A Proposed Qualification Methodology for Additively Manufactured Spaceflight Propulsion Hardware

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Outline

- SLM in NASA Propulsion Systems
- Snapshot of SLM Standardization
- MSFC's Qualification Approach to SLM
- Observations on SLM and Quality
- Summary
- Questions

SLM Applications

Commercial Crew Program
DRAGON V2

Launch 2017

Exploration Systems Development
ORION and SLS

Launch 2018

Launch 2023+

Standardization

Active AM Standardization Community

- Societies: ASTM/ISO, SAE-AMS, AWS, UL
- Government: NIST, NASA, USAF, FAA, ORNL, LLNL
- Commercial: AR, SX, PWR, GE

NASA's challenge: Few aerospace-quality standards and specification are currently available for SLM

Critical Process Control

NASA's Safety and Mission Assurance practitioners rely on commercial specs and standards for control of critical processes.

Agency-level standards provide general requirements

- NASA-STD-6016 for Materials"
- NASA-STD-5012 for Propulsion Structures"
- NASA-STD-5019 for Fracture Control"
- NASA-STD-5009 for NDE "

Call

Commercially-available specs and stds provide category rqmts

- SAE AMS 2175 Classification and Inspection of Castings"
- SAE AMS 4985 Ti-6-4 Investment Castings"
- AWS D17.1 Fusion Welding for Aerospace Applications"

Call

"Applicable documents" provide specialized rqmts

MSFC's SLM Standard

- Draft interim standard: *Engineering and Quality Standard for AM Spaceflight Hardware* (July 2015)
- Set of 26 requirements that address
  - SLM Design
  - Material Property Development
  - Metallurgical Process Control
  - Part Process Control
  - Part Inspection and Acceptance
  - Equipment Process Control
  - Vendor Process Control


National Aeronautics and Space Administration

MSFC-STD-xxxx
REVISION: DRAFT 1
EFFECTIVE DATE: Not Released

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EM20

MSFC TECHNICAL STANDARD

Engineering and Quality Standard for Additively Manufactured Spaceflight Hardware

DRAFT 1 – JULY 7, 2015

This official draft has not been approved and is subject to modification.
DO NOT USE PRIOR TO APPROVAL

CHECK THE MASTER LIST—
VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

THIS STANDARD HAS NOT BEEN REVIEWED FOR EXPORT CONTROL RESTRICTIONS
DRAFT VERSIONS DISTRIBUTED FOR REVIEW ARE NOT TO BE DISSEMINATED

Attributes of MSFC's SLM Quality Methodology

1. Metallurgical Control
2. Material Properties & Statistical Process Control
3. Inspection

1. Metallurgical Control

Feedstock controls

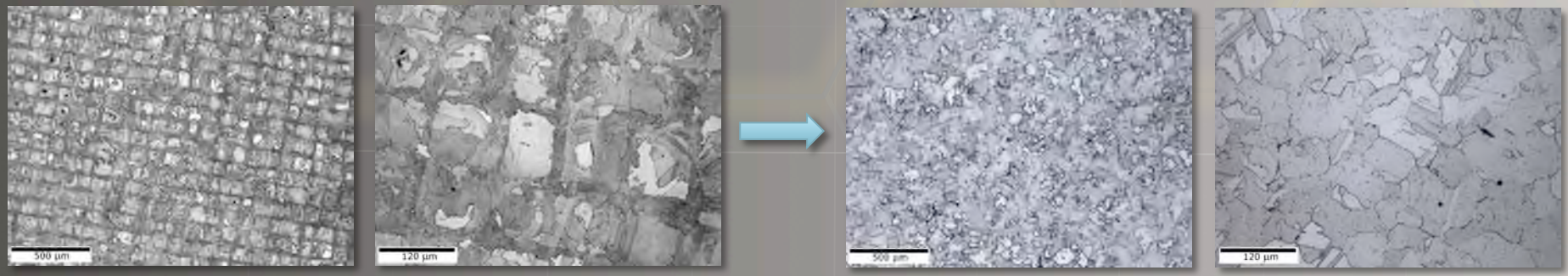
- Chemistry
- Powder morphology (PSD, shape, atomization methods)

Fusion controls

- Machine type
- Parameters: laser power, speed, layer thickness, hatch width
- Chamber atmosphere

Thermal controls

- Microstructural evolution from as-built structure to recrystallized material
- Densification after HIP



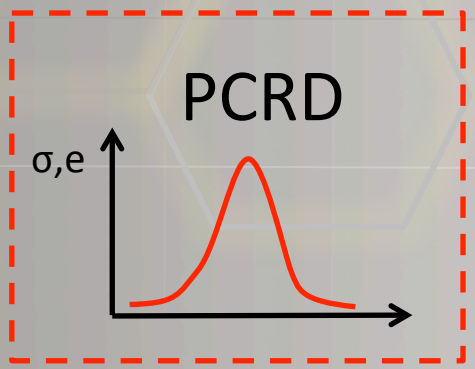
2. Material Properties & SPC

- Material properties derive from statistical process control methodology that relies on continuous monitoring of process performance

used in lieu of

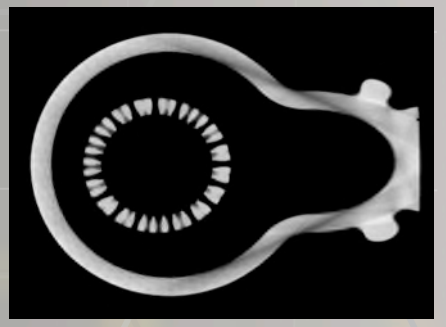
traditional MMPDS design allowable approaches that attempt to capture all process variability in a single evaluation of a collection of material lots and specimens.

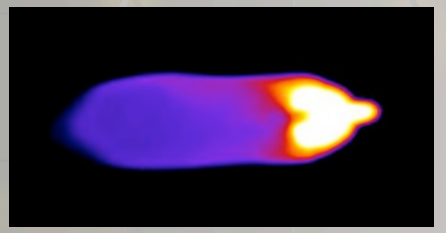
- Material design values are set and maintained relative to SPC limits.
- Small-lot process control and statistics present a challenge to SPC.



3. Inspection

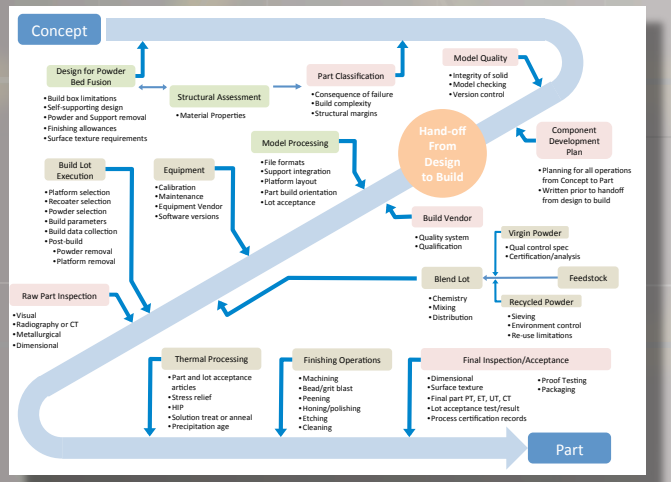
- “Open loop” layer-wise processing presents opportunity for defects
- Traditional NDI techniques ineffective for SLM features such as as-built surfaces, blind internal passages, grain structure, and high density.
- Need to develop and validate in-situ monitoring controls and feedback loops.





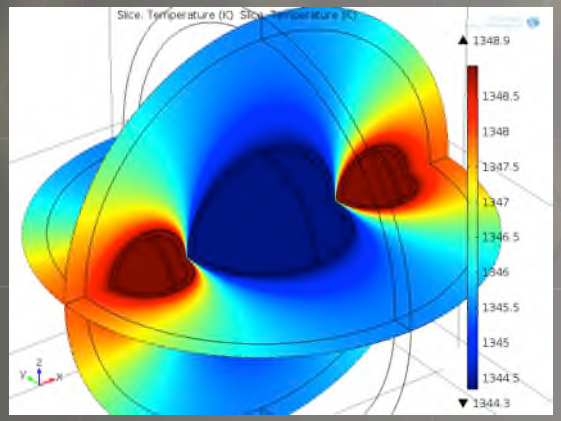
Active Quality Involvement

- Reliance on internal specs and standards
- Path-dependent process and material
- Recommend pFMEA to ensure that all influential steps are represented in the planning record



Consistency in Method & Message

- Need for complementary specs and standards
- Coordinated adoption of advanced process control technologies



- In-situ monitoring
- Multi-physics modeling
- Process feedback controls
- Small-lot process control

Adaptability

- AM will continue to change and evolve
  - First generation machines nearing obsolescence
  - Vendor base is fluid and fragmented
- Trends*
  - Introduction of two and more laser systems
  - Optimized layer structure with different layer thicknesses
  - Process parallelization by simultaneous powder dispensing and laser melting
  - Optimization of powder dispensing process
  - Introduction of two or more chamber systems for continuous production
  - Increased process stability due to online monitoring systems

*Source: Roland Berger

Summary

- Requirement choices dictate how we embrace, foster, and protect SLM and its opportunities
- We must develop and adopt aerospace recognized standards to govern product, process and material certification
- To enable the full capabilities of SLM, we need to
  - Create closed-loop and adaptive control systems that are anchored on predictive models of system responses to process changes
  - Develop and validate NDI for internal dimensional measurement and part assessment

Questions?

*Source: Roland Berger