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ADDITIVE MANUFACTURING

Recent Progress on ASTM AM Standardization and R&D Efforts

U.S. NRC Workshop on Advanced Manufacturing Technologies for Nuclear Applications

December 9th, 2020

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Introduction

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- **ASTM has significant history with Nuclear Industry**
  - ASTM Committee E10 on Nuclear Technology formed in 1951 – approximately 150 members
    - 75+ published Standards
  - ASTM Committee C26 on Nuclear Fuel Cycle formed in 1969 – approximately 150 members
    - 175+ published Standards
- **Introducing the ASTM Additive Manufacturing Center of Excellence**
  - Founded in 2018 – aimed to accelerate ASTM standardization activities and fill some of the skill gaps
    - Supporting F42 Additive Manufacturing Committee and other technical committees relevant to AM
- **Objectives**
  - ASTM and its AM CoE is here to listen!
    - Understand challenges and opportunities presented at the workshop
      - Participated at ANS/NEI Advanced Reactor Standards and Codes Virtual Workshop Presentations, June 23, 2020
  - Identify where ASTM efforts are already providing solutions that can **immediately add value & present solutions**
  - Consider next steps:
    - **How can the ASTM support beyond this workshop and work with U.S. NRC and nuclear industry?**

ASTM Nuclear Pedigree

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• E10 – Nuclear Technology & Applications:

"To promote the advancement of nuclear science and technology and the safe application of energy, including end-of-fuel-cycle activities such as decontamination and decommissioning"

- Standardizing measurement techniques and specifications for:
  - Radiation effects
  - Dosimetry, including materials response
  - Instrument response
  - Determination of radiation exposure
  - Fuel burnup
- Standardizing the nomenclature and definitions used
- Maintaining a broad expertise in the application of nuclear science and technology, especially the measurement of radiation effects from environments of nuclear reactors, charged particle accelerators, indigenous space, spacecraft, and radioisotopes.
- Sponsoring scientific and technical symposia, workshops, and publications in the Committee's fields of specialization.

• C26 – Nuclear Fuel Cycle:

"To develop consensus standards for, and promote commercialization of, nuclear fuel cycle, materials, products and processes"

- Provide internationally accepted standards which facilitate the commerce; worker safety; public and environmental health; and regulatory compliance within the Nuclear Fuel Cycle.
- All aspects of the nuclear fuel cycle are included with emphasis on
  - Nuclear fuel
  - Reactor materials processing
  - Analysis
  - Disposal/disposition technologies and applications.
  - Nuclear fuel cycle activities of both the commercial nuclear industry and the defense community fall within the scope of this committee.
- The work of the Committee(s) will be coordinated with other ASTM International committees and national and international organizations having mutual interest.

ASTM Nuclear Pedigree

Roadmap published in 2012

- This roadmap identifies top priorities and opportunities in the commercial nuclear energy sector that:
  - Encompass the objectives of NESCC Task Group on Standards Prioritization;
  - Build on the results of the ASTM nuclear survey and Nuclear Standards Workshop (described further in this roadmap); and
  - Manage gaps in the underlying technology and standards based on their significance to the NESCC goals.
- The roadmap is of importance to ASTM International because it provides:
  - The formation of a self-sustaining nuclear energy focal point within ASTM;
  - The strengthening of alliances with other societies and international organizations;
  - An increased understanding of the nuclear energy sector and how to effectively contribute to this industry through the actions of ASTM technical committees;
  - The identification of gaps in current and emerging technologies and related standards;

Download at: https://www.astm.org/portals/nuclear_roadmap.pdf

ANS/NEI Advanced Reactor Standards and Codes Virtual Workshop, June 2020

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- Purpose of the workshop:
  - Facilitate discussions on needs for codes/standards

- Recommended actions:
  - Conduct gap analysis
  - Development of standards that were identified high priority for this sector
  - Many more

https://www.ans.org/file/1716/2/NEI-ANS%20Advanced%20Reactor%20Codes%20&%20Standards%20Workshop%20Presentations.pdf

New Sub-Committee on Applications

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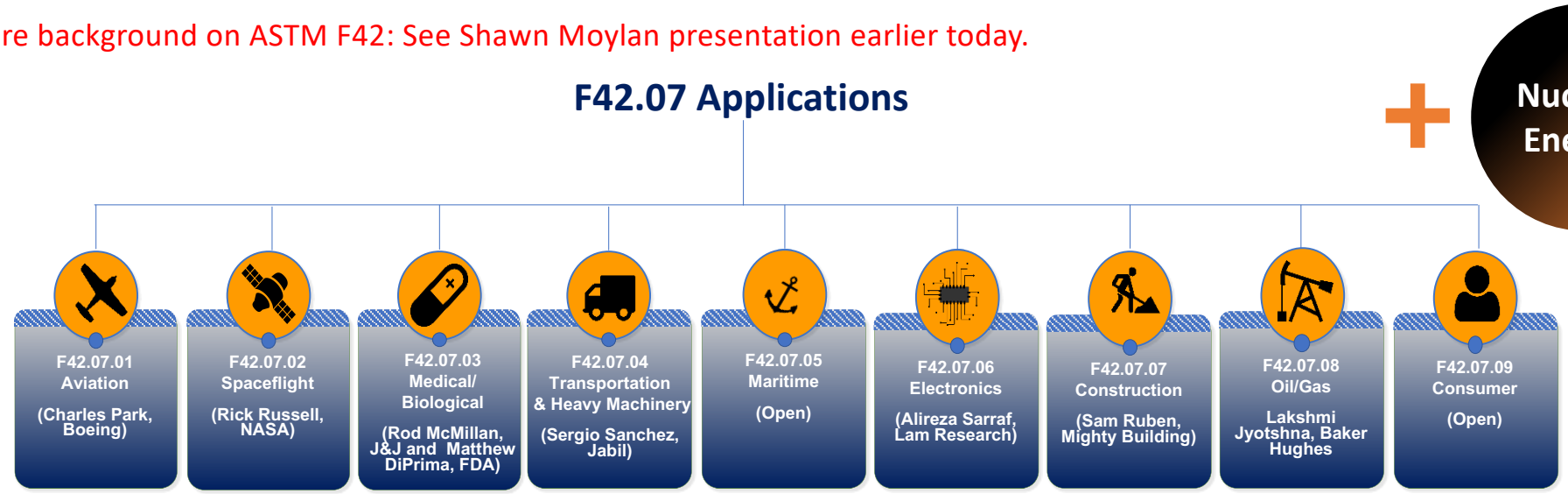
More background on ASTM F42: See Shawn Moylan presentation earlier today.

F42.07 Applications



\+ Nuclear/ Energy?

Scope

- The development of **standards for additive manufacturing** in a variety of industry-specific applications, settings, & conditions.
- The work of this subcommittee will be coordinated with other F42 subcommittees, ASTM technical committees, and national/international organizations having mutual or related interests.

ASTM AM Footprint: Collaborative nature

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- Partnership with ISO TC261 (& CEN TC438): Agreement since 2011
- Strategic Relationships:
  - America Makes: MoU since 2013
  - Government agencies: NIST, NASA, FAA, FDA, DoD, U.S. NRC, etc.
  - Other groups: MMPDS (MoU), CMH17, etc.
- AM Center of Excellence partnership:
  - AU, EWI, MTC, NIAR, NASA, NAMIC
- Certification bodies:
  - SEI (ASTM Subsidiary)
  - UL: MoU to develop AM Safety standard (UL3400)
  - TUV SUD: MoU to develop joint programs
- Other SDOs:
  - ASME, AWS, SAE, etc.

More background on ASTM F42: See Shawn Moylan presentation earlier today.

The Impact of Standards

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- Recent Key Standards/Drafts for AM
  - Installation, Operation, and Performance Qualification for Production (**ISO/ASTM 52930**)
  - Best Practices for Metal Powder Bed Fusion Process to Meet Critical Applications (**ISO/ASTM 52904**)
  - Qualifying machine operators of LB-PBF machines and equipment used in aerospace applications (**ISO/ASTM 52942**)
  - Feedstock materials technical specifications on metal powder (**WK62190**)
  - Standard Guide for In-Situ Monitoring of Metal AM Parts (**WK62181**)
- How ASTM Standards interact
  - See example Quality System in slide 9

Snapshot of ISO/ASTM Standards (partial list)

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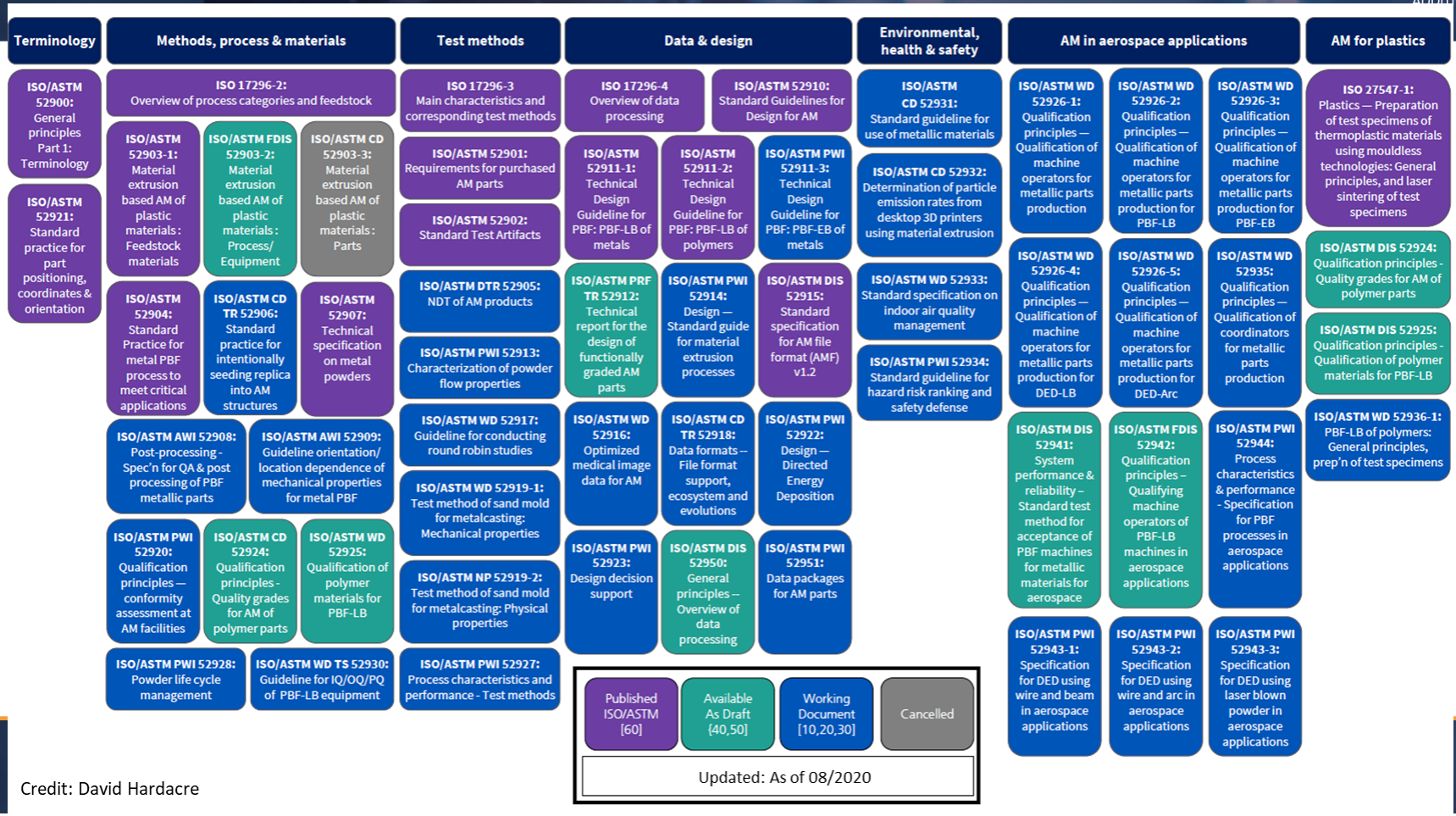

Credit: David Hardacre

An example Quality System Leveraging ASTM/ISO Standards

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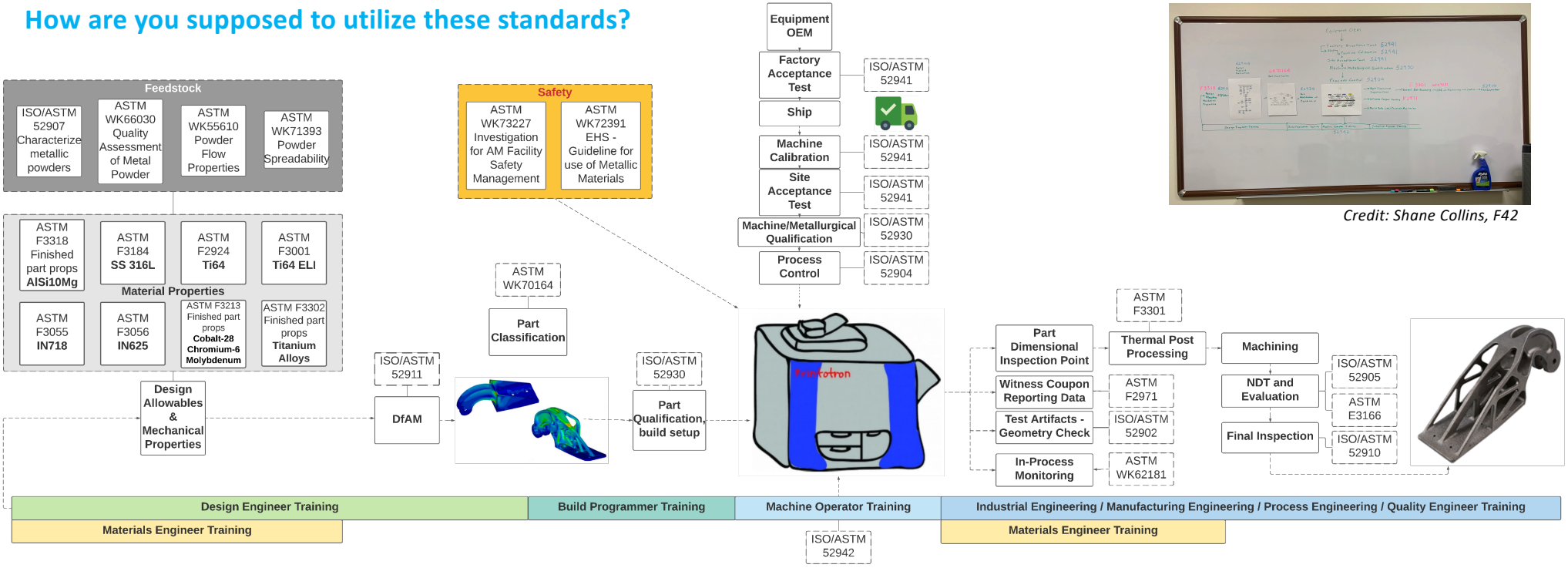
How are you supposed to utilize these standards?



Credit: Shane Collins, F42

Note: Not inclusive of all Standards

Guidelines for Installation, Operation and Performance Qualification (LB-PBF)

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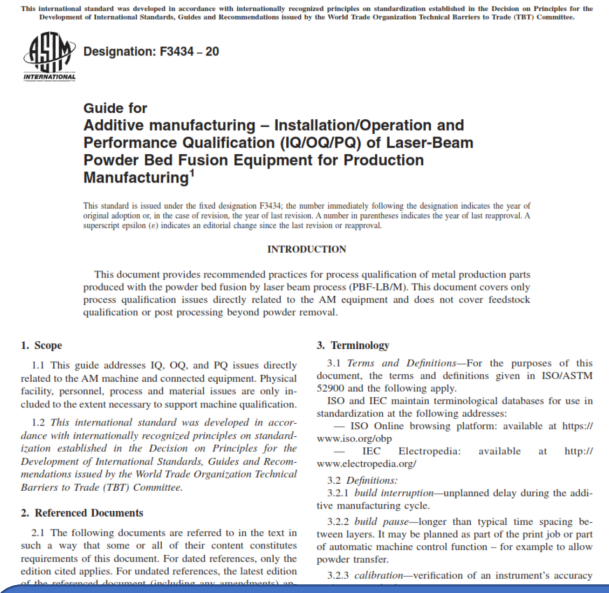
- **ISO/ASTM 52930**
  - Ballot ended in April, currently available as *ASTM F3434-20*
  - Covers the key elements for Process Validation
- **Installation Qualification:**
  - Equipment design & validation: FAT/SAT, Installation conditions, environmental operating limits, calibration…
- **Operational Qualification:**
  - Show the relationship of the input variables to the measured output for the specific combination of equipment with specific parts produced
  - KPVs, control of variability, optimal processing parameters…
- **Performance/Part Qualification:**
  - Validation vs requirements, Failure modes, Production Controls, In Process monitoring, data to be collected…
  - Scenarios requiring **Revalidation**:
    - Software/firmware updates, installation of additional components, repair/replacement of components, changes to location/environment



This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Designation: F3434 – 20

Guide for
Additive manufacturing – Installation/Operation and Performance Qualification (IQ/OQ/PQ) of Laser-Beam Powder Bed Fusion Equipment for Production Manufacturing[1]

This standard is issued under the fixed designation F3434; 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

This document provides recommended practices for process qualification of metal production parts produced with the powder bed fusion by laser beam process (PBF-LB/M). This document covers only process qualification issues directly related to the AM equipment and does not cover feedstock qualification or post processing beyond powder removal.

1. Scope

1.1 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 only included to the extent necessary to support machine qualification.

1.2 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition

3. Terminology

3.1 *Terms and Definitions*—For the purposes of this document, the terms and definitions given in ISO/ASTM 52900 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.2 *Definitions:*

3.2.1 *build interruption*—unplanned delay during the additive manufacturing cycle.

3.2.2 *build pause*—longer than typical time spacing between layers. It may be planned as part of the print job or part of automatic machine control function – for example to allow powder transfer.

3.2.3 *calibration*—verification of an instrument's accuracy

This guideline 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

Process Characteristics and Performance: Practice for Metal Powder Bed Fusion to Meet Critical Applications

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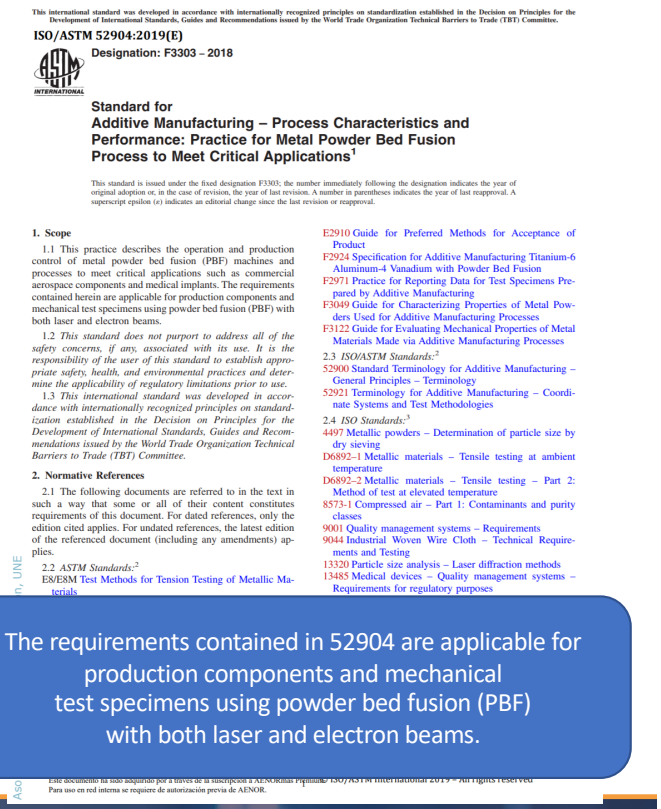
- **ISO/ASTM 52904**
  - Released in June 2020
  - Covers the control of machines (**Laser and Electron Beam**) and process required to meet critical applications such as aerospace components
- **Feedstock Batches:**
  - Powder container requirements, CoC, approval of material suppliers, feedstock material specification, guidance on used powder
- **Qualification:**
  - Pre-build checks, periodic preventative maintenance, machine/process/part qualification
- **Manufacturing Plan:**
  - Plan to detail the steps required for the PBF process, including pre-build check records, machining stock added, part nesting, reference parts etc.
  - Guidance on **Configuration Control** of digital data and software control



This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

ISO/ASTM 52904:2019(E)

Designation: F3303 – 2018

Standard for
Additive Manufacturing – Process Characteristics and Performance: Practice for Metal Powder Bed Fusion Process to Meet Critical Applications[1]

This standard is issued under the fixed designation F3303; 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 practice describes the operation and production control of metal powder bed fusion (PBF) machines and processes to meet critical applications such as commercial aerospace components and medical implants. The requirements contained herein are applicable for production components and mechanical test specimens using powder bed fusion (PBF) with both laser and electron beams.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.3 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Normative References

2.1 The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

2.2 *ASTM Standards:*[2]
E8/E8M Test Methods for Tension Testing of Metallic Materials
E2910 Guide for Preferred Methods for Acceptance of Product
F2924 Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium with Powder Bed Fusion
F2971 Practice for Reporting Data for Test Specimens Prepared by Additive Manufacturing
F3049 Guide for Characterizing Properties of Metal Powders Used for Additive Manufacturing Processes
F3122 Guide for Evaluating Mechanical Properties of Metal Materials Made via Additive Manufacturing Processes

2.3 *ISO/ASTM Standards:*[2]
52900 Standard Terminology for Additive Manufacturing – General Principles – Terminology
52921 Terminology for Additive Manufacturing – Coordinate Systems and Test Methodologies

2.4 *ISO Standards:*[3]
4497 Metallic powders – Determination of particle size by dry sieving
D6892-1 Metallic materials – Tensile testing at ambient temperature
D6892-2 Metallic materials – Tensile testing – Part 2: Method of test at elevated temperature
8573-1 Compressed air – Part 1: Contaminants and purity classes
9001 Quality management systems – Requirements
9044 Industrial Woven Wire Cloth – Technical Requirements and Testing
13320 Particle size analysis – Laser diffraction methods
13485 Medical devices – Quality management systems – Requirements for regulatory purposes

The requirements contained in 52904 are applicable for production components and mechanical test specimens using powder bed fusion (PBF) with both laser and electron beams.

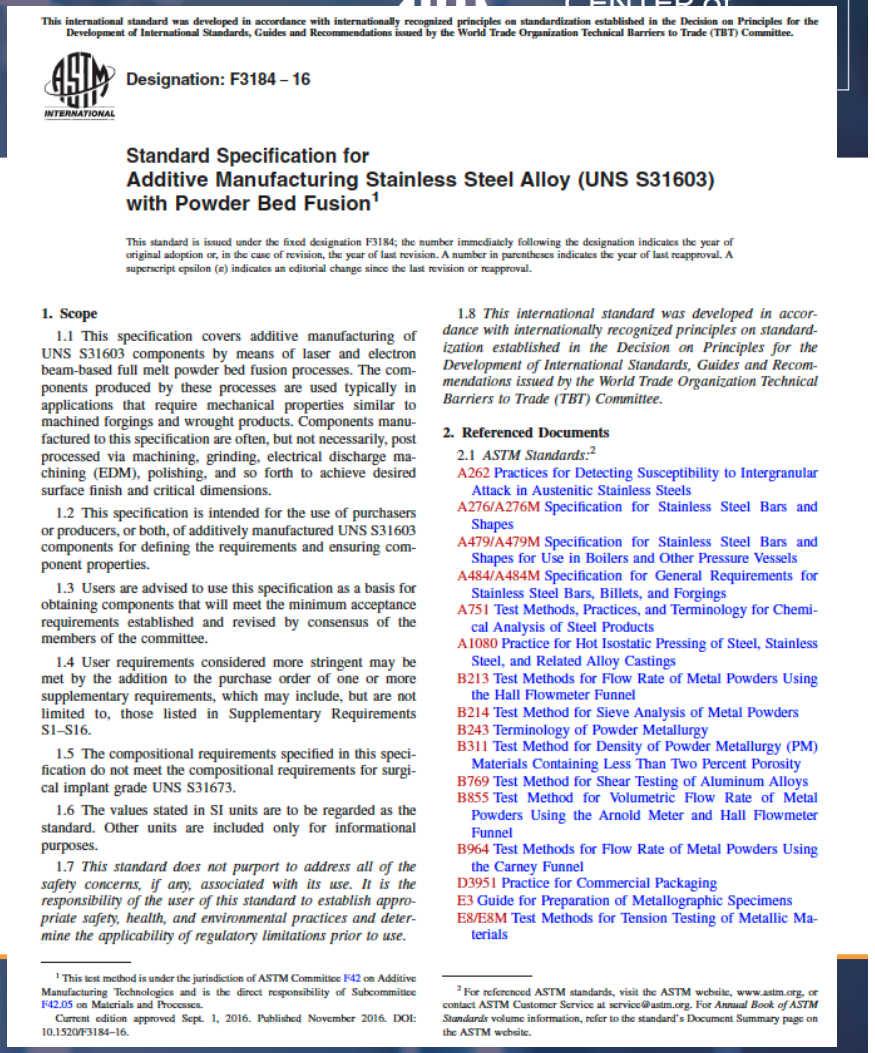
Material Standards:
316 L as an example

- Covers AM components made from Electron Beam and Laser Powder Bed
- Provides Minimum Tensile Properties
  - Similar to machined forgings & wrought
- This specification intended to be used by both the Purchaser and the Producer of AM Material
- Serves as a link to other key standards (testing, quality, terminology, etc.)

TABLE 3 Minimum Tensile Requirements[A]

Room Temperature Condition	Tensile Strength, MPa (ksi), X and Y Directions	Tensile Strength, MPa (ksi), Z Direction	Yield Strength at 0.2% Offset, MPa (ksi), X and Y Directions	Yield Strength at 0.2% Offset, MPa (ksi), Z Direction	Elongation in 50 mm (2 in.) or 4D, (%), X and Y Directions	Elongation in 50 mm (2 in.) or 4D, (%), Z Direction	Reduction of Area, %, X and Y Directions	Reduction of Area, %, Z Direction
A - Stress Relieved[B]	515 (75)	515 (75)	205 (30)	205 (30)	30	30	40	40
A - Solution Annealed	515 (75)	515 (75)	205 (30)	205 (30)	30	30	30	30
B	515 (75)	515 (75)	205 (30)	205 (30)	30	30	30	30
C	515 (75)	515 (75)	205 (30)	205 (30)	30	30	30	30
E	no requirement	no requirement	no requirement	no requirement	no requirement	no requirement	no requirement	no requirement

[A] A gauge length corresponding to ISO 6892 may be used when agreed upon by the component supplier and purchaser.
[B] Mechanical properties conform to Specification A479/A479M.



This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Designation: F3184 – 16

Standard Specification for Additive Manufacturing Stainless Steel Alloy (UNS S31603) with Powder Bed Fusion[1]

This standard is issued under the fixed designation F3184; 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 UNS S31603 components by means of laser and electron beam-based full melt powder bed fusion processes. The components produced by these processes are used typically in applications that require mechanical properties similar to machined forgings and wrought products. Components manufactured to this specification are often, but not necessarily, post processed via machining, grinding, electrical discharge machining (EDM), polishing, and so forth to achieve desired surface finish and critical dimensions.

1.2 This specification is intended for the use of purchasers or producers, or both, of additively manufactured UNS S31603 components for defining the requirements and ensuring component properties.

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

1.4 User requirements considered more stringent may be met by the addition to the purchase order of one or more supplementary requirements, which may include, but are not limited to, those listed in Supplementary Requirements S1–S16.

1.5 The compositional requirements specified in this specification do not meet the compositional requirements for surgical implant grade UNS S31673.

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

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A262 Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels
A276/A276M Specification for Stainless Steel Bars and Shapes
A479/A479M Specification for Stainless Steel Bars and Shapes for Use in Boilers and Other Pressure Vessels
A484/A484M Specification for General Requirements for Stainless Steel Bars, Billets, and Forgings
A751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products
A1080 Practice for Hot Isostatic Pressing of Steel, Stainless Steel, and Related Alloy Castings
B213 Test Methods for Flow Rate of Metal Powders Using the Hall Flowmeter Funnel
B214 Test Method for Sieve Analysis of Metal Powders
B243 Terminology of Powder Metallurgy
B311 Test Method for Density of Powder Metallurgy (PM) Materials Containing Less Than Two Percent Porosity
B769 Test Method for Shear Testing of Aluminum Alloys
B855 Test Method for Volumetric Flow Rate of Metal Powders Using the Arnold Meter and Hall Flowmeter Funnel
B964 Test Methods for Flow Rate of Metal Powders Using the Carney Funnel
D3951 Practice for Commercial Packaging
E3 Guide for Preparation of Metallographic Specimens
E8/E8M Test Methods for Tension Testing of Metallic Materials

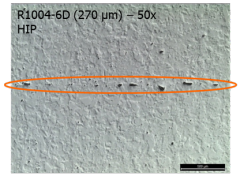
[1] This test method is under the jurisdiction of ASTM Committee F42 on Additive Manufacturing Technologies and is the direct responsibility of Subcommittee F42.05 on Materials and Processes.
Current edition approved Sept. 1, 2016. Published November 2016. DOI: 10.1520/F3184–16.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

NDT Standards led by E07 committee on NDT

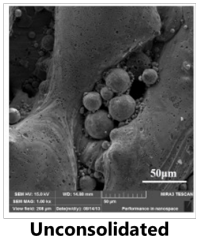
Relevant standards:

- **ASTM E3166** – Guide for Nondestructive Testing of Metal Additively Manufactured Metal Aerospace Parts After Build
- **ASTM WK62181** – Standard Guide for In-Situ Monitoring of Metal AM Aerospace Parts
- **ASTM WK56649** - Additive Manufacturing — Non-Destructive Testing and Evaluation — Standard Guideline for Intentionally Seeding Flaws Metallic Parts
- **ISO/ASTM JG59 DTR 52905** - Standard Guideline for Defect Detection in Metallic Parts

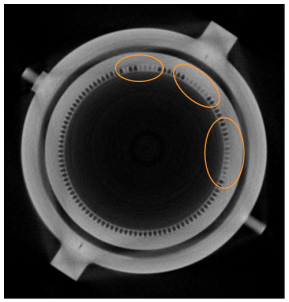


Layer Defect
(Skipped layer/stop-start, horizontal LOF)

Cross-Layer Defect
(vertical LOF)



Unconsolidated Powder



Trapped Powder

TABLE 1 Nondestructive Test Detection of Typical Additive Manufacturing Flaws[A,B]

Flaw/Artifact[C]	Observed in PBF or DED?	Why?	Post-Process Detection	Comment
Porosity	both	Poor selection of parameters, moisture or contamination of feed material or process environment, inadequate handling, storage, vaporization of minor alloying constituents depending on material feedstock. Errors in precision of beam delivery.	Depending on sample geometry and size of porosity, may be detected using CT/ET[G] /IRT/PCRT/RT/UT	HIP recoverable (may not be fully recoverable)
Voids	both	Powder run out, changes in the energy density of the impinging beam creating keyhole melting or vaporization conditions that entrap voids or create spatter (spherical molten ejecta) leaving holes, and voids that may be covered by subsequent layers of fused materials. System drift or calibration issues may come into play to create conditions of LOF. Bridging of powder in the hopper/poor flow properties.	Depending on sample geometry and size of voids, may be detected using CT/ET[G] /IRT/PCRT/RT/UT	HIP recoverable depending on size (not fully recoverable regardless)
Layer flaws	Unique to AM[F]	Interruption to powder supply, optics systems errors (laser) or errors in data. Contamination of build environment purity (inert gas interruption) or other process interruption such as changing the filament emitter within an electron beam gun. Powder supply blending or mixing between one batch and another, a new lot of filler wire, etc.	Depending on sample geometry and size of flaw, may be detected using CT/ET[G] /PCRT/RT/UT	HIP recoverable depending on size (not fully recoverable regardless)
Cross-layer flaws	Unique to AM[F]	Poor selection of parameters, contamination or degradation of the processing environment. Discoloration (for example, DED-PA of Ti alloys) as detected visually can indicate a process out of control. Error in the precision of the beam delivery.	Depending on sample geometry and size of flaw, may be detected using CT/ET[G] /PCRT/RT/UT	HIP recoverable depending on size (not fully recoverable regardless)
Under melted material/ unconsolidated powder (LOF)	both	Poor selection of parameters, poorly developed and controlled process or a process out of control creating a poorly resolved flaw state. Errors in the precision of beam delivery.	Most probably CT, and PCRT, detectability depends on sample geometry and size	Only fixable during the process
Cracking[D]	Unique to AM[F]	AM PBF failure to clean one alloy powder completely from the build environment prior to processing another, DED large assemblies extensive solidification stresses present within large buildups, There is a host of metallurgical issues associated with crack susceptibility. Extremely large range of potential thermal and mechanical conditions present, across all AM processes, that may lead to cracking are poorly characterized.	Depending on sample geometry and size of crack, may be detected using CT/IRT/PCRT/ET[G] /RT/UT	–
Reduced mechanical properties	both	New powder out of spec or degraded through reuse, poorly developed/controlled process, interruption of feedstock supply. Residual stresses produced by rapid cooling, in a state of pre-stress, thus reducing the effective structural load that can be applied on the part, or causing structural weaknesses in a part in regions that have lower mechanical properties compared with the rest of the part.	Check powder (X-ray diffraction) at end of process and mechanical properties of finished part, stress related reduced properties can be detected using PCRT	–
Poor dimensional accuracy	both	Scaling/offset factors are effected by part geometry, beam intensity, and the density of the powder bed or build platform shift. SLM –scan head/optics problems. EBM – presence of EMF interference.	Usually easy (visually), as part has step on surface, but localized defects may require laser CMM and internal deviations with CT compared with CAD.	–
Inclusions	both	Debris from AM or post processing equipment.	Depends on the nature of the contamination and complexity of part, some inclusions are detectable using CT/ET[G] /IRT/PCRT/RT/UT	Remove all potential sources of contamination; sieve/ analyze powder before and after.
Residual stress	both	Poor selection of parameters.	Usually easy (visually), as part has step on surface, but localized defects may require laser CMM and internal deviations with CT compared with CAD. CT/ET[G] /PCRT	Poor selection of parameters.
Stop/start flaws[E]	both	Consequence of long builds or interruption of feedstock leading to reduced mechanical properties.	Check mechanical properties of finished part; PCRT individual frequencies may correlate also.	–
Surface flaws	Unique to AM[F]	Includes partially fused powder, linear or planar conditions or irregularities. Similar to spatter, undercut, irregular top bead, ropey bead, and slumping noted for welded parts.	ET/MET/PCRT/PT	–
Trapped powder	Unique to AM[F]	–	Most probably, CT or PCRT detectability depends on sample geometry and part size.	–

ASTM AM Center of Excellence (CoE)

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- Overview of AM R&D portfolio and their impact on AM standards portfolio
- New program development in workforce development
- Expansion of in-person workshops attracting over 300 AM professionals in Paris, Virginia and Texas
- AM CoE's COVID-19 response
- And more…

ASTM AM Center of Excellence (CoE)

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Why ASTM create the AM CoE?

About the CoE

Rationale:

- Critical need to support accelerate development of globally accepted AM standards due to large gaps
- Critical need to educate the next generation of AM professionals and implementation of standards

Objective:

- To coordinate and conduct R&D that supports AM standards development
- To support related education, training and other programs

Expected outcome: AM standards via committees and standards related products and services

- Reducing time-to-market
- Increasing widespread adoption

CoE relation with respect to F42 Committee: ***F42 membership and other committees can leverage AM CoE as a platform*** to conduct research that can fill gaps in ongoing standardization efforts

Mission

The Center bridges standards development with R&D to better enable efficient development of:

- Standards
- Education and training and
- Certification and proficiency testing programs

Vision

The Center facilitates collaboration and coordination among government, academia, and industry to:

- Advance AM standardization
- Expand ASTM International's and our partners' capabilities.

Role of AM CoE with respect to F42

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ASTM Committee F42

Dedicated to AM and has technical subcommittees focused on the **development of consensus-based standards.** **This is happening in partnership with ISO TC261.**

ASTM AM CoE

A collaborative partnership among ASTM and organization representing government, industry, and academia that **conducts strategic R&D to advance standards across all aspects of AM** **in addition to develop E&WD and Certification Programs.**

Platform for F42 members and AM community

- AM CoE is a platform that F42 members can tap into to conduct research to fill gaps in the AM standards.
- AM CoE is also a platform open for other ASTM technical committees to utilize resources.

Focal point for standard-related R&D activities

- AM CoE houses and facilitates AM R&D generation to support global standardization efforts

Global hub for AM innovation to support standardization

- Create strong national and international industry-government-university partnerships;
- Develop education, training, proficiency testing, and certification programs; and
- Host ASTM committee related events, workshops, and symposia.

AM CoE R&D: High Priority Areas

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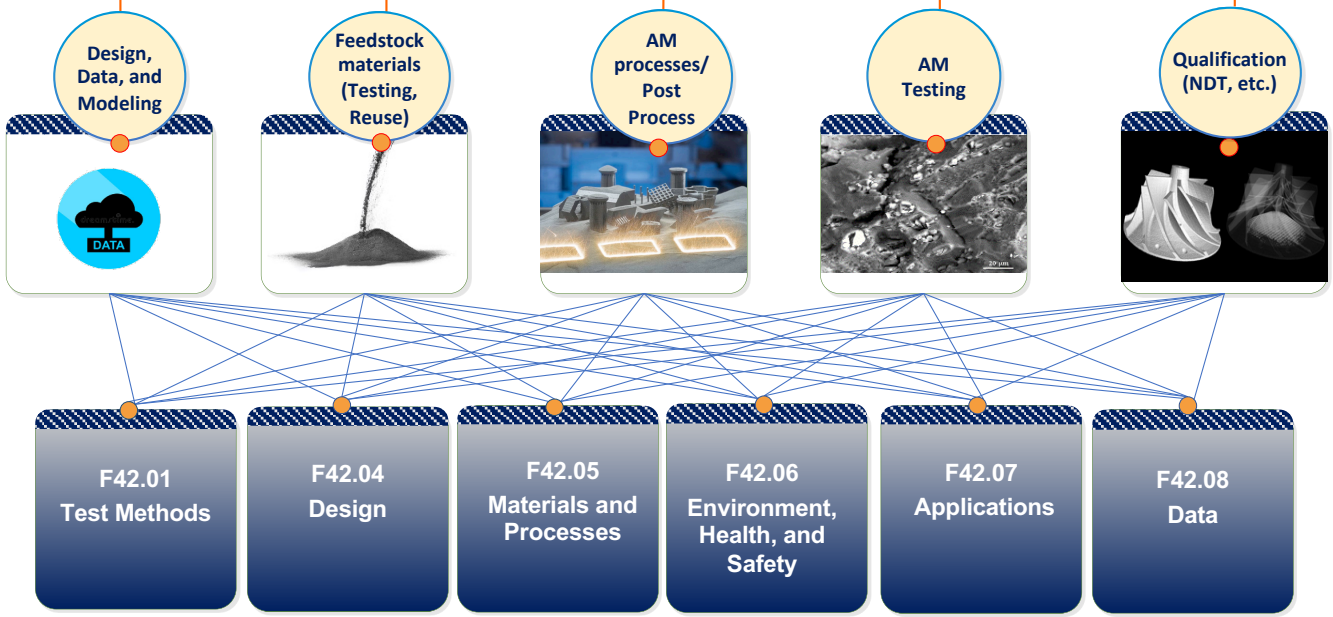
AM CoE R&D Themes

CoE R&D Areas

Topics are crosslinked to create synergy!

F42.07 Applications



1. Defined based on the input of the AM CoE R&D team
2. Short-term
3. Highly-focused
4. High-priority (linked to AMSC roadmap and Committee F42)
5. Aligned with America Makes projects
6. Coordination/collaboration with NIST, other agencies

America Makes

NIST

AM CoE R&D Projects (Rounds 1 & 2)

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R&D Projects

Round 1: 2018-2019 (5 projects)

EWI — Post Processing (Surface finishing and Characterization)	NASA / Auburn University — LB-PBF Process Qualification
mtc Manufacturing Technology Centre — Feedstock (Powder quality guide)	NIAR — Polymer AM Test Specimen Design
Auburn University — Mechanical Testing of Metal AM	

Round 2: 2019-2020 (9 projects)

EWI — Standardization of Data Pedigree	NASA / Auburn University — LB-PBF Process Qualification – Phase II
mtc Manufacturing Technology Centre — Design Guide for Post-Processing	NIAR — Polymer AM Design Value Tests
mtc Manufacturing Technology Centre — Powder Spreadability	NIAR — Dynamic Testing of Polymer AM
Auburn University — Rapid Quality Inspection Specimen (RQIS)	NAMIC National Additive Manufacturing Innovation Cluster — In-process Monitoring
	NAMIC National Additive Manufacturing Innovation Cluster — Design Guides for AM Processes

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LAUNCHED **14** Total Research Projects

ADDRESSING **25** Total Standards Gaps | IMPACTING **53** Total Standards

https://www.amcoe.org/projects

Research to Standardization

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1. Work item scoping and registration	2. Draft under development	3. Editorial support and pre-ballot	4. Undergoing balloting and final approval of a standard
TBD	WK62867 WK65929 WK66682 WK71391 WK73340 WK74390	WK66030 WK71393 WK71395	*WK49229** *WK65937** WK66029 WK72172 WK73444 **Approved:** ASTM F3413 – 19

* Existing Work Items

	Completed
	In process
	Upcoming

Status Key:

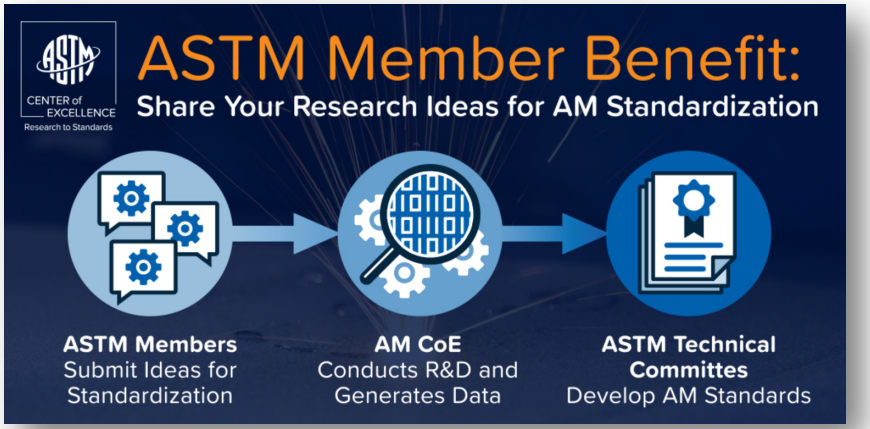
1. Work item scoping and registration
2. Draft under development
3. Editorial Support and Pre-Ballot
4. Undergoing Balloting and Final approval as a standard

PARTNER	FUNDING YEAR	PROJECT	STANDARD WORK ITEM	STATUS 1	2	3	4
	2018	**1801: Metal AM Testing**	WK49229				
	2019	**1901: Rapid Quality Inspection Specimen**	WK71395				
EWI	2018	**1802: AM Post Processing**	WK66682				
EWI	2019	**1902: Data Pedigree**	WK72172				
mtc	2018	**1803: AM Feedstock Evaluation**	WK66030				
mtc	2019	**1903: AM Powder Spreadability**	WK71393				
mtc	2019	**1904: Design for Post Processing**	WK73444				
NAMIC	2019	**1905: Design Guides for AM Processes**	WK62867 F3413-19 (WK62946)				
NAMIC	2019	**1906: In-process Monitoring**	WK74390				
NASA	2018/2019	**1804/1907: LB-PBF Process Qualification**	WK65937 WK65929				
NIAR	2018	**1805: Polymer AM Testing**	WK66029				
NIAR	2018	**1805: Polymer AM Testing**	WK71391				
NIAR	2019	**1908: Polymer AM Design Value Tests**	TBD				
NIAR	2019	**1909: Dynamic Testing of Polymer AM**	WK73340				

3rd Round of Projects

2020 Request for Ideas

- The idea solicitation process was expanded to all ASTM members as a membership benefit
  - Over 60 ideas were received during the survey
- Submissions addressed a wide range of challenges in AM that members face, including:
  - Design, Data, and Modeling
  - Feedstock
  - Processes and Post processing
  - AM Testing
  - Inspection and Qualification
- Project selection process
  - Ideas were evaluated by the F42.90.05 team
  - AM CoE Partners are developing SOWs
  - Projects will start in October 2020



3rd Round of Projects

Summary of Ideas

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- Over 60 ideas were received during the RFI

Design, Data, and Modelling	Feedstock	Processes/ Post Processes	Testing	Qualification
❖ Standard data formats and terminology to enable exchange of data between organizations and across process steps ❖ Definition of minimum viable data packages for process steps ❖ Data processing techniques to improve visualizations and usefulness ❖ Benchmark datasets for calibration of models and simulations	❖ Recycling & reuse guidelines for powders and resins ❖ Methods for evaluating contamination (e.g. chemical, moisture) of metal powders ❖ Methods for evaluating feedstock variability ❖ Material standards specifically for additive manufacturing applications ❖ Material safety guidance and considerations	❖ Calibration and maintenance of AM machines; particularly multi-laser systems ❖ Guidance for use of post-processing methods (e.g. hot isostatic pressing, wet-chemical support removal) ❖ Process safety guidance and considerations (e.g. fume, safety incident database) ❖ Methods for manufacturing multi-material/functionally graded components	❖ Test methods and specimen designs for mechanical testing ❖ Guidelines for implementation and use of witness testing ❖ Test methods for evaluating lattice structures ❖ Guidelines for non-destructive evaluation	❖ Guidance for acceptance criteria of surface finish in fatigue-critical applications ❖ Guidance for acceptance criteria based on size, type, and location of defects ❖ Framework for quality control in an environment with multiple AM machines ❖ Guidance for implementation, analysis, and use of in-process monitoring data for qualification

3rd round of R&D Projects

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Lead	Project Title	Material	Topic
Auburn	Specimen Design for Compression Testing of Metallic Lattice Structures	Metal	Testing
EWI	Common Data Exchange Format (CDEF) for Powder Characterization	Metal	Design, Data, & Modeling
mtc	Metal Powder Feedstock Recycling and Sampling Strategies	Metal	Feedstock
mtc	Recycling and Re-Use of Polymer Powders	Polymer	Feedstock
NAMIC	Miniature Tensile Specimens for Additive Manufacturing	Metal	Testing
NAMIC	Volume-Traceability (VT) Development in Porosity Characterization with XCT for Integrity and Quality Assurance of AM Parts	Metal	Testing
NAMIC	Development of Specification for Maraging Steel	Metal	Feedstock
NASA, Auburn	Thermal Tolerance Test for LB-PBF Process Parameters	Metal	Processes & Post-Processes
NIAR	Continuation of AM Polymer Projects (Design Value and Dynamic Testing)*	Polymer	Testing

Material
- Metal
- Polymer
- Ceramic

Topic
- Design, Data, & Modeling
- Feedstock
- Processes & Post-Processes
- Testing
- Qualification

* Continuation of projects initiated in 2019

Other notable efforts

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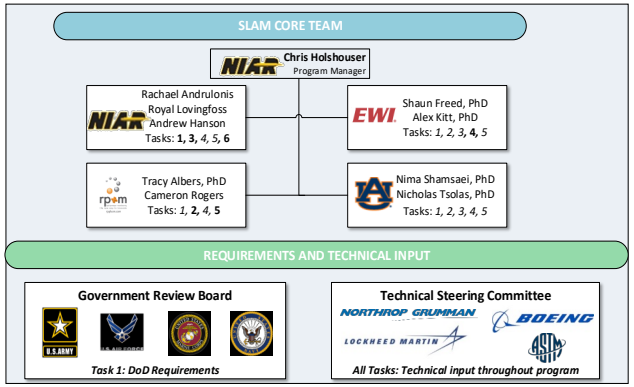
ATRQ (Advanced Tools for Rapid Qualification)

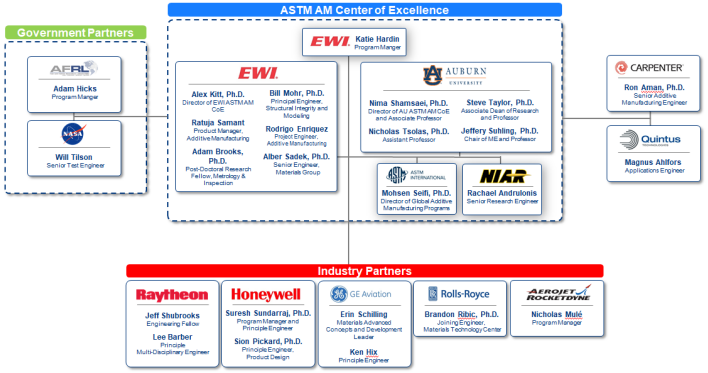
Total Federal Funding: ~$1M



- **Problem Statement:** Service life predictive tools for application specific characterization do not exist for polymer AM materials exposed to harsh environmental conditions
- **Objective:** Quantify service life of AM polymer parts used in harsh/severe field environments

AAPT (Advancing Additive Manufacturing Post-Processing Techniques)

Total Federal Funding: ~$800K



- **Problem Statement:** lack of best practices for post-processing of AM components
- **Objective:** determine and enable the use of quantitative mechanical performance debits for both as-built and HIP'ed thin-walled components and components with narrow flow channels

Standard transition phase has defined in both projects – multiple work items has been registered

New Project Call Mechanism

New Call for Projects (CFP) mechanism allowing <u>non-AM CoE partners to receive support to conduct targeted R&D projects</u>

- **Objectives**
  - Allow the AM community to participate in Research to Standardization initiative
  - Evaluate the possibility of bringing on additional partners to the AM CoE team, to further accelerate standard development in AM

PROPOSAL DUE	NOVEMBER 24, 2020
SELECTION ANNOUNCEMENT	JANUARY 2021
ANTICIPATED START DATE	MARCH 2021

Review by F42.90.05 (Research and Innovation) is in progress

Research & Development

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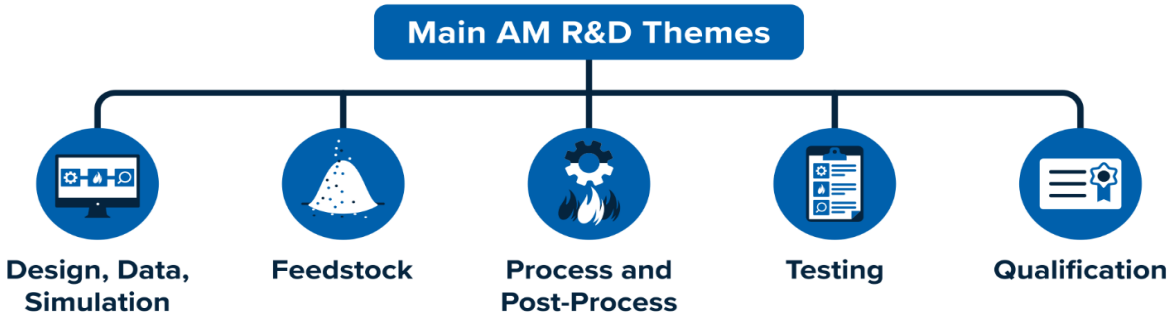
Public R&D Roadmap Objectives

- Communicate the **goals and current progress** of the AM CoE's R&D program
- Provide a **common vision for AM R&D's future** for the AM community to work toward



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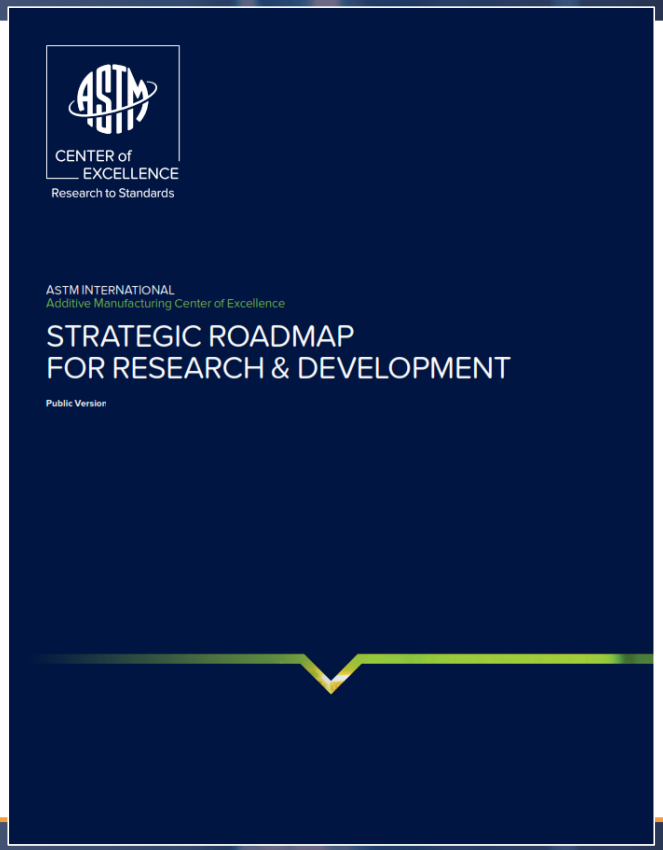

AM Data Management and Schema

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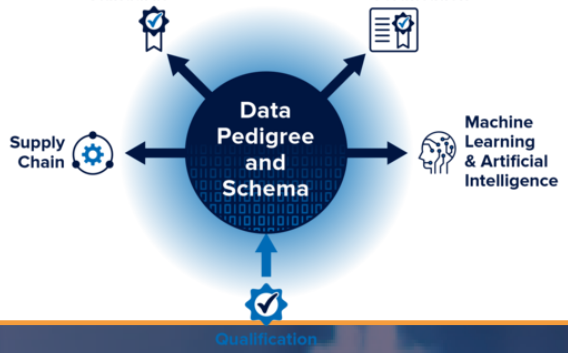
- Collaborative workshop with America Makes
- Workshop held December 2019
- Two-day event: 20 technical talks, panel, roadmapping session
- Objective:
  - Identify challenges, gaps, and pain points
  - Discuss solutions
  - Build a momentum

- **Gaps and Challenges**: Participants brainstormed gaps and challenges in small groups and voted on the highest priorities for the AM community.
- **Potential Solutions:** Participants brainstormed solutions to the priority gaps and challenges from the previous exercise and again voted on the highest priority solutions for the AM community.
- **Detailed Action Plans:** Participants worked in small groups to develop detailed action plans for the highest priority solutions by identifying major tasks, milestones, stakeholder roles, and resource requirements.



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Data - Highest Rated Gaps

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Data Acquisition

- Potential for manual data entry to lead to human error

Data Security

- Data traceability/integrity/provenance
- Protection of intellectual property (IP) during data sharing

Data Practices

- Minimum viable data packages
- Common terms and semantics for data definition

Data Management

- The need for unique, unified data identifiers (e.g., bar codes, alphanumeric tags, etc.) for AM data

Data Use

- Correlating data to part performance
- Format or presentation mode of data

37 Gaps

- **Formation of F42.08:** Sub-committee dedicated to data
- **ASTM WK72172:** New Practice for Additive manufacturing -- General principles -- Overview of data pedigree
  - The standard identifies classes of AM data (buckets), important terms for data that fit within those buckets, and relationships that exist between the buckets.
  - Balloting completed, negative comments are being addressed (Tech contact: Yan Lu, NIST)
- **Common Data Exchange Format (CDEF)**
  - Facilitates data sharing among data management systems, Will be registered in Nov. 2020 (Lead org: EWI)
- **ASTM WK73978:** New Specification for Additive Manufacturing - Data Registration
  - This standard practice comprises actions that users need take to register datasets and store them in a repository.
- Several other data related activities at F42 ISO/ASTM joint groups such as JG64, JG67, JG70, JG7

Highest Rated Action Plans

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- Summarized gaps and challenges with respect to Data in AM, and provided solutions and action plans

Common Data Dictionary (Underway: WK72172)
To standardize data elements that are collected during an AM process

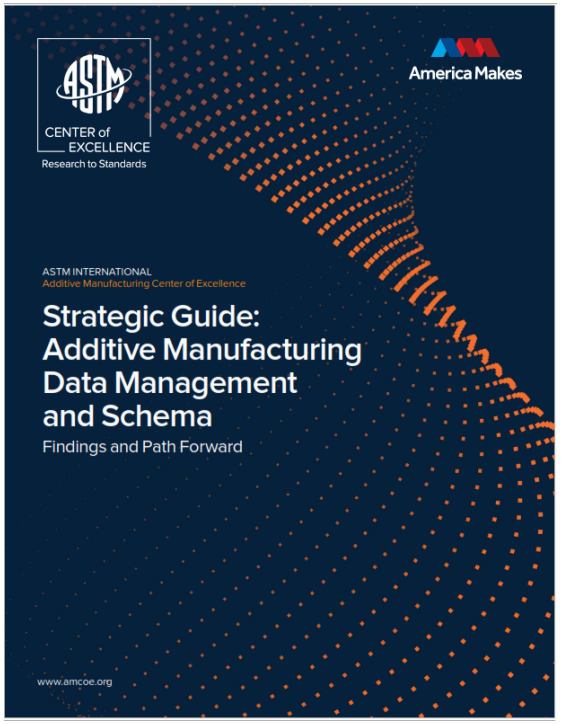
Common Data Exchange Format (Underway: work item to be registered next month)
A neutral and open data format that simplifies data exchange between data management systems that have built the appropriate translators.

Automated Data Acquisition
To reduce human error, and enable application of advanced analytics

Minimum Viable Datable Package
To correlate key AM variables to part performance

Public Use Cases
To understand the ROI of the AM Data Ecosystem (Qual./Cert., Supply Chain, R&D)


Executive Summary

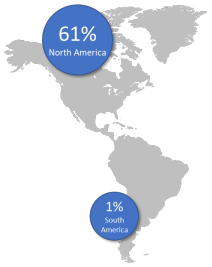


Download at: https://amcoe.org/rd-publications

Other Initiatives/Activities

In-Process Monitoring Project

- Assessment of State-of-the-Art of In-Process Control and In-Situ Monitoring for Additive Manufacturing
  - Conducted literature review of available monitoring technique
  - Evaluated TRL/MRL level
  - Conducted survey (20+ experts in North America and Europe)
  - Report to be published for public before end of the year



- Data structure a primary concern
  - High spatial resolution sensor data produces very large volumes of data
  - Real time data processing is challenging and expensive
  - Parameterization reduces data volume for analysis and storage, but loses fidelity
  - Variation between companies constrains development of universal acceptance criteria
  - Standardization of data simplification will be necessary for allowance in certification/qualification

Clearance from NASA to publish Soon.

Other Initiatives/Activities

NASA-ASTM Cooperative Agreement

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- This cooperative agreement will be the basis to expand the AM CoE and NASA's evolving partnership
  - Three-year contract
  - Formalize collaboration aimed at supporting projects identified by NASA for the AM CoE execution
- First project
  - Qualification framework for laser beam powder bed fusion (LB-PBF) AM processes
    - One of the largest impediments to the growing implementation of AM into many applications.
    - Need to standardize process qualification that ultimately contribute to robust data generation, collection and specification

NASA

ASTM INTERNATIONAL

Other Initiatives/Activities

AM Cyber Security Training Project

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- America Makes Open Project Call
  - ASTM and Auburn University: AM Cyber Security training
- Security is a critical gap for digital manufacturing-related technologies
- The contribution ensures the creation of new curricula and programs to train the AM industry in the subject and help ensure the integrity and security of the entire value chain

America Makes

ASTM INTERNATIONAL

ASTM ICAM 2020: 5th event in a row

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18 Symposium topics linked to ASTM technical committees

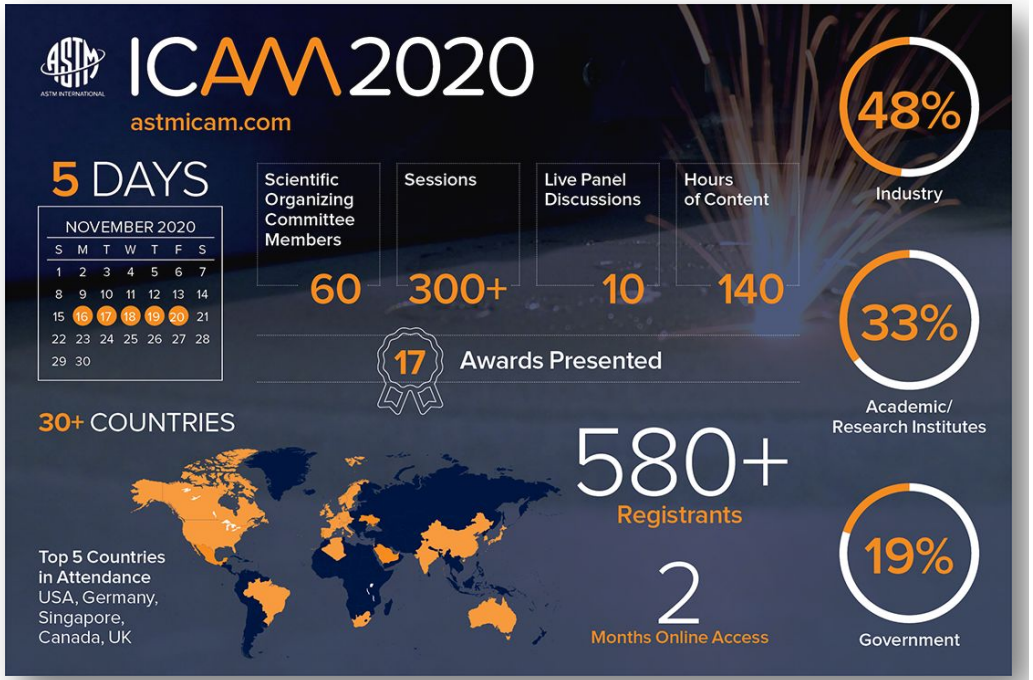
1. Structural Integrity
2. i4.0
3. Feedstock
4. Microstructure
5. NDE
6. In-Situ Monitoring/Control
7. Fatigue
8. Mechanical testing
9. General topics
10. Ceramics
11. Polymers

11
AM related topics

+Nuclear /Energy?

7
Application topics

1. Construction
2. Maritime and Oil & Gas
3. Electronics
4. Medical
5. Aviation and Spaceflight
6. Transportation/Heavy Machinery
7. Defense



ASTM Perspective on AM Standardization

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- AM technologies continue to rapidly evolve across several industry sectors
  - We continue to see evolution of applications in the energy sector including nuclear, renewables, oil/gas, etc.
- ASTM continues to support closure of standardization gaps by relying on key roadmaps, industry needs, coordination, etc.
- We believe in developing agile and innovative solutions as the needs of industry continue to evolve
- Opportunities exist to accelerate standardization
  - Role of government agencies by defining standard deliverables in project calls is key
  - ASTM will actively participate in research to standardization projects
- No need to reinvent the wheel and duplicate efforts
- ASTM continues to collaborate and coordinate with other active bodies and open to new collaborations (example is interaction with ISO)
- Ultimately, what drives the industry forward in terms of implementation is the quality and utility of the standards that are coming out

Q&A

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Thank you for your attention!

Dr. Mohsen Seifi
mseifi@astm.org
www.amcoe.org

Appendix

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- List of standards from ASTM and ISO

List of Published standards (As of 07/2020)

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Research to Standards
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15 Standards published by ASTM Only

ASTM F2971-13	Standard Practice for Reporting Data for Test Specimens Prepared by Additive Manufacturing
ASTM F3049-14	Standard Guide for Characterizing Properties of Metal Powders Used for Additive Manufacturing Processes
ASTM F3001-14	Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium ELI (Extra Low Interstitial) with Powder Bed Fusion
ASTM F3091/F3091M-14	Standard Specification for Powder Bed Fusion of Plastic Materials
ASTM F3122-14	Standard Guide for Evaluating Mechanical Properties of Metal Materials Made via Additive Manufacturing Processes
ASTM F2924-14	Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium with Powder Bed Fusion
ASTM F3056-14e1	Standard Specification for Additive Manufacturing Nickel Alloy (UNS N06625) with Powder Bed Fusion
ASTM F3055-14a	Standard Specification for Additive Manufacturing Nickel Alloy (UNS N07718) with Powder Bed Fusion
ASTM F3184-16	Standard Specification for Additive Manufacturing Stainless Steel Alloy (UNS S31603) with Powder Bed Fusion
ASTM F3187-16	Standard Guide for Directed Energy Deposition of Metals
ASTM F3213-17	Standard for Additive Manufacturing — Finished Part Properties — Standard Specification for Cobalt-28 Chromium-6 Molybdenum via Powder Bed Fusion
ASTM F3302-18	Standard for Additive Manufacturing — Finished Part Properties — Standard Specification for Titanium Alloys via Powder Bed Fusion
ASTM F3318-18	Standard for Additive Manufacturing — Finished Part Properties — Specification for AlSi10Mg with Powder Bed Fusion — Laser Beam
ASTM F3301-18a	Standard for Additive Manufacturing — Post Processing Methods — Standard Specification for Thermal Post-Processing Metal Parts Made Via Powder Bed Fusion1, 2
ASTM F3335-20	Standard Guide for Assessing the Removal of Additive Manufacturing Residues in Medical Devices Fabricated by Powder Bed Fusion

10 Standards published by ISO/ASTM

ISO/ASTM52900-15	Standard Terminology for Additive Manufacturing — General Principles — Terminology1, 2
ISO/ASTM52901-16	Standard Guide for Additive Manufacturing — General Principles — Requirements for Purchased AM Parts
ISO/ASTM52915-16	Standard Specification for Additive Manufacturing File Format (AMF) Version 1.
ISO/ASTM52910-18	Additive manufacturing — Design — Requirements, guidelines and recommendations
ISO/ASTM52902-19	Additive manufacturing — Test artifacts — Geometric capability assessment of additive manufacturing systems
ISO/ASTM52921-13(2019)	Standard Terminology for Additive Manufacturing—Coordinate Systems and Test Methodologies
ISO/ASTM52907-19	Additive manufacturing — Feedstock materials — Methods to characterize metallic powders
ISO/ASTM52911-1-19	Additive manufacturing — Design — Part 1: Laser-based powder bed fusion of metals
ISO/ASTM52911-2-19	Additive manufacturing — Design — Part 2: Laser-based powder bed fusion of polymers
ISO/ASTM52904-19	Additive Manufacturing — Process Characteristics and Performance: Practice for Metal Powder Bed Fusion Process to Meet Critical Applications

4 Standards published by ISO

ISO 17296-2:2015	Additive manufacturing — General principles — Part 2: Overview of process categories and feedstock
ISO 17296-3:2014	Additive manufacturing — General principles — Part 3: Main characteristics and corresponding test methods
ISO 17296-4:2014	Additive manufacturing — General principles — Part 4: Overview of data processing
ISO 27547-1:2010	Plastics — Preparation of test specimens of thermoplastic materials using mouldless technologies — Part 1: General principles, and laser sintering of test specimens

List of Under Development standards (continued)

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20 Standards currently under development: ASTM

ASTM WK66029	New Guide for Mechanical Testing of Polymer Additively Manufactured Materials
ASTM WK66030	Quality Assessment of Metal Powder Feedstock Characterization Data for Additive Manufacturing
ASTM WK67454	Additive manufacturing -- Feedstock materials -- Methods to characterize metallic powders
ASTM WK69371	Standard practice for generating mechanical performance debits
ASTM WK69731	New Guide for Additive Manufacturing -- Non-Destructive Testing (NDT) for Use in Directed Energy Deposition (DED) Additive Manufacturing Processes
ASTM WK71391	Additive Manufacturing -- Static Properties for Polymer AM (Continuation)
ASTM WK71393	Additive manufacturing -- assessment of powder spreadability for powder bed fusion (PBF) processes
ASTM WK71395	Additive manufacturing -- accelerated quality inspection of build health for laser beam powder bed fusion process
ASTM WK48549	AMF Support for Solid Modeling: Voxel Information, Constructive Solid Geometry Representations and Solid Texturing
ASTM WK72172	Additive manufacturing -- General principles -- Overview of data pedigree
ASTM WK65937	Additive Manufacturing -- Space Application -- Flight Hardware made by Laser Beam Powder Bed Fusion Process
ASTM WK69730	Additive Manufacturing -- Wire for Directed Energy Deposition (DED) Processes in Additive Manufacturing
ASTM WK69732	Additive Manufacturing -- Wire Arc Additive Manufacturing
ASTM WK72317	Additive Manufacturing -- Powder Bed Fusion -- Multiple Energy Sources
ASTM WK72457	Additive manufacturing processes -- Laser sintering of polymer parts/laser-based powder bed fusion of polymer parts -- Qualification of materials
ASTM WK66637	Additive Manufacturing -- Finished Part Properties -- Specification for 4340 Steel via Laser Beam Powder Bed Fusion for Transportation and Heavy Equipment Industries
ASTM WK67583	Additive Manufacturing -- Feedstock Materials -- Powder Reuse Schema in Powder Bed Fusion Processes for Medical Applications
ASTM WK70164	Additive Manufacturing -- Finished Part Properties -- Standard Practice for Assigning Part Classifications for Metallic Materials
ASTM WK71891	Additive Manufacturing of Titanium-6 Aluminum-4 Vanadium ELI (Extra Low Interstitial) with Powder Bed Fusion for Medical Devices
ASTM WK66682	Evaluating Post-processing and Characterization Techniques for AM Part Surfaces

List of standards (continued)

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Research to Standards
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45 Standards currently under development: ISO/ASTM

ISO/ASTM 52903-1	Additive manufacturing — Material extrusion-based additive manufacturing of plastic materials — Part 1: Feedstock materials
ISO/ASTM DIS 52903-2	Additive manufacturing — Standard specification for material extrusion based additive manufacturing of plastic materials — Part 2: Process — Equipment
ISO/ASTM DTR 52905	Additive manufacturing — General principles — Non-destructive testing of additive manufactured products
ISO/ASTM CD TR 52906	Additive manufacturing — Non-destructive testing and evaluation — Standard guideline for intentionally seeding flaws in parts
ISO/ASTM AWI 52908	Additive manufacturing — Post-processing methods — Standard specification for quality assurance and post processing of powder bed fusion metallic parts
ISO/ASTM AWI 52909	Additive manufacturing — Finished part properties — Orientation and location dependence of mechanical properties for metal powder bed fusion
ISO/ASTM PWI 52911-3	Additive manufacturing -- Technical design guideline for powder bed fusion -- Part 3: Standard guideline for electron-based powder bed fusion of metals
ISO/ASTM PRF TR 52912	Additive manufacturing - Design - Functionally graded additive manufacturing
ISO/ASTM PWI 52913-1	Additive manufacturing -- Test methods for characterization of powder flow properties for AM applications - Part 1: General requirements
ISO/ASTM PWI 52914	Additive manufacturing -- Design -- Standard guide for material extrusion processes
ISO/ASTM WD 52916	Additive manufacturing — Data formats — Standard specification for optimized medical image data
ISO/ASTM WD 52917	Additive manufacturing — Round Robin Testing — Guidance for conducting Round Robin studies
ISO/ASTM CD TR 52918	Additive manufacturing — Data formats — File format support, ecosystem and evolutions
ISO/ASTM WD 52919-1	Additive manufacturing — Test method of sand mold for metalcasting — Part 1: Mechanical properties
ISO/ASTM WD 52919-2	Additive manufacturing — Test method of sand mold for metalcasting — Part 2: Physical properties
ISO/ASTM PWI 52920-1	Additive manufacturing — Qualification principles — Part 1: Conformity assessment for AM system in industrial use
ISO/ASTM WD 52920-2	Additive manufacturing — Qualification principles — Part 2: Requirements for industrial additive manufacturing sites
ISO/ASTM DIS 52921	Additive manufacturing — General principles — Standard practice for part positioning, coordinates and orientation
ISO/ASTM PWI 52922	Additive manufacturing -- Design -- Directed energy deposition
ISO/ASTM PWI 52923	Additive manufacturing -- Design decision support
ISO/ASTM DIS 52924	Additive manufacturing — Qualification principles — Classification of part properties for additive manufacturing of polymer parts
ISO/ASTM DIS 52925	Additive manufacturing — Qualification principles — Qualification of polymer materials for powder bed fusion using a laser
ISO/ASTM WD 52926-1	Additive manufacturing — Qualification principles — Part 1: Qualification of machine operators for metallic parts production
ISO/ASTM WD 52926-2	Additive manufacturing — Qualification principles — Part 2: Qualification of machine operators for metallic parts production for PBF-LB
ISO/ASTM WD 52926-3	Additive manufacturing — Qualification principles — Part 3: Qualification of machine operators for metallic parts production for PBF-EB
ISO/ASTM WD 52926-4	Additive manufacturing — Qualification principles — Part 4: Qualification of machine operators for metallic parts production for DED-LB
ISO/ASTM WD 52926-5	Additive manufacturing — Qualification principles — Part 5: Qualification of machine operators for metallic parts production for DED-Arc
ISO/ASTM PWI 52927	Additive manufacturing -- Process characteristics and performance - Test methods
ISO/ASTM PWI 52928	Powder life cycle management
ISO/ASTM NP 52930	Guideline for installation -- Operation -- Performance Qualification (IQ/OQ/PQ) of laser-beampowder bed fusion equipment for production manufacturing
ISO/ASTM CD 52931	Additive manufacturing — Environmental health and safety — Standard guideline for use of metallic materials
ISO/ASTM WD 52932	Additive manufacturing — Environmental health and safety — Standard test method for determination of particle emission rates from desktop 3D printers using material extrusion
ISO/ASTM NP 52933	Additive manufacturing — Environment, health and safety — Consideration for the reduction of hazardous substances emitted during the operation of the non-industrial ME type 3D printer in workplaces, and corresponding test method
ISO/ASTM PWI 52934	Additive manufacturing -- Environmental health and safety -- Standard guideline for hazard risk ranking and safety defense
ISO/ASTM NP 52935	Additive manufacturing — Qualification Principles — Qualification of coordinators for metallic parts production
ISO/ASTM WD 52936-1	Additive manufacturing — Qualification principles — Laser-based powder bed fusion of polymers — Part 1: General principles, preparation of test specimens
ISO/ASTM PWI 52937	Additive manufacturing — Qualification principles — Qualification of designers for metallic parts production
ISO/ASTM DIS 52941	Additive manufacturing — System performance and reliability — Standard test method for acceptance of powder-bed fusion machines for metallic materials for aerospace application
ISO/ASTM DIS 52942	Additive manufacturing — Qualification principles — Qualifying machine operators of laser metal powder bed fusion machines and equipment used in aerospace applications
ISO/ASTM PWI 52943-1	Additive manufacturing -- Process characteristics and performance -- Part 1: Standard specification for directed energy deposition using wire and beam in aerospace applications
ISO/ASTM PWI 52943-2	Additive manufacturing -- Process characteristics and performance -- Part 2: Standard specification for directed energy deposition using wire and arc in aerospace applications
ISO/ASTM PWI 52943-3	Additive manufacturing -- Process characteristics and performance -- Part 3: Standard specification for directed energy deposition using laser blown powder in aerospace applications
ISO/ASTM PWI 52944	Additive manufacturing -- Process characteristics and performance -- Standard specification for powder bed processes in aerospace applications
ISO/ASTM DIS 52950	Additive manufacturing — General principles — Overview of data processing
ISO/ASTM PWI 52951	Additive manufacturing -- Data packages for AM parts