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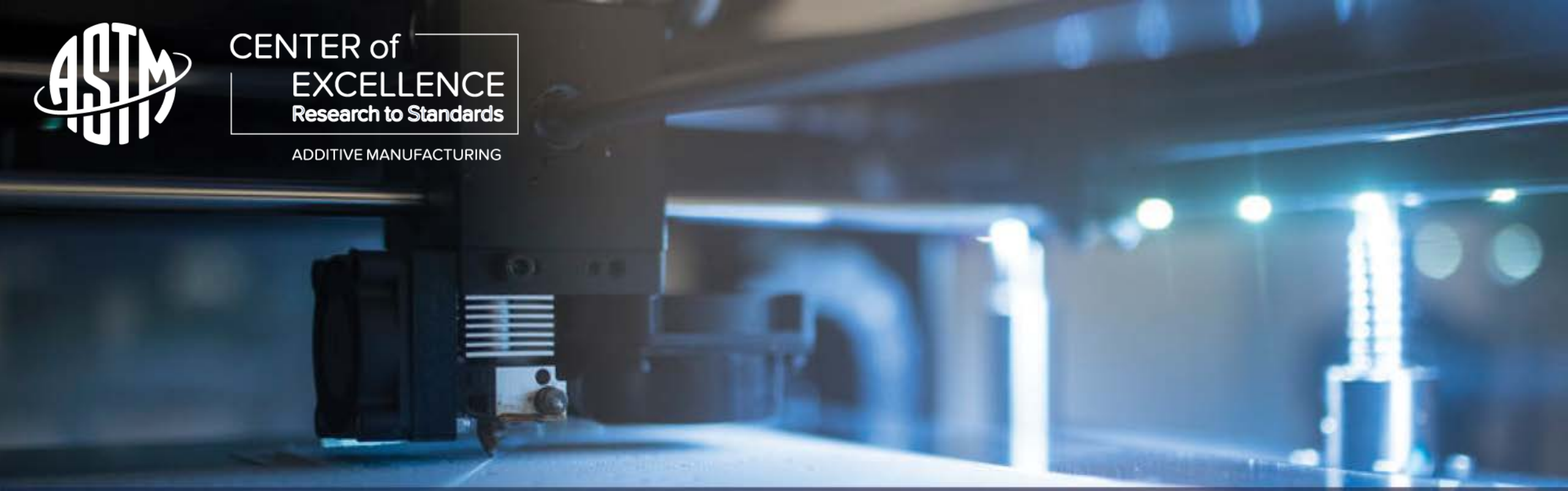

What's New with ASTM F42 On Additive Manufacturing

July 13, Virtual

Shane Collins, Head AM Advisory Services

ASTM INTERNATIONAL
AUBURN UNIVERSITY
EWI We Manufacture Innovation
mtc Manufacturing Technology Centre
NAMIC NATIONAL ADDITIVE MANUFACTURING INNOVATION CLUSTER
NASA
NIAR

Shane Collins

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- **Head of Additive Manufacturing Advisory Services – ASTM Center of Excellence**

- 20-year veteran of the AM Industry
  - Operations, product management, business development for metal and polymer additive manufacturing
- Produced production class parts to specifications from:
  - Boeing E-PBF, L-PBF - Lockheed Martin E-PBF, L-PBF - Northrop Grumman E-PBF, L-PBF - GE Aviation L-PBF - Pratt and Whitney L-PBF - Space Systems Loral E-PBF - JPL E-PBF, L-PBF
  - Experience includes CalRAM – First organisation to achieve Nadcap for L-PBF and EB-PBF
- ASTM F42 Fellow
  - Chair of the ASTM F42.07 on additive manufacturing Applications
  - Formerly for 10 years, Chair of F42.05 on Materials and Process
  - ASTM Robert F. Painter Memorial Award in 2017, the ASTM Award of Merit in 2018

ASTM Additive Manufacturing Footprint

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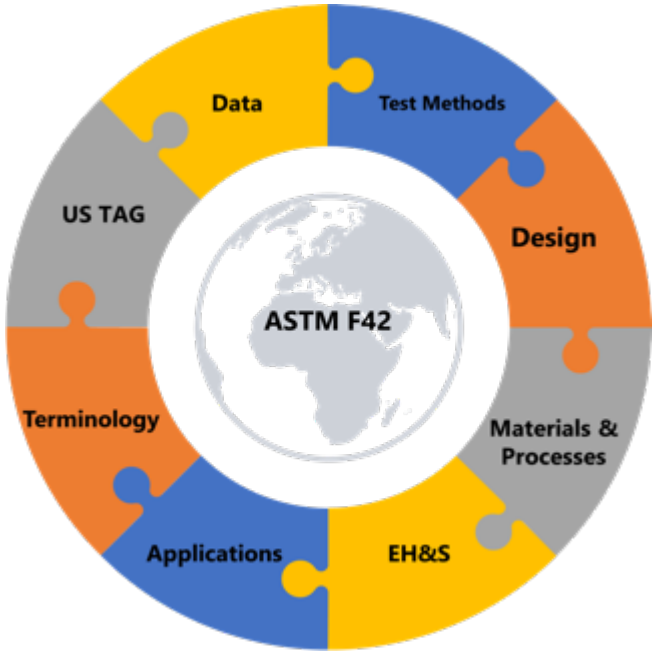
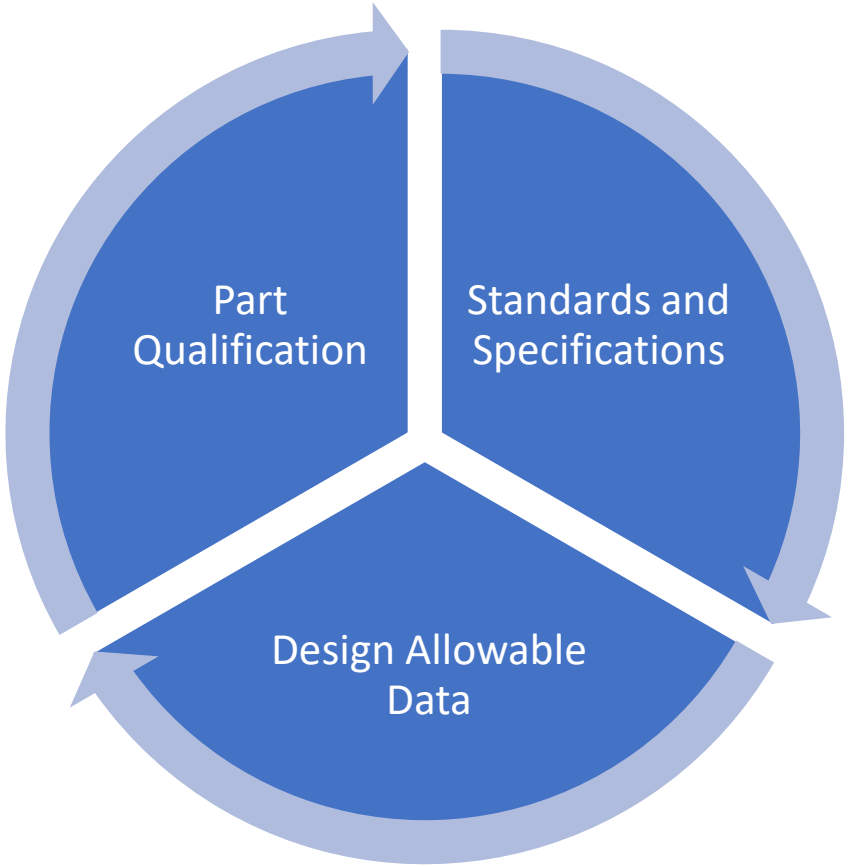


- **Established:** 2009 (Oldest, largest committee on AM)
- **Current Membership:** 1000+ members (Over 30% outside the US)
- **Standards: 30+** approved, **45+** in development (Jointly with ISO)
- **Global Representation:** 35+ countries involved

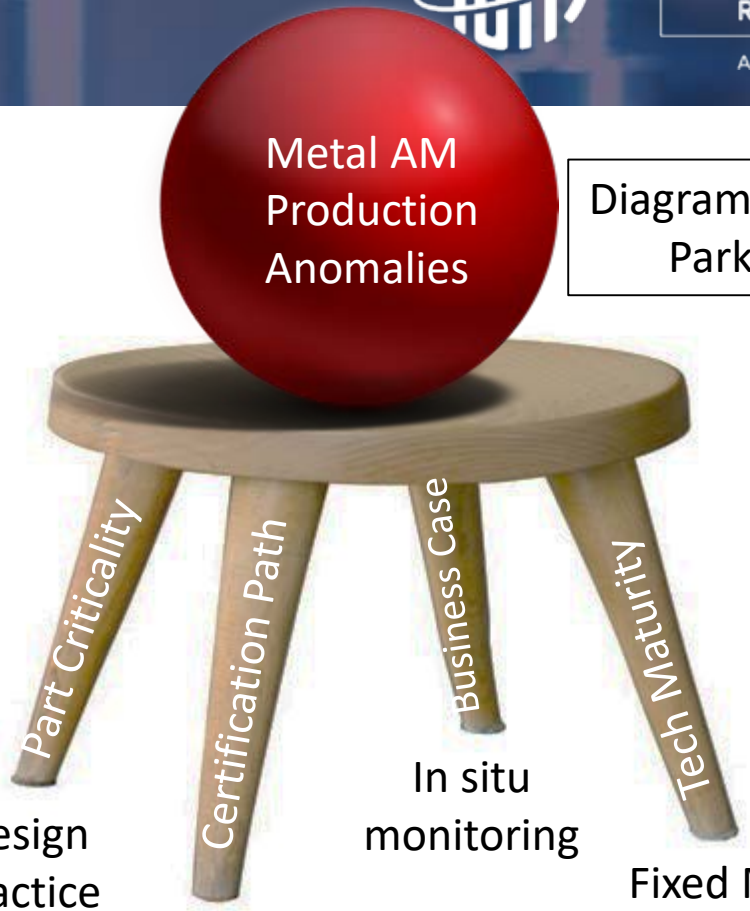
- **Collaboration:**
  - Partnership with ISO TC261 (& CEN TC438)
  - Strategic Relationships – America Makes, NIST, NASA, FAA, FDA, DOD, MMPDS, CMH17 ASTM F4, ASTM E07

Evolution of AM Part Qualification



Historical Perspective

Past two years



Design Practice

Post-print NDE and final inspection

In situ monitoring

Fixed M&P Controls

Diagram credit Charles Park @ Boeing

AS

Assessment Methodology

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How do we show parts are Safe?

Defect Free

- No defects above a certain size
- Strict process controls and inspection to avoid defects
- Assessment approaches based on fatigue life (crack initiation)
- Safe operating life is up to the point of initiation of an engineering defect.

- Analysis route is relatively simple
- Problematic where inspection is difficult or risk of initial defects not negligible

Defect Tolerant

- Accept defects exist in the structure
- Critical defect sizes (resulting in fracture) are calculated
- Safe life based on the time for an initial defect to grow to the critical size
- Analysis based on engineering fracture mechanics and fatigue crack growth
- Inspection used to limit the initial defect size

- Inspection and process requirements lower
- Analysis route potentially more complex and may require more data

Ref: Dr Simon Lewis, Norton-Straw Consultancy, "Cost Effective Characterisation of Defect Populations in AM Materials" ICAM 2020

Part Qualification Can Only Evolve with a Robust Party Classification System

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This Standard Guideline will ballot as WK77559

F42.07.01 Aviation Part Classification Matrix (May 2021 Draft)

	Aviation Guidance Materials									Other Related References		
F42 Classification	Description	ARMY Policy 070-062	ASIP (MIL-STD-1530)	NAVAIR SWP-AA10-013	JAMA (Joint AM Acceptability)	AC43-18	AC25.571	AC25.1309	Engine part classification (Part 33)	NASA-STD-6030	AWS D20.1	AMS2175
Class A	Part that contributes significantly to the carrying of flight, ground, or pressurization loads and whose integrity is essential in maintaining the overall integrity of the airplane. The failure of the part could cause a catastrophic or critical failure resulting in the loss of or serious damage to the aircraft, an unacceptable risk of personal injury or loss of life.	Category 6 Flight Parts/Components that Pose a Safety Impact to include CSIs	Fracture Critical Traceable Part A fracture-critical traceable part is a safety-of-flight structural component that is either single load path or judged to require serialization and traceability. Fracture Critical Part A fracture-critical part is a safety-of-flight structural component that is not single load path nor judged to require serialization and traceability.	Class IV Part consequence of failure: High	Category 3 Items that pose a severe risk of damage to other equipment or personnel (e.g. CSI)	Category 1 A fabricated part, the failure of which could prevent continued safe flight and landing; resulting consequences could reduce safety margins, degrade performance, or cause loss of capability to conduct certain flight operations.	Principal Structural Element (AC25.571-1D) An element that contributes significantly to the carrying of flight, ground, or pressurization loads and whose integrity is essential in maintaining the overall structural integrity of the airplane	FHA = Hazardous or Catastrophic Large reduction in functional capabilities or safety margins on airplane. Serious or fatal injury to passengers or cabin crew. Excessive workload of flight crew.	TBD	Class A	Class A Critical application. A component, whose failure would cause significant danger to personnel, loss of control, loss of a system, loss of a major component, or an operating penalty.	Class 1 A casting, the single failure of which would endanger the lives of operating personnel, or cause the loss of a missile, aircraft, or other vehicle.
Class B	Part whose failure could affect the integrity of the airplane. The failure of the part can pose an operational impact due to the reduction in functional capabilities, but does not have safety impact. The loss of the part can result in injuries to the occupants and a significant increase in workload of flight crew.	Category 5 Flight Parts/Components that Pose an Operational Impact but no Safety Impact Category 4 Flight Parts/Components with a Readiness Impact, but no Safety or Operational Impact	Durability Critical A non-safety-of-flight structural component that is judged to require additional controls beyond those for normal-controls parts.	Class III Part consequence of failure: Medium CAI with acceptable safety impact Not Fatigue Critical	Category 2 Items that pose a risk of damage to other equipment of personnel (e.g. CAI)	Category 2 A fabricated part, the failure of which would not prevent continued safe flight and landing, but would reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions or subsequent failures.	Primary Structure A structural detail, element or assembly whose failure could affect the integrity of the airplane	FHA = Major Significant reduction in functional capabilities or safety margins on airplane. Physical distress, possibly including injuries to the occupants. A significant increase in workload of flight crew.	TBD	Class B	Class B Semi-critical application. A component whose failure would reduce the overall strength of the equipment or system or preclude the intended functioning or use of equipment, but loss of the system or the endangerment of personnel would not occur.	Class 2 A casting, the single failure of which would result in a significant operational penalty. In the case of missiles, aircraft, and other vehicles, this includes loss of major components, unintentional release or inability to release armament stores, or failure of weapon installation components.
Class C	Part that does not significantly transmit ground, flight and/or pressure loads.	Category 3 Flight Parts/Components with no Safety, Operation or Readiness Impact	Normal Controls Part A normal-controls part is a non-safety-of-flight structural component where standard aerospace practices are sufficient in the design, manufacturing, and maintenance of the part to ensure structural integrity.	Class II Part consequence of failure: Low No safety consequence Not Fatigue critical Not an aircraft system structural component Not a CAI/CSI	Category 1 Items that pose little to no risk of damage to other equipment or personnel (e.g. not CSI or CAI)	Category 3 A fabricated part, the failure of which would have no effect on the continued safe flight and landing of the aircraft.	Secondary Structure Structural parts that do not significantly transmit ground, flight and/or pressure loads	FHA = Minor Slight reduction in functional capabilities or safety margins on airplane. Slight increase in workload of flight crew	TBD	Class C		Class 3 Castings not included in Class 1 or Class 2 and having a margin of safety of 200 percent or less.
Class D	Negligible to no effect on operational capabilities, safety, or occupants/flight crew.	Category 2 Aviation Ground Support Equipment Category 1 Fixtures, Jigs, Shop Aids and Tooling	Exempt	Class I Part consequence of failure: Negligible No mission performance impact Non Structural No Air worthiness impact No risk of injury to personnel	Category 0 Items that pose no risk of damage to other equipment or personnel (e.g. not CSI or CAI)	N/A	Low Critical Application Not captured in higher structural classifications	No Safety Effect. No effect on operational capabilities or safety, and not effect on occupants or flight crew.	TBD	N/A	Class C Noncritical application. A component whose failure would not affect the operation of the system or endanger personnel.	Class 4 Castings not included in Class 1 or Class 2 and having a margin of safety greater than 200 percent.

F42.07.01 Aviation

- WK70164

Date: 2-21-21
To: Subcommittee F42.07
Tech Contact: John Schmelzle
Work Item #: WKXXXXX
Ballot Action: New Standard
Rationale: This is a new standard that will specify the assignment of part classifications across all industries

Standard for

Additive Manufacturing – Standard for Assigning Part Classifications for Additive Manufactured parts used in Aviation

This standard is issued under the fixed designation FXXXX; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

Part classification is required to provide a consistent metric for aviation parts based on a part's consequence of failure. Without carefully defined part classes, the ability to accurately gauge the consequence of failure associated with AM aviation parts within and across programs, projects, and suppliers becomes exceedingly difficult, resulting in mitigations that are either not commensurate or consistent. This classification system does not affect a part's functional requirements, but rather is used to group AM Aviation parts into classifications which can be used as a metric to ensure, to within a level of confidence, varied by the classification, the acceptable level that defects are permitted. Consequently, this classification system can be used in material and process specifications to determine the appropriate levels of process control, thermal post processing, qualification, and inspection to ensure AM aviation parts meet their required application. This classification does not identify a level of defects permitted, nor does is specify how the classification is used in any downstream processes. The use of the classification shall be left to the downstream documents which reference this standard.

An example Quality System Leveraging ASTM/ISO Standards

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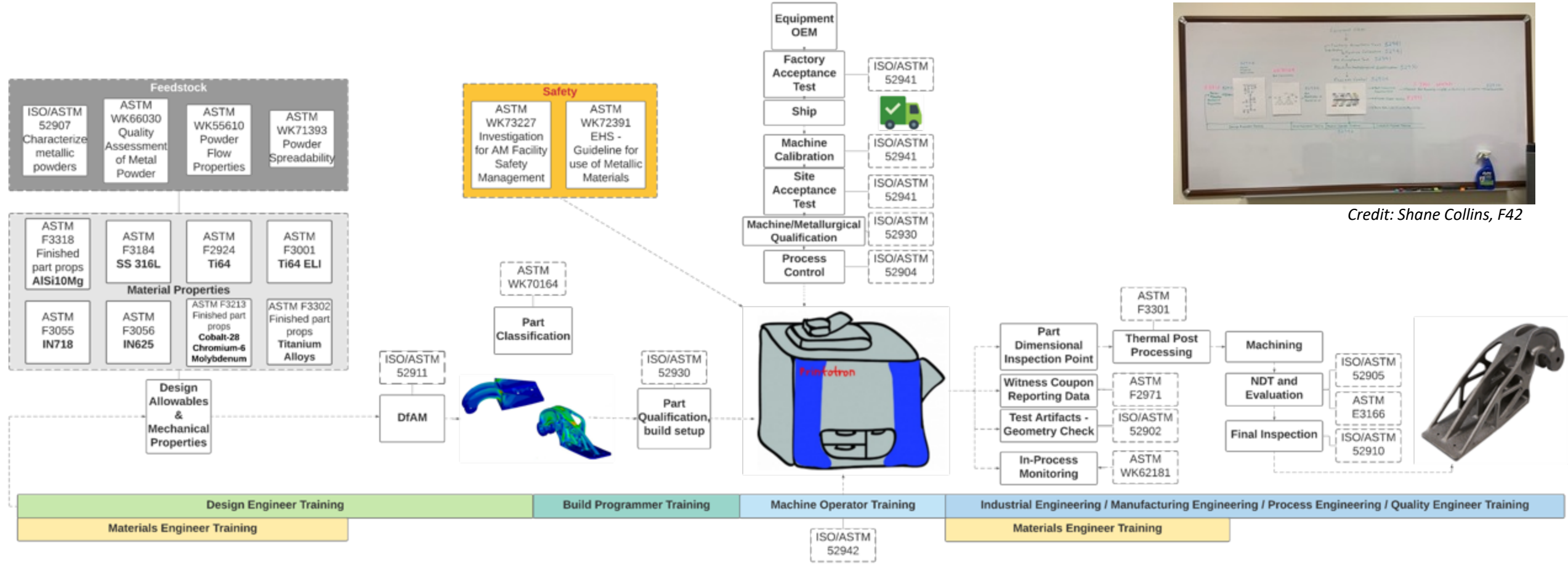

Credit: Shane Collins, F42

Note: Not inclusive of all Standards. Note also that some Standards are not issued yet; please check ISO/ASTM websites for latest information

Process Mapping with Standards

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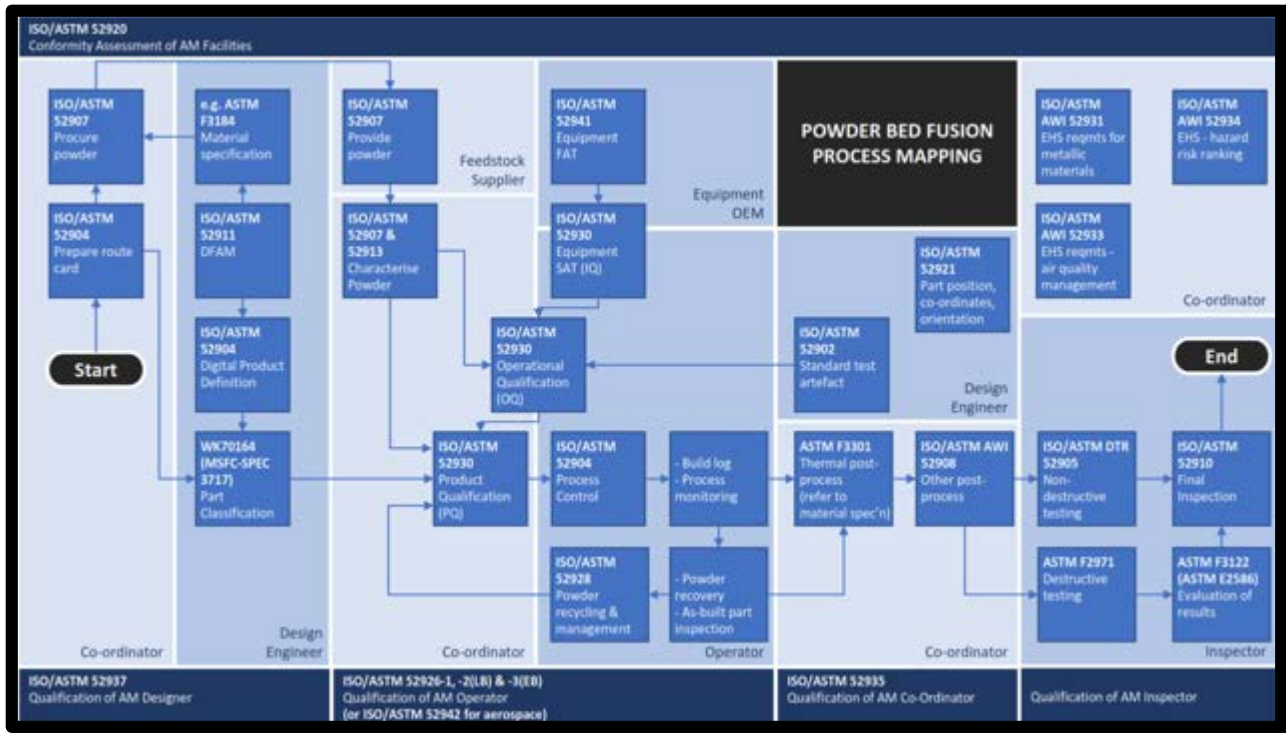

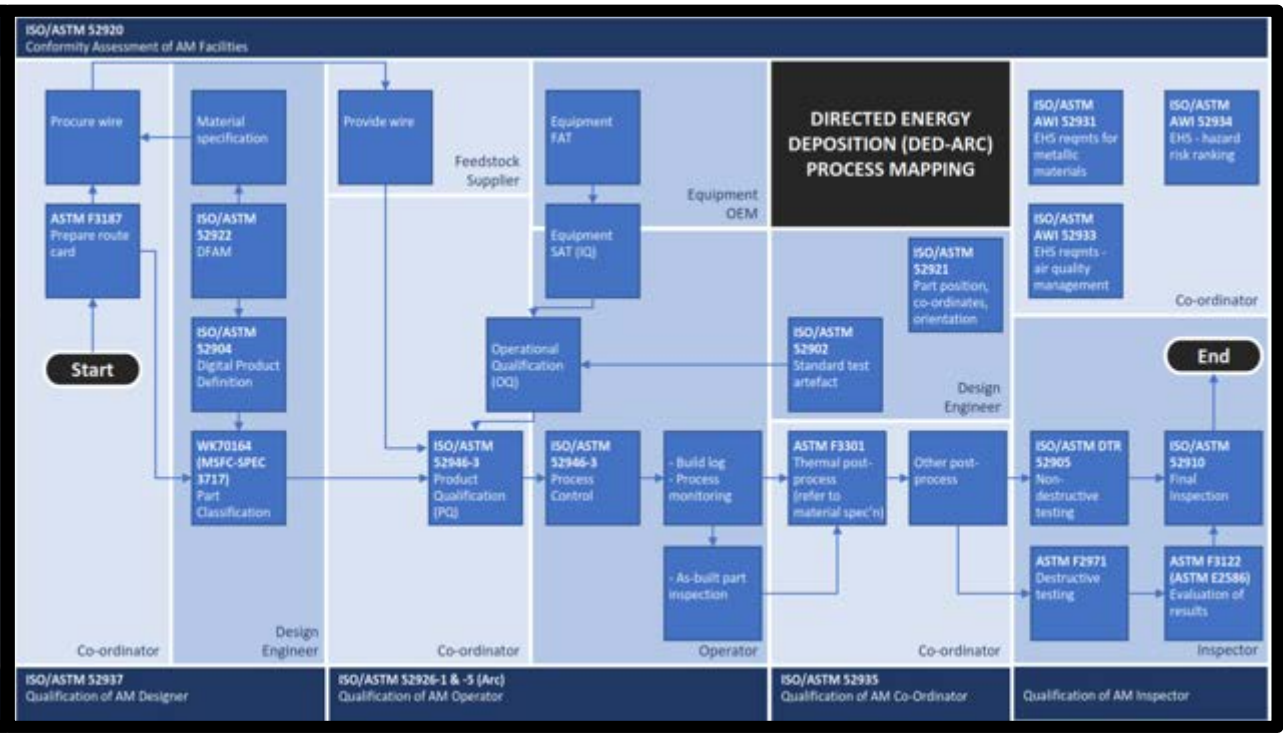

- Using Standards as part of your Quality System drives 'best practices' into your organisation
- Reduce workload – you don't have to reinvent the wheel

https://www.iso.org/committee/629086/x/catalogue/p/0/u/1/w/0/d/0
Forthcoming ISO Standards

Ref David Hardacre, Lloyds Register
https://www.flam3d.be/get-the-iso-astm-standards-overview/

ISO/ASTM 52941

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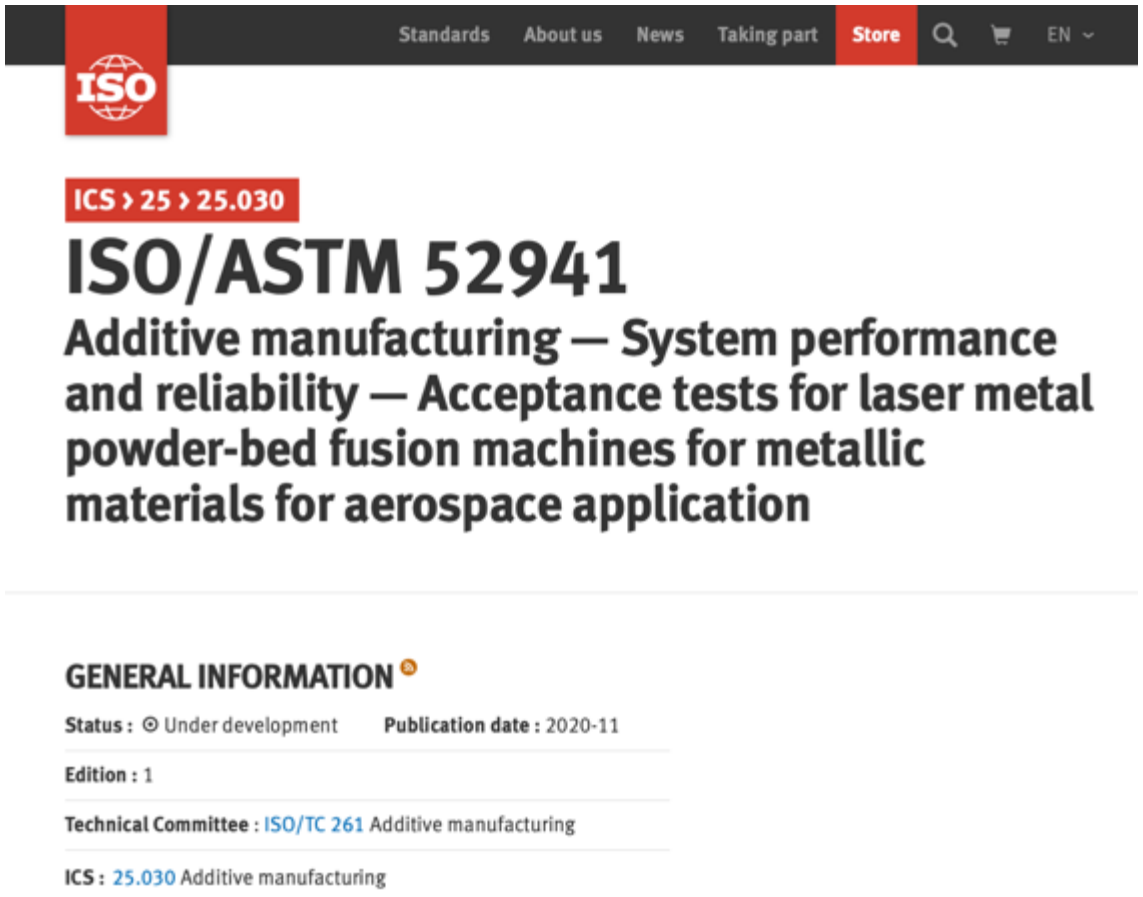
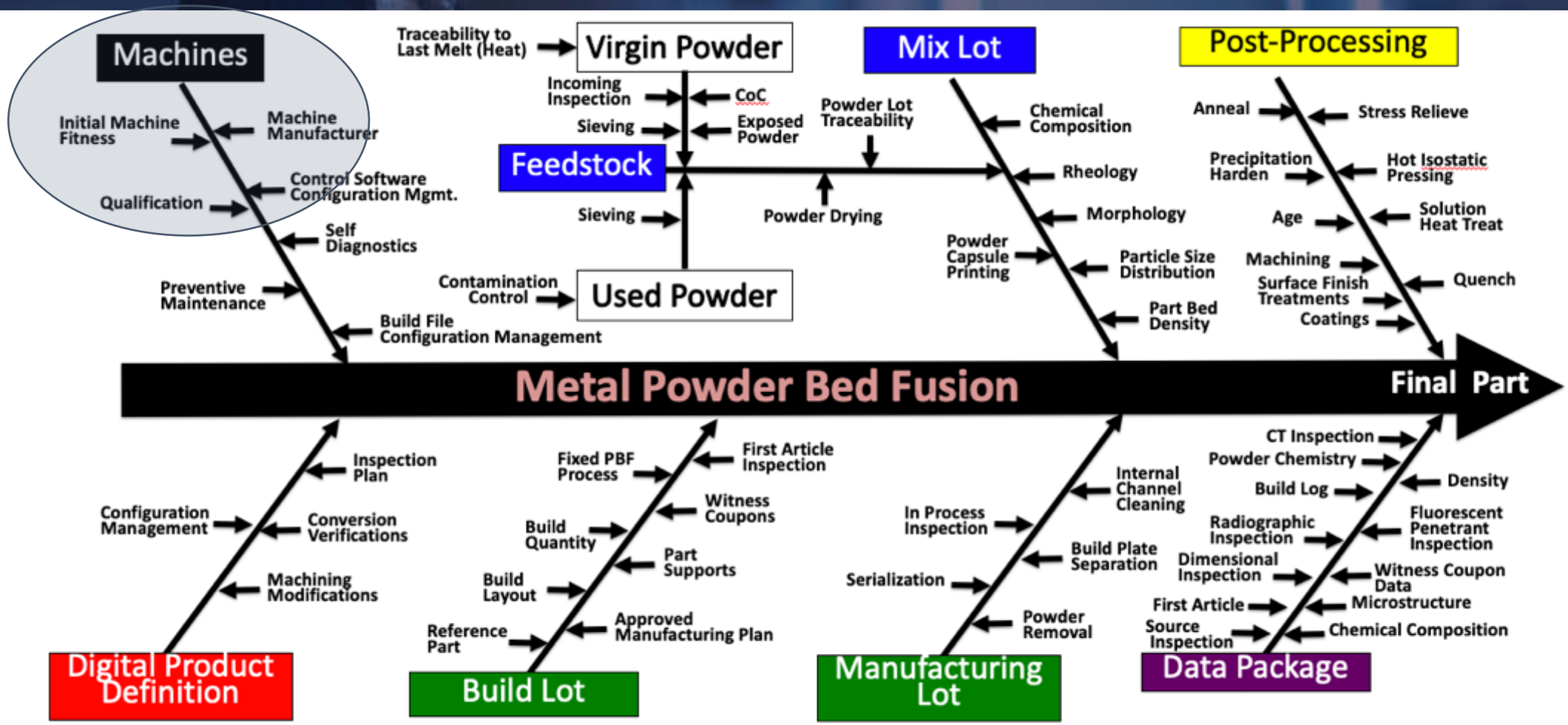
International Organization for Standardization



This standard is highlighted to demonstrate the detail required when considering **Quality Assurance for AM Machines**, as well as some of the **fundamentals required in a facility** to enable the machine use

- Can be used for FAT/SAT & calibration

ISO/ASTM 52941 Establishes Machine Fitness



ISO/ASTM 52941

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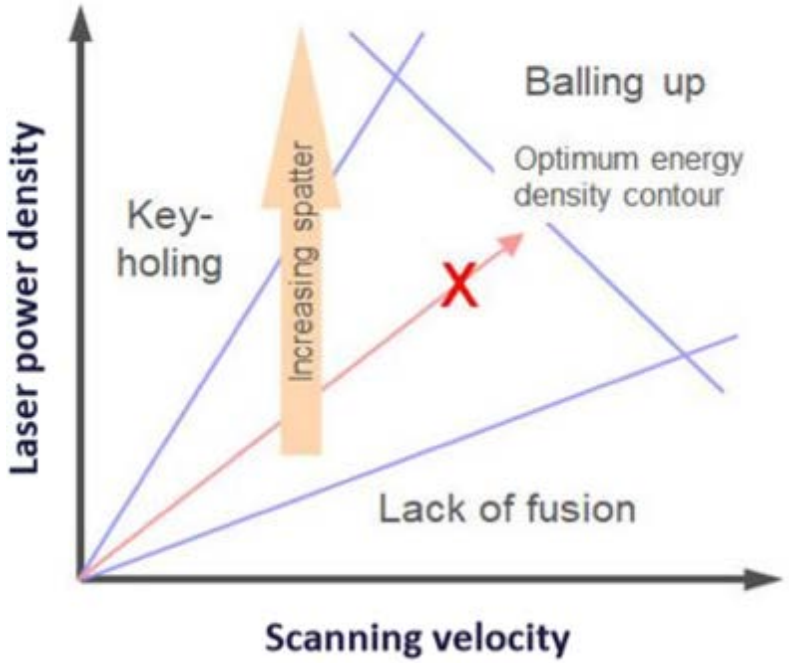
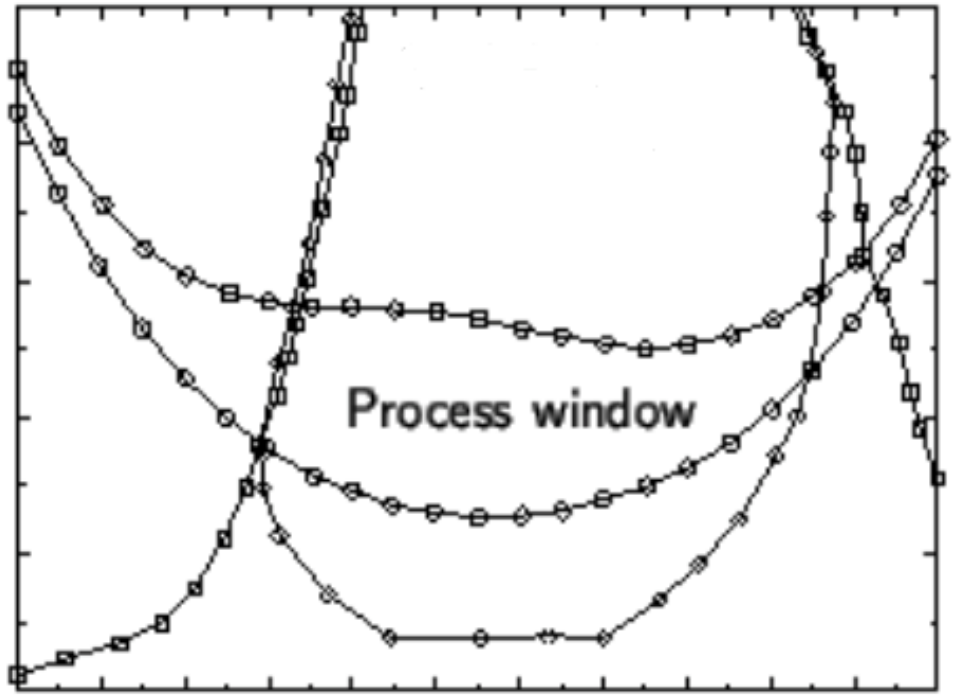
- This standard for additive manufacturing will enable users to maintain operation within the process window - realizing the process window is much more than energy density





Key Standards for Critical Applications

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Forthcoming ASTM Qualification Program

Machine

Operators

Installation/ Operation/ Performance - **PRODUCTION**

ISO/ASTM 52901

Standard Guide for AM – General Principles – Requirements for Purchased AM Parts

Provides requirements for purchased parts from AM. Includes part ordering information, part geometry, tolerances, repair methods allowed, and other requirements to be considered

ISO/ASTM 52904

Practice for Metal Powder Bed Fusion Process to Meet Critical Applications

Provides requirements applicable for *critical* components and mechanical

test specimens using powder bed fusion (PBF)

with both laser and electron beams

ISO/ASTM 52941

System Performance and Reliability – Acceptance Tests for Laser Metal PBF Machine for Metallic Materials for Aerospace

Specifies requirements & test methods for qual & re-qual of Laser PBF machines. Can be used to verify machine features during inspection, or after maintenance & repair

ISO/ASTM 52942

Qualifying Machine Operators of Laser Metal Powder Bed Machines and Equipment used in Aerospace Applications

Specifies requirements for operators of Laser Metal Powder Bed Machine and equipment for AM in Aerospace applications. Qualification tests to include theory & practical tests, and evidence of visual acuity

ASTM F3434

Installation, Operation, and Performance Qualification for Production

This guide addresses IQ, OQ, and PQ issues directly related to the AM machine and connected equipment. Physical facility, personnel, process and material issues are included to the extent necessary to

support machine qualification

Common Data Dictionary (WK72172) New Practice for Additive manufacturing – General principles – Overview of data pedigree

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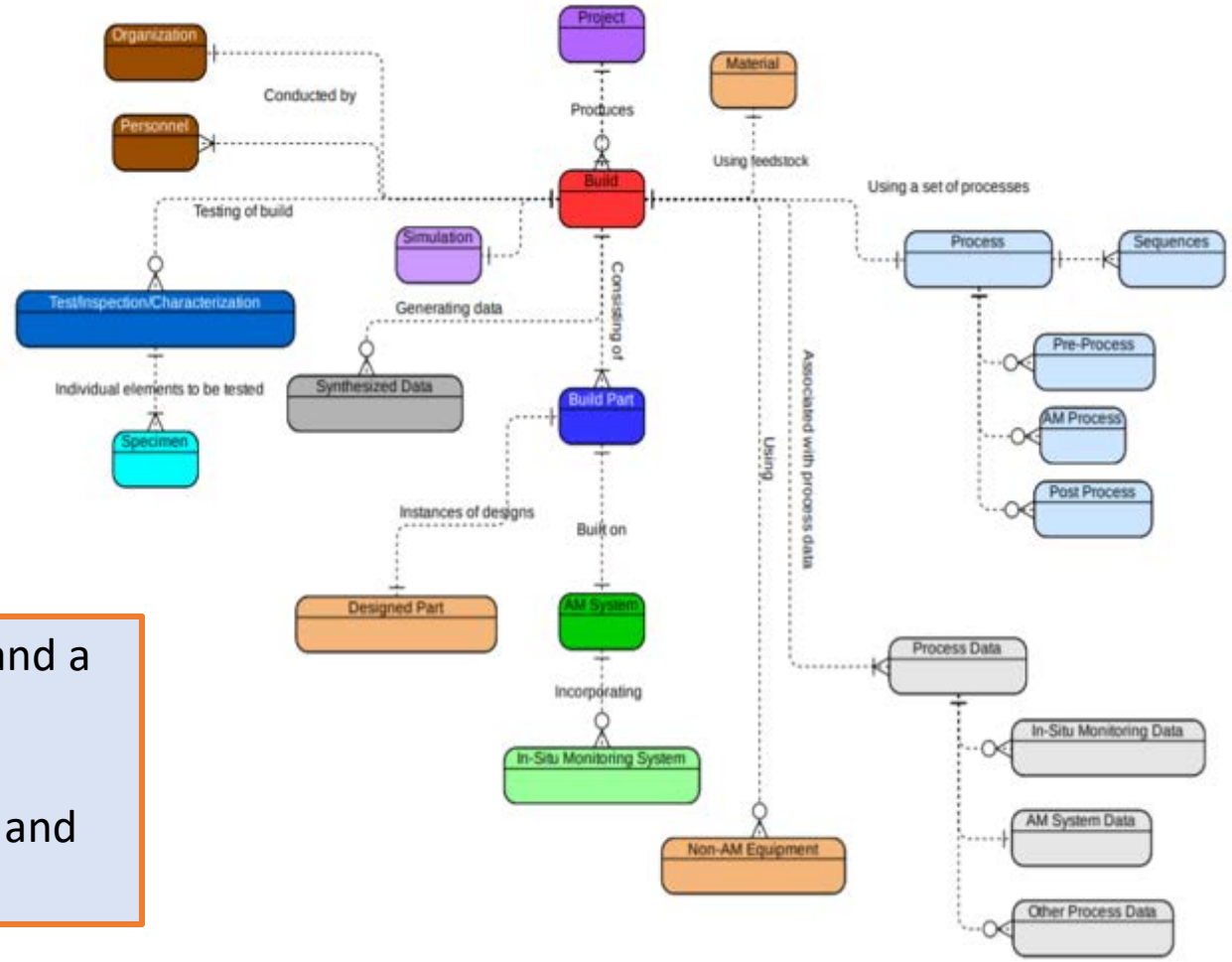
- Development of the Common Data Dictionary (F42.08)
  - Means to exchange AM data between stakeholders
- Essential for AM Data-System developers
  - To meet requirements
  - Standard definitions of data element, data types, and allowable values
- Neutral definitions for essential AM data terms
  - Can be mapped to Proprietary data systems



These concepts can be used to develop a common data model and a common data-exchange format.

This enables seamless data integration via both exporting from, and importing to, the original native formats.

Key Standards *in Development*

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Feedstock		Test	NDT/In-Process Monitoring	
WK62190	**WK66030**	**WK75901**	**WK62181**	**WK75329**
Feedstock Materials Technical Specifications on Metal Powder	**New Guide for Quality Assessment of Metal Powder Feedstock Characterization Data for Additive Manufacturing**	**Additive Manufacturing – Test Artifacts – Miniature Tension Testing of Metallic Materials**	**Standard Guide for In-Situ Monitoring of Metal AM Aerospace Parts**	**New Practice for NDT, Part Quality, and Acceptability Levels of Additively Manufactured Laser Based Powder Bed Fusion Aerospace Components**
Documentation & traceability, sampling, particle size & distribution, chemical composition, characteristics, density, morphology, flowability, contamination, packaging and storage	Guides on when to release powder test data from laboratories, to allow end users to accept powder batches from suppliers, understand when to refresh recycled powders and when to quarantine powder batches	Miniature rectangular cross-section tension test specimens with gauge length 10-15mm for metallic materials. Comparable tensile results to 25mm gauge length	Guide to ensure that parts/products meet the stipulated In-Process Quality Assurance. Will consider multiple techniques, such as Infrared Thermography, Laser Ultrasonic Testing, Melt-pool, Acoustic Microscopy	Provides supplier and customer NDT acceptance criteria for products used in aviation and space application. This practice provides a part quality level, acceptance criteria and identifies some applicable NDT methods

F42.07.02 Spaceflight

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Designation: WK77186

Additive Manufacturing - Finished Part Properties - Standard Specification for Niobium-Hafnium Alloy UNS R04295 via Laser Beam Powder Bed Fusion for Spaceflight Applications[1]

This standard is issued under the fixed designation F; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers additive manufacturing of parts manufactured via laser beam powder bed fusion (PBF-LB) processing of niobium-hafnium alloy used in spaceflight applications. Parts made using this processing method are typically used in applications that require mechanical properties similar to wrought products. Products built to this specification may require additional post-processing in the form of machining, polishing etc. to meet necessary surface finish and dimensional tolerances.

1.2 This specification is intended for the use of purchasers or producers, or both, of PBF-LB R04295 parts for defining the requirements based on classification methodology.

1.3 Users are advised to use this specification as a basis for obtaining parts that will meet the minimum acceptance requirements established and revised by consensus of committee members.

1.4 User requirements considered more stringent may be met by the addition to the purchase order.

1.5 *Units*—The values stated in SI units are to be regarded as the standard. Other units are included only for informational purposes.

F42.07.04 Transportation

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Designation: WK66637

Additive Manufacturing - Finished Part Properties - Standard Specification for 4340 Alloy Steel UNS G43400 via Laser Beam Powder Bed Fusion for Transportation Applications[1]

This standard is issued under the fixed designation F; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers additive manufacturing of parts manufactured via laser beam powder bed fusion (PBF-LB) processing of ~~4043~~ 4340 alloy used in transportation applications, including automotive applications Parts made using this processing method require heat treatment to achieve maximum strength and are typically used in applications that require mechanical properties similar to wrought 4340 products. Products built to this specification may require additional post-processing in the form of machining, polishing etc. to meet necessary surface finish and dimensional tolerances.

1.2 This specification is intended for the use of purchasers or producers, or both, of PBF-LB G43400 parts for defining the requirements based on classification methodology.

1.3 Users are advised to use this specification as a basis for obtaining parts that will meet the minimum acceptance requirements established and revised by consensus of committee members.

1.4 User requirements considered more stringent may be met by the addition to the purchase order.

1.5 *Units*—The values stated in SI units are to be regarded as the standard. Other units are included only for informational purposes.

AM In Construction F42.07.07

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WK74302

Standard Specification for Manufactured Polymeric Ultraviolet (UV)-Cured Structures for Residential Construction[1]

This standard is issued under the fixed designation X XXXX; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification is intended to apply to structures for residential construction manufactured with a three-dimensional (3D) printing process with polymeric ultraviolet (UV)-cured materials in which the structures can be buildings components or complete modules of the construction building. The manufactured UV-cured structures that comply with this specification are intended

Thank You

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