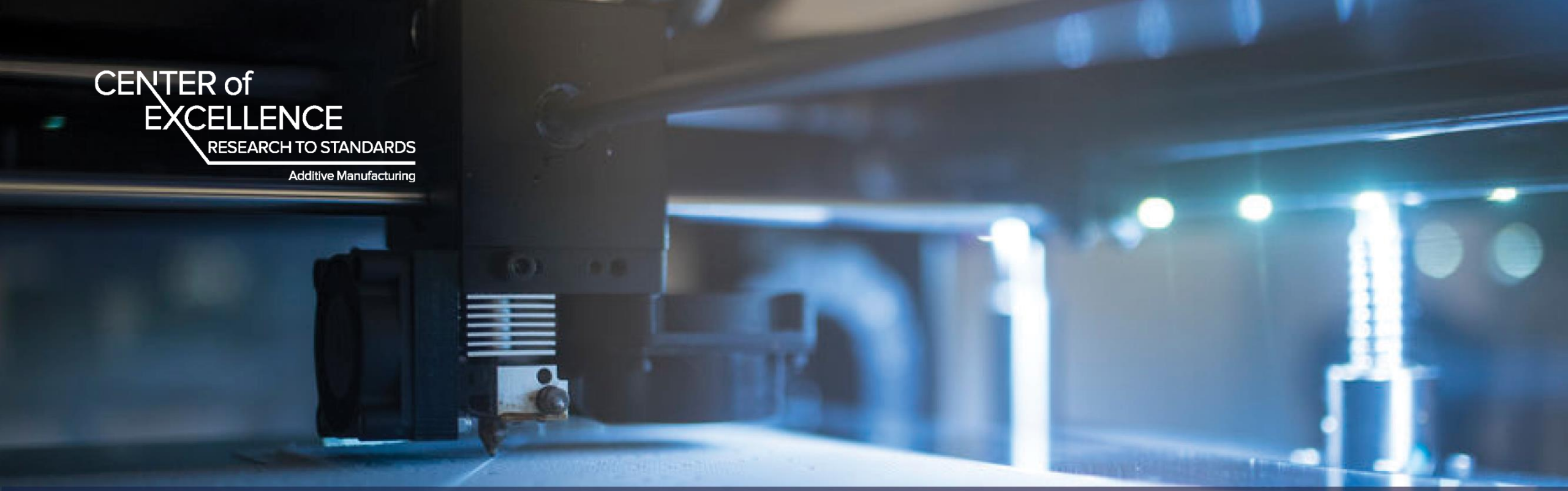


1st ASTM AM CoE Training Workshop

Metallic Laser Beam Powder Bed Fusion Process Qualification

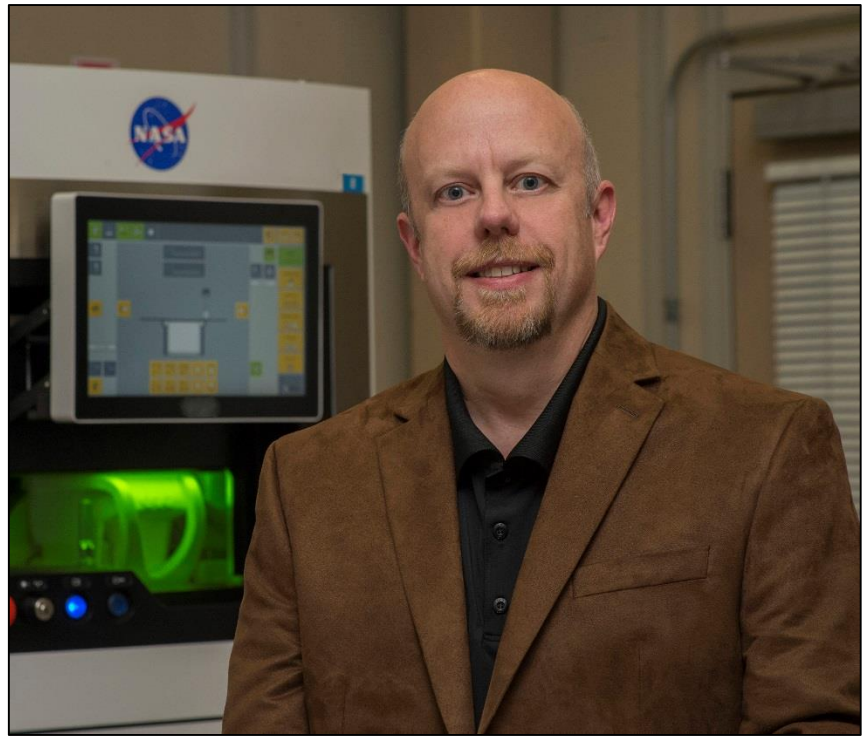
Douglas N. Wells, NASA Marshall Space Flight Center

Presenter Bio

Douglas Wells

NASA Marshall Space Flight Center

- Structural Materials Engineer, Materials and Processes Laboratory
- 25 years experience in fatigue, damage tolerance, and fracture control of flight structures.
- 8 years developing methodologies for the qualification and certification of additively manufactured spaceflight hardware
- Developed first NASA standards to establish requirements for incorporating additively manufactured hardware into flight vehicles



Introduction and Overview

Metallic Laser Beam Powder Bed Fusion Process Qualification

- *Machine and Process Qualification are Fundamental.*

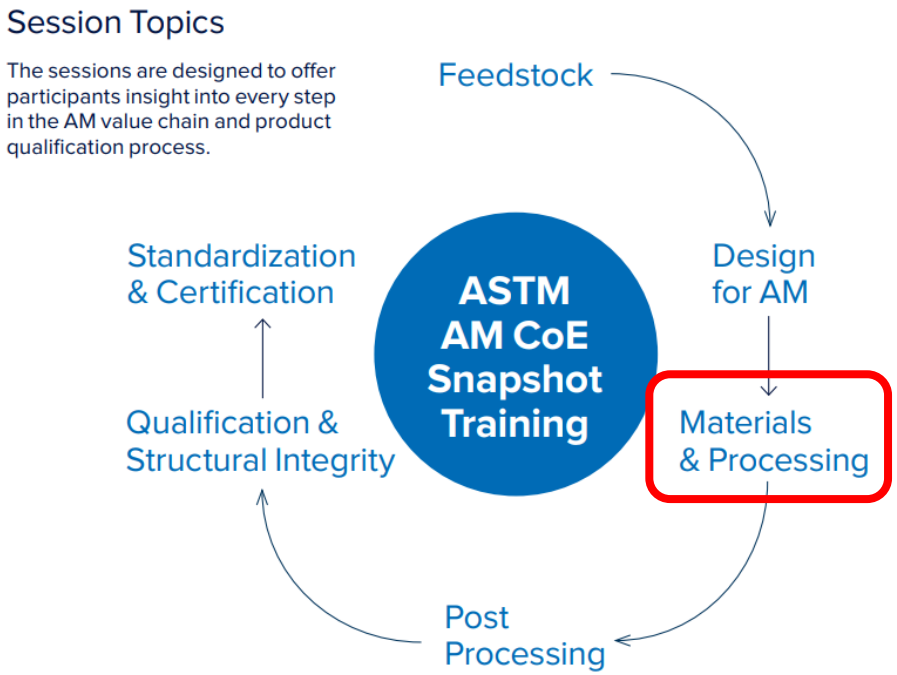
- For any manufacturing process that is dependent upon continuous and ardent control to produce quality-critical products, companies, purchase stakeholders, and regulatory agencies anchor their confidence in the most basic aspect of process control:

The foundational act of qualifying the process to demonstrate it meets a well-defined degree of quality and stability.

Introduction and Overview

Laser Powder Bed Fusion Process Qualification

- Lack of standardization for LB-PBF machine and process qualification
- Commonly treated as proprietary information
- Current declarations of machine and process qualification have little meaning because the declaration lacks definition
- Proprietary process qualification standards are evaluated on a case-by-case basis, leading to significant burden on vendors, purchasers, and regulatory bodies to continuously evaluate the rigor of unique and varied methodologies of qualification.
- For safety-critical applications, this non-standardized, vendor-unique qualification review adds risk related to potential unidentified shortfalls in the unique qualification scheme

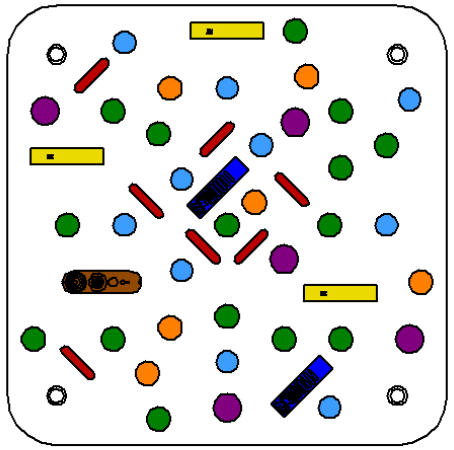


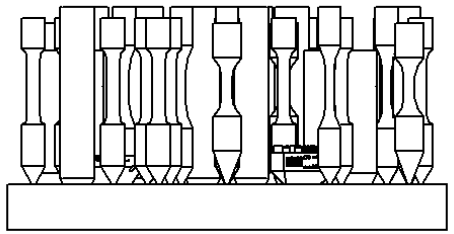
Introduction and Overview

Laser Powder Bed Fusion Process Qualification

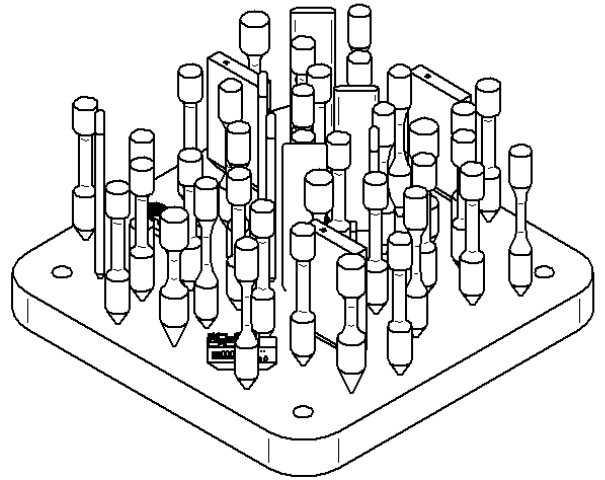
Key Challenges

- Time and expense of qualification are significant – efficiency is critical
- Consensus lacking on the scope, proper metrics, and evaluation criteria
- Part criticality influence on qualification
- Re-qualification needs are frequent
  - How and when
  - Maintenance / troubleshooting
  - Relates to monitoring and efficiency of witness feedback





Specimen Type	Qty	Name	Key
High Cycle Fatigue	10	HCF-1 thru HCF-10	
Low Cycle Fatigue	5	LCF-1 thru LCF-5	
Tensile (RT)	15	TN-1 thru TN-15	
Tensile (Cryo, ET)	6	TN-16 thru TN-21	
Fracture Toughness	3	FT-1 thru FT-3	
Metallographic Samples	7	MET-1 thru MET-7	
Dimensional Samples	2	D-1 thru D-2	
Contour Analysis Samples	1	C-1	



Standardized Practices

Limited standardization has been established for LB-PBF qualification

- There are limited released standards within the SDOs: recent AWS D20.1 most relevant addition
- Tangential activities exist within ASTM F42, SAE AMS-AM
- Needs are discussed in the America Makes/AMSC Standardization Roadmap for Additive Manufacturing, Version 2.0, Section 2.3.3.1 on "Processes on Procedures."
- Prior to AWS D20.1, only openly available standards for LB-PBF machine/process qualification
  - MSFC-STD-3716 "Standard for Additively Manufactured Spaceflight Hardware by Laser Powder Bed Fusion in Metals"
  - MSFC-SPEC-3717 "Specification for Control and Qualification of Laser Powder Bed Fusion Metallurgical Processes"
- Variants of these documents are currently in draft within ASTM F42 and SAE AMS-AM
- These documents serve as a "point of departure" for evaluations in this effort.

Objectives

Objectives of the LB-PBF Process Qualification CoE Activity

1. Develop consensus within the ASTM CoE community regarding minimum requirements for the qualification of L-PBF machines and processes.
2. Establish a standard set of procedures, test methods, and evaluations used to establish L-PBF qualification based on fundamental objectives.
3. Establish quantitative and/or qualitative metrics applicable to each evaluation to define successful machine and process qualification.
4. Conduct development and round-robin-style trials of the qualification evaluations and associated metrics.
5. Establish a set of recommendations to appropriate F42 sub-committees for standards implementation.

Current Assumptions Under Scrutiny

Key underlying assumptions in the MSFC-STD-3617/MSFC-SPEC-3717 approach

1. LB-PBF machines run open-loop on a fixed set of parameters throughout the entire build. Fixed parameter set may include different conditions for contours, fills, down-facing or up-facing surface, etc.
2. Each LB-PBF machine is an independent entity requiring specific qualification for each process implemented.
3. A defined set of requirements for AM machine calibration and maintenance is a prerequisite to AM machine and process qualification. Methods of physical machine calibration are not part of the effort in this SoW.
4. LB-PBF Part Qualification is separate and distinct from Machine/Process Qualification
5. A candidate LB-PBF metallurgical process consists of three entities: a) feedstock controls, b) fusion process controls, and c) post-build thermal processes, each of which are interdependent and influence the quality of the final metallurgical product.

Current Assumptions Under Scrutiny

Key underlying assumptions in the MSFC-STD-3617/MSFC-SPEC-3717 approach, Continued

6. Final qualification of AM machine and process are synonymous, achieved through evaluations of material and build quality produced by the machine when operating under the defined process. Machine qualification requires confirmed calibration state and successful process qualification.
7. Changes to AM machines or aspects of the defined process nullify qualification and instigate need for re-qualification. Defining the categories and scope of events requiring re-qualification are also part of the qualification requirements.
8. Process qualification is a prerequisite for statistically substantiated material design values
9. A qualified process provides a high likelihood of success when building parts, but each part is considered a unique application of the qualified process and must be evaluated through an independent part qualification methodology (pre-production article) to ensure the intended process quality was achieved.

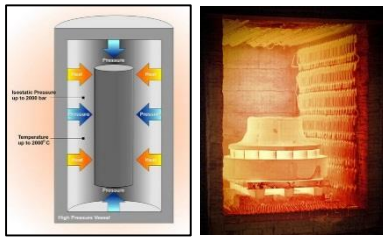
The Starting Foundation

MSFC-SPEC-3717 Qualification Foundation: Qualified Metallurgical Process (QMP)

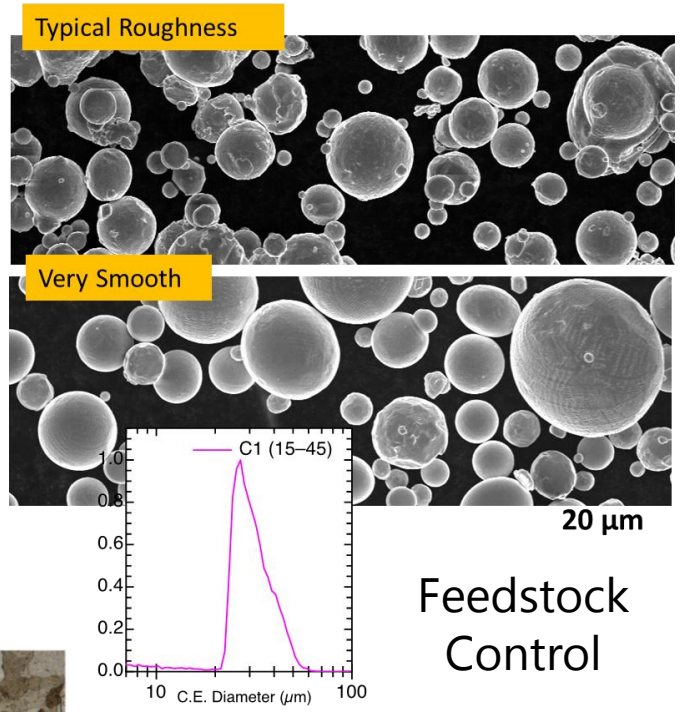
a) Feedstock controls

b) Fusion process controls

c) Post-build thermal processes

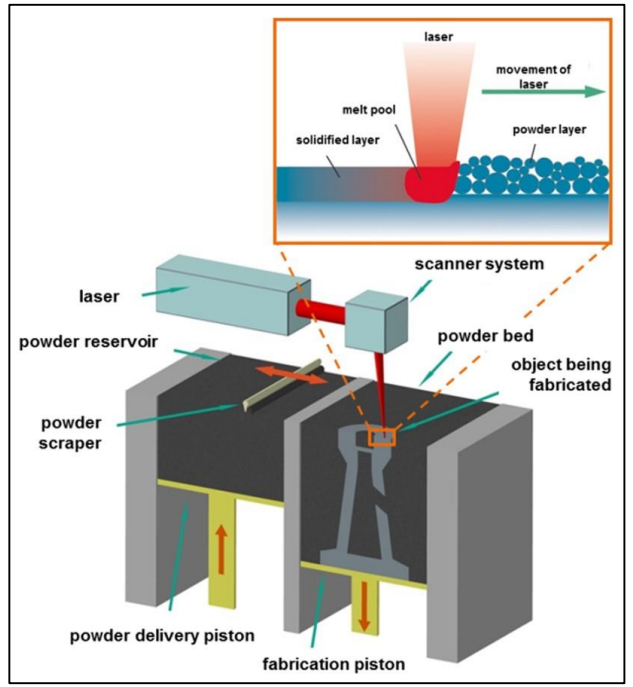


IN718 Microstructural Evolution



Feedstock Control

Fusion Process Controls



Source: Fraunhofer IWU

The Starting Foundation

Current evaluations required for establishing the QMP in -3717 include:

a) Quality of material microstructure as-built by the machine/process
   i. Consistency throughout build area
   ii. Demonstration to tolerance to thermal history extremes
   iii. Restart layer interfaces (if allowed)
   iv. Interfaces in scan patterns, surface contours, or cosmetic passes
   v. Melt pool evaluations for process characterization

b) Microstructural evolution caused by post-build thermal processing

c) Reference parts providing evaluation of surface texture and detail resolution metrics

d) Mechanical properties that demonstrate the process achieves material capability in family with data used to establish and monitor process control and develop design values.

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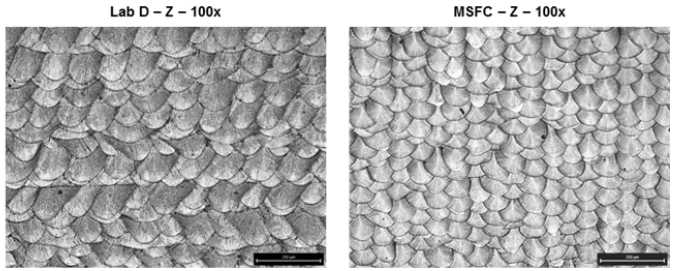
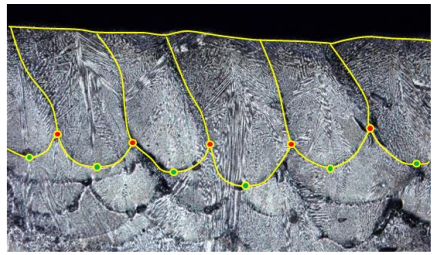
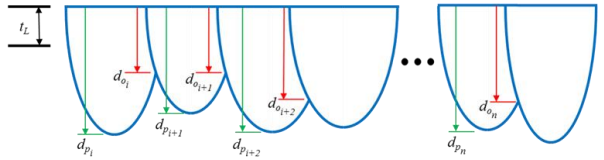
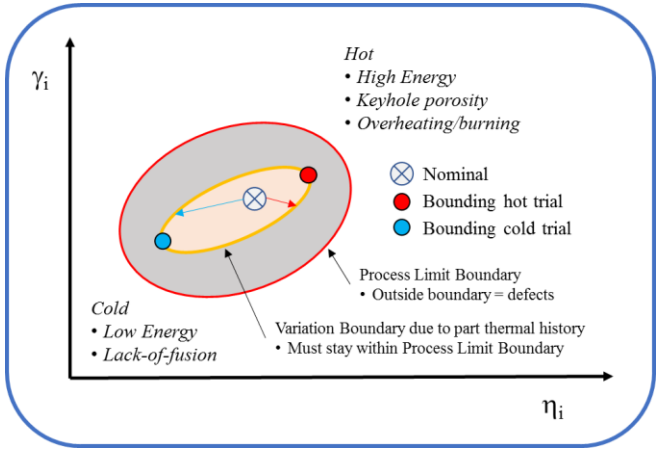
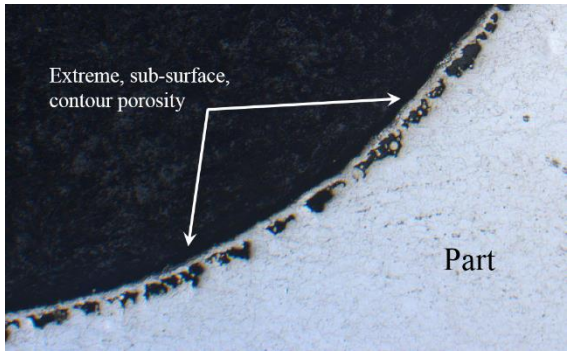






Melt Pool Evaluation





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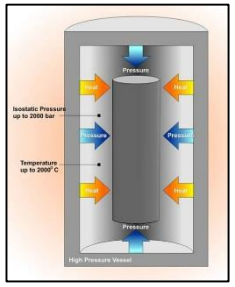

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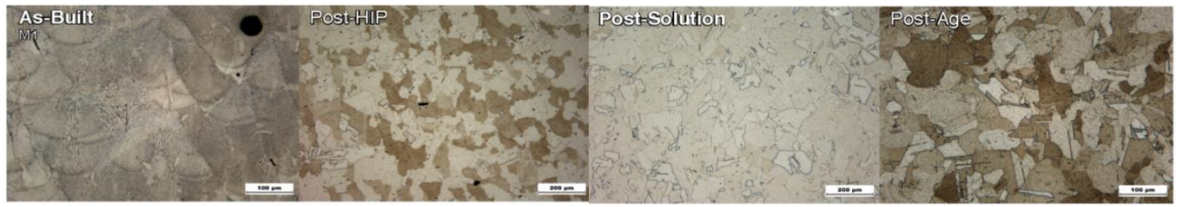

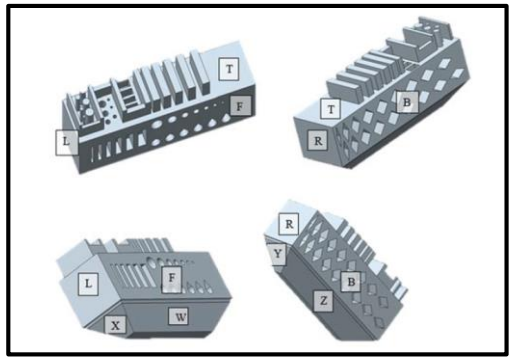

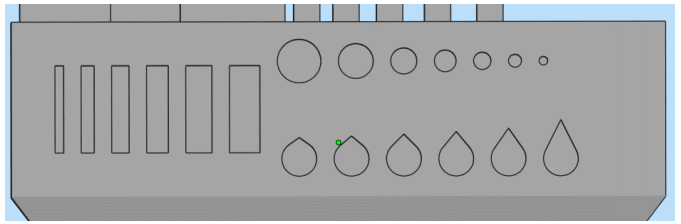

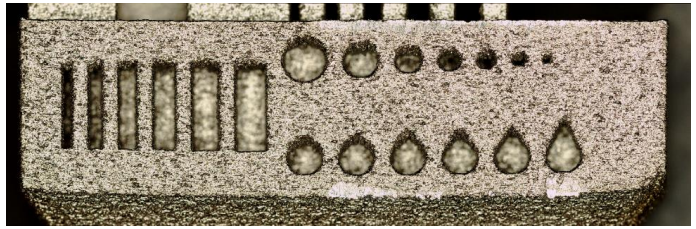

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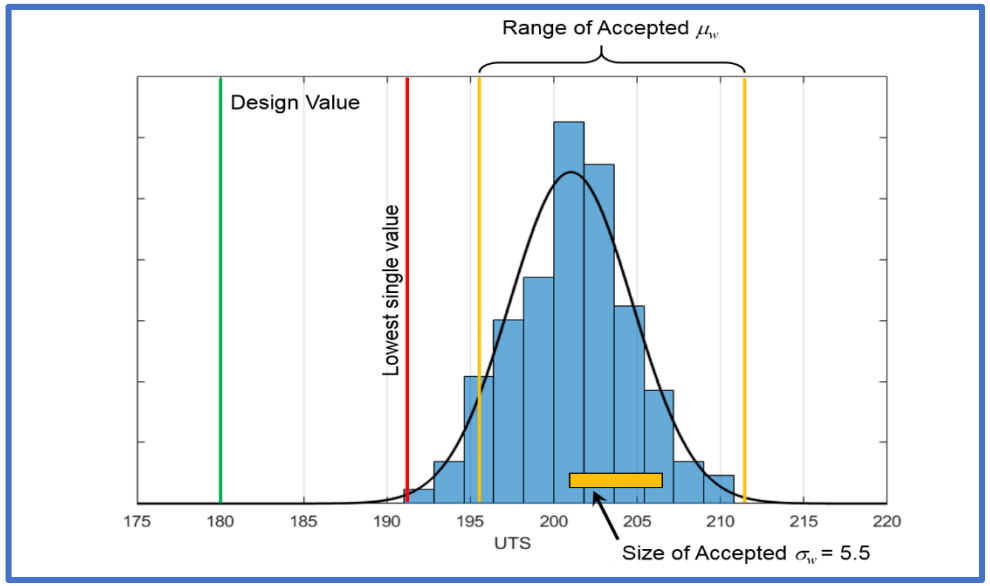
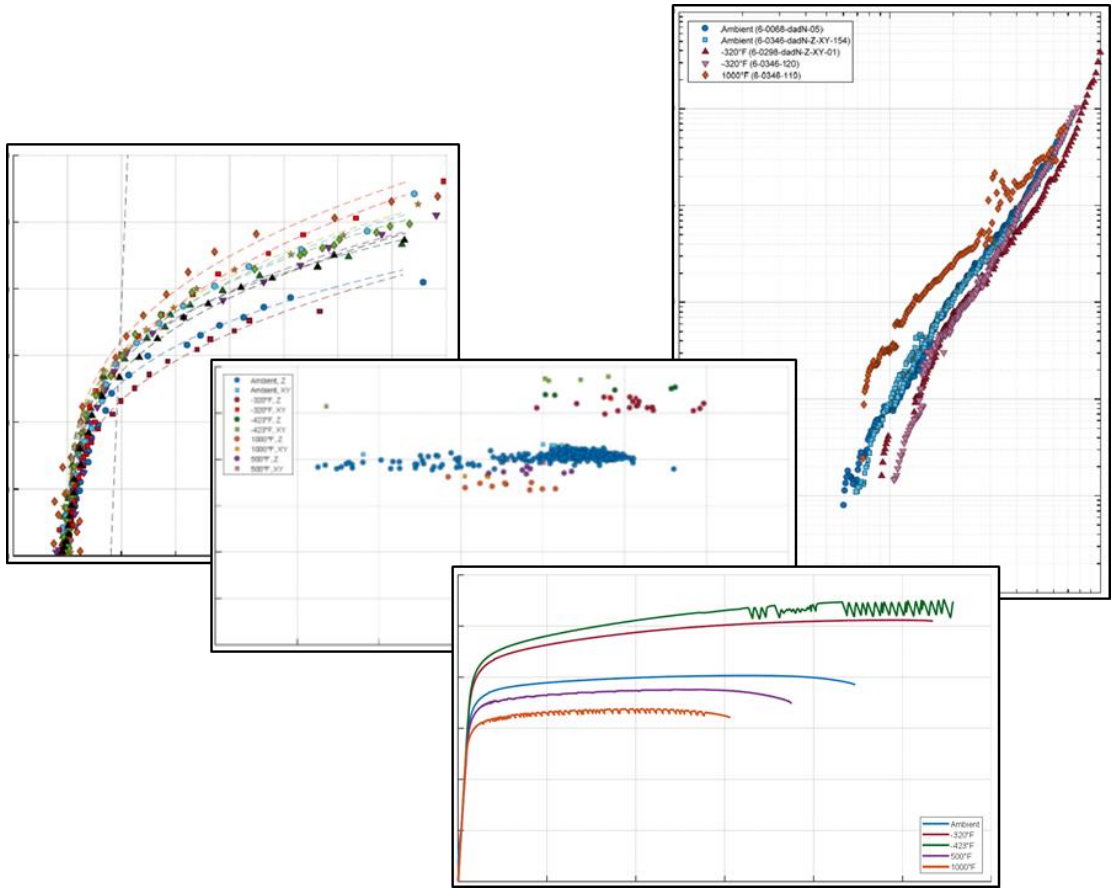




The CoE LB-PBF Qualification Project

Approach / Key Decisions:

- Use MSFC-STD-3716 and MSFC-SPEC-3717 as baseline
  - Perform critical assessment of qualification procedures and metrics
  - Identify strengths and weaknesses in the methodology of these standards
- Develop consensus on key policies, procedures, and metrics
- Standardize terminology regarding process (procedure) qualification, machine calibration, and machine qualification
- Determine if process qualification should be scaled with part classification

Implementation - Three Phase Project:

1. Position papers on machine and process qualification; Evaluation for common denominators critical aspects; Reach consensus within ASTM AM CoE
2. Shared development and round robin trials for individual qualification procedures and acceptance metrics
3. Draft qualification requirements in standards form; Round robin trials on complete qualification requirements set across CoE; Merge with **pre-coordinated** F42 activities

Project Relationship to Ongoing F42 Topics

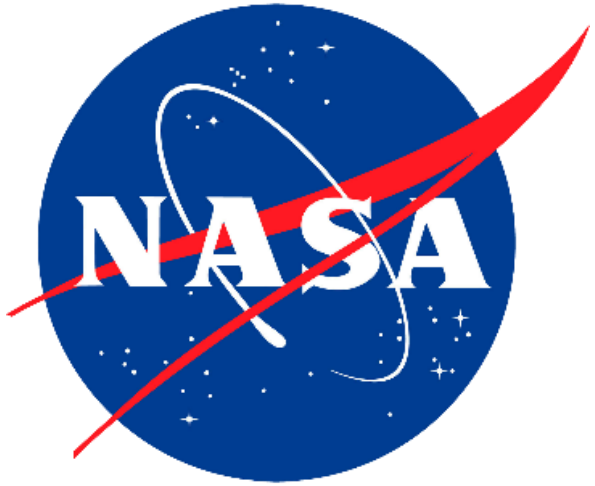
- The project is intended to fill a known gap in the ASTM standards hierarchy
- Essential for AM parts with meaningful consequence of failure (safety or financial)
- Resulting standard(s) will provide key information needed for existing F42 documents
  - ASTM F3303 - 18 Standard for Additive Manufacturing – Process Characteristics and Performance: Practice for Metal Powder Bed Fusion Process to Meet Critical Applications
- Outcome intended to be strongly influential to (and influenced by) ongoing F42 Work Items:
  - ASTM WK65929: New Specification for Additive Manufacturing-Finished Part Properties and Post Processing - Additively Manufactured Spaceflight Hardware by Laser Beam Powder Bed Fusion In Metals
  - ASTM WK65937: New Specification for Additive Manufacturing Process Characteristics and Performance - Control and Qualification of Laser Beam Powder Bed Fusion Processes
  - ASTM WK65420: New Specification for Additive Manufacturing Qualification Principles for Equipment - Standard Guidelines Laser Powder Bed Fusion (L-PBF) for Metal

Current CoE LB-PBF Qualification Project Status

- LB-PBF Project is directed by NASA/MSFC for the CoE
- Multi-partner project by definition
- CoE partners and participants Auburn, EWI, MTC, NIAR, and Oerlikon are engaged
- Other interested parties willing to provide in-kind support to the effort are welcome
  - Contact: Douglas.N.Wells@nasa.gov
  - There will be a limit for practical purposes, but broad consensus is the goal
- First defined task, critique of MSFC documents, is nearing completion
- AWS D20.1 may be added to the critique

Q&A

Questions?



Douglas.N.Wells@nasa.gov

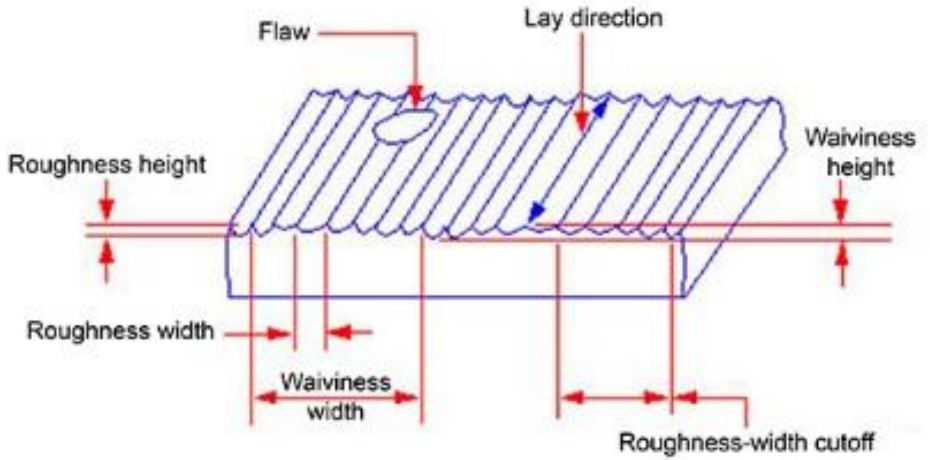
Next Topic: AM Part Post-Processing

LB-PBF Process Qualification Foundation:

a) Feedstock controls

b) Fusion process controls → Surface characteristics

c) Post-build thermal processes



Surface characteristics (Courtesy, ANSI B46.1 - 1962)

Are existing surface characterization methods and metrics meaningful to AM?

AM Part Qualification and Part Performance

- Surface characterization is important for process qualification and control
- Post-Build, part-specific processing key to actual material and part performance
- Surface improvement techniques often dictate part performance characteristics