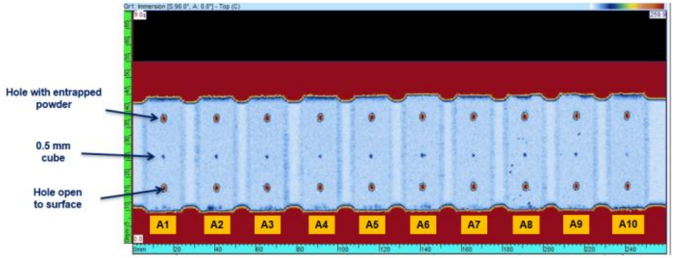


A7075 Powder



Si Powder

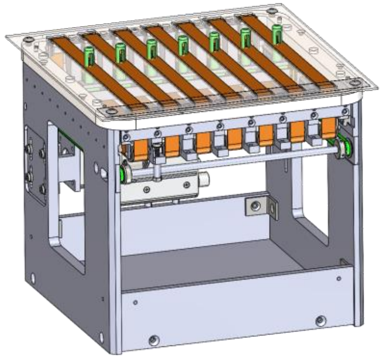




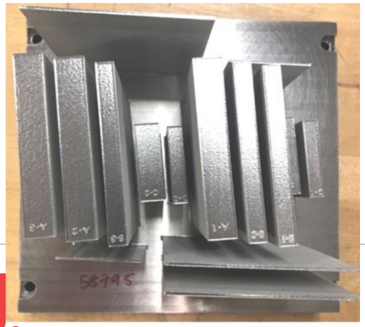
- **Phase 2a – Continuation of evaluating new AM technologies**
  - Continuing researching new AM technologies, obtaining samples for testing and surveys on the technologies
- **Phase 4 - Material Characterization & Testing for high strength aluminum alloys (7075)**
  - Evaluating effect of adding Silicon to AL7075 and comparing to commercial powders from Elementum3D and HRL
- **Investigation into multi-laser systems**
  - Evaluating performance of a Ti-64 build from various quad laser systems (EOS, SLM, Renishaw)
- **Phase 3 – Evaluation of NDE techniques**
  - Continuing study of NDE techniques of using ultrasound and PCRT to detect defects

2020 AMC Projects

- **Factors affecting AS built surfaces (vertical, upskin, downskin)**
  - Study of effect of surface angle on as built surfaces for various layer thicknesses

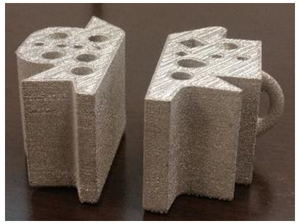


- **How to qualify machine performance across various manufacturers**
  - Evaluating how to qualify machine performance, specifically looking at airflow and laser power but also looking at accuracy



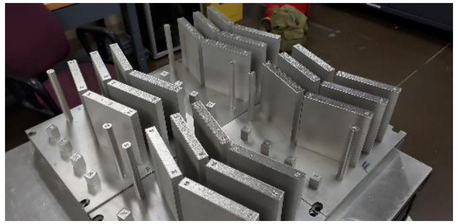
- **Phase 6 - Continuation of IN625/IN718 – Effect of thickness on microstructure**
  - Studying of effect of thickness on microstructure

2019 AMC Projects



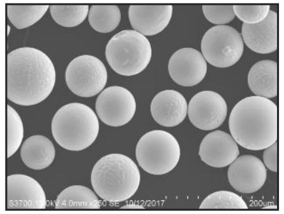
- **Phase II: Evaluation of Post Process Techniques for AM**
  - Processing a part using 8 post process techniques and comparing results. This year looking at the effect of post processing on fatigue results

- **Phase III: In-Process Monitoring**
  - Evaluating all of the commercial available in-process monitoring systems for L-PBF and comparing their results.



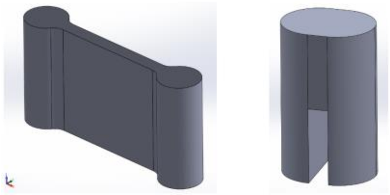
- **Phase V: Continuing Further Testing on Current Projects IN 625 and IN 718 and Relating Microstructure to AM Properties – Fatigue & Creep**
  - Studying the fatigue and creep resistance of AM printed parts

2019 AMC Projects

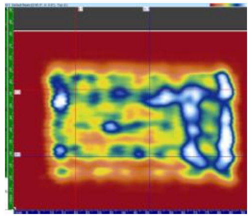


- **Evaluation and compare powder measurement techniques**
  - Evaluation of available powder measurement techniques to determine what system works best for specific types of powder

- **Assessment of new AM metal AM technologies**
  - Reviewing the “new” metal AM technologies and then comparing the properties of parts printed using those technologies



- **Feature wise Parameter development for L-PBF**
  - Looking at how parameters should be varied for specific types of geometries (ie: bridges or thin walls)



- **Phase II: Evaluation of NDE techniques for complex AM parts**
  - Determining the best NDE techniques to analyze a complex AM part

ASTM AM Center of Excellence

AM standards advancement is not happening fast enough to keep pace with rapid AM technology development.

Current ad hoc approach results in:

Standards gaps and duplication	Inconsistent standards R&D across industries and geographies	No dedicated workforce to drive R&D for standards	Lack of global acceptance of standards

ASTM AM CoE Partners

Facilitator of R&D, standards development, and enabling qualification & certification

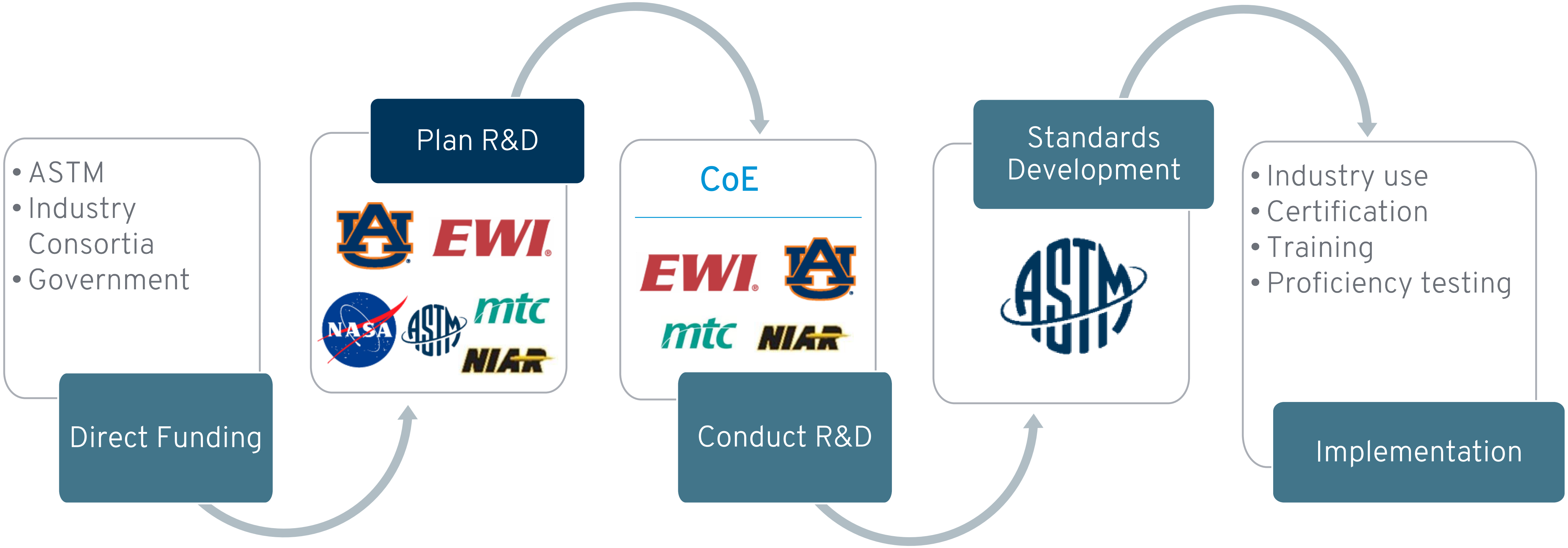
Build industry consortia and work with them to identify and advance standards

In addition to R&D, Develop education and training resources and tools

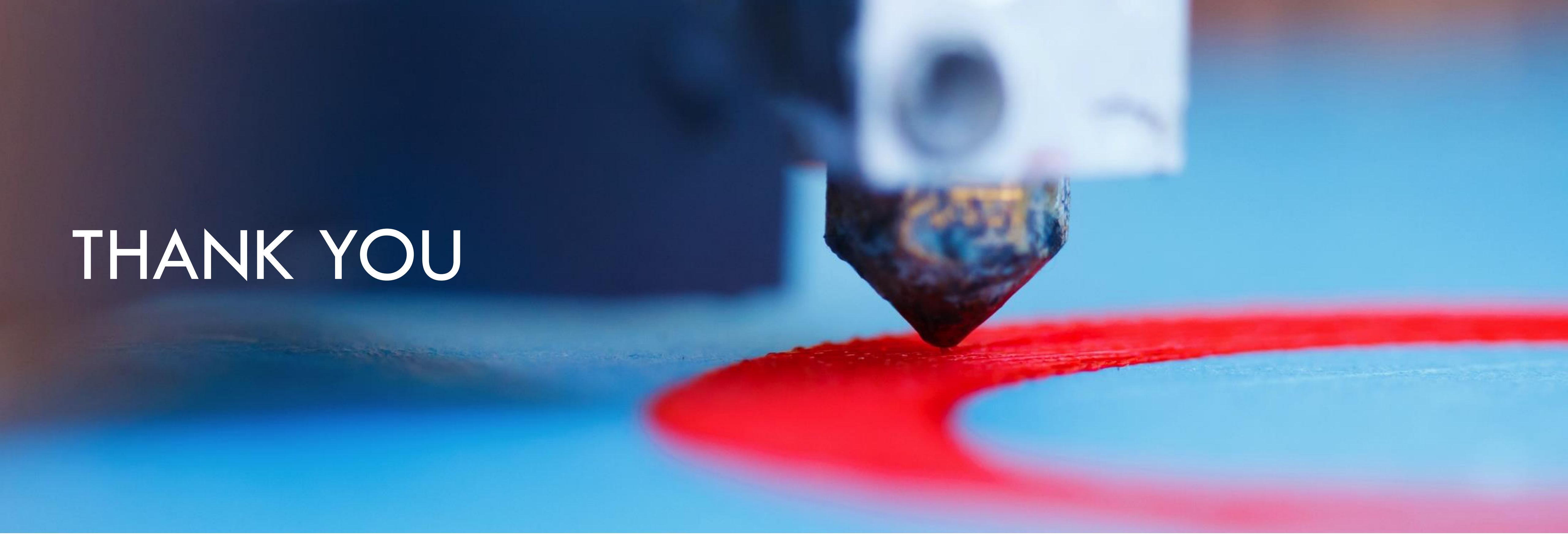
Provide expertise in conducting R&D for standards in the aerospace and aviation fields

Global perspective on conducting R&D for standards for AM

How it works



Benchmarking materials, testing, processes, and machinery for standards development



THANK YOU

Contact Information:

Mark Barfoot

Director, AM Programs

mbarfoot@ewi.org

716-710-5597