A Proposed Qualification Methodology for Additively Manufactured Spaceflight Propulsion Hardware

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CQSDI, 8 March 2016
Outline

• SLM in NASA Propulsion Systems
• Snapshot of SLM Standardization
• MSFC’s Qualification Approach to SLM
• Observations on SLM and Quality
• Summary
• Questions
Commercial Crew Program
DRAGON V2

Launch 2017

Exploration Systems Development
ORION and SLS

Launch 2018

ORION Crew Capsule

RS-25 Core Stage Engine

Launch 2023+

Aerojet Rocketdyne

SuperDraco Thrusters

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SLS Space Launch System
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
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

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

“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
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?