April 2021 Progress Report on AMSC Roadmap v2 Gaps

The America Makes and ANSI Additive Manufacturing Standardization Collaborative (AMSC) is tracking progress by standards developing organizations (SDOs) and others to address the gaps identified in the AMSC's *Standardization Roadmap for Additive Manufacturing* (Version 2.0, June 2018). The updates provided in this progress report were derived from various sources: direct inputs from SDO staff and subject matter experts (with attribution), SDO alert mechanisms, and independent research by ANSI staff based on publicly available SDO work programmes and other information. As such, this report should not be viewed as a consensus document and it does not necessarily reflect the views of the individuals or organizations named. It is intended to be a "living document" that will be maintained and periodically re-published as standards development work continues, until such time as the AMSC undertakes to develop a next version of its standardization roadmap. Margin comments and suggested edits to the gaps are left in intentionally to be addressed at that time.

Click on any of the roadmap gap titles below for the most recent updates (highlighted and dated) since the last progress report was published (10/17/2019). You will see fields for updates since roadmap version 2 was published, new published standards, and new in-development standards. In some cases, staff has determined that a published standard or in-development standard may be responsive to an identified v2 gap(s) or topical area based on the standard's title/abstract. In other cases, staff was unable to make such a determination and, in such cases, the standard is listed at the end of a chapter.

Updates, corrections, and suggested edits should be sent to amsc@ansi.org.

Navigational links:

- Control + click in table of contents takes you to the chapter list of gaps
- Control + click in the chapter list of gaps (organized by high, medium, low priority) takes you to the gap
- Control + click on a gap takes you to the chapter list of gaps
- Control + click on "back to top" takes you to the top of the document

Table of Contents

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Chapter 2.1. Design

High Priority

Medium Priority

Low Priority

Back to Top

Gap D1: Decision Support: Additive vs. Subtractive. Currently there is no standard that helps users understand the advantages/disadvantages of AM processes versus traditional manufacturing processes while also providing decision criteria so informed design/manufacturing decisions can be made.
R&D Needed: TBD
Recommendation: Develop a guideline that helps understand trade-offs between AM processes and traditional processes (e.g., sacrifice design freedom for greater certainty of established processes in terms of material properties, reliability, etc.).
Priority: Medium
Organization: ISO/ASTM, AWS, SAE, SME
v2 Status of Progress: Green (SME) in terms of a tool providing general guidance, though not a standard
v2 Update: No standards are planned or in development. Commercial tools are available. SME and its ITEAM (Independent Technical Evaluation of Additive Manufacturing) are developing the RAPID Additive Manufacturing Platform (RAMP). The Additive Manufacturing Equipment and Materials Repository, a core aspect of RAMP, was released in beta, with beta testing continuing during the summer of 2018. The SAM-CT demo evaluation application will utilize RAMP. Application providers are being encouraged to develop additional additive manufacturing evaluation applications.
Updates Since v2 was Published: **11/13/2020, MW**: Steve Weinman, ASME, comment: ASME is forming a Working Group on Practical Guide to Engineers for AM - all applications available to them. Exploration of capabilities, feature identification, Software identification and more.

New Published Standards	New In-Development Standards
	3/31/2021, JM: Per presentation by David Rosen, ASTM F42/ISO/TC 261 JG54: ASTM WK64190, *Additive Manufacturing Design - Decision Guide*

Back to Top

Gap D2: Decision Support: Additive Processes. The version 1.0 gap stated that there is no standard that normalizes the characteristics of the general AM process and ranks the pros/cons or strengths/weaknesses of each process, allowing users to make informed decisions about which AM process best suits their need. In 2017, ISO/ASTM published ISO/ASTM 52910-17, *Standard Guidelines for Design for Additive Manufacturing* (work item previously known as ASTM WK38342). The standard briefly addresses AM process selection, providing an example of a high-level diagram and with section 6.8.2, specific process considerations. However, additional standards may be needed to address trade-off criteria between processes.
R&D Needed: Yes. R&D is needed to identify trade-off criteria.
Recommendation: Continue work to complement what has been published in ISO/ASTM 52910:2017. Focus on identification of trade-off criteria between processes. There is still a need to develop a standard for reporting process inputs and capabilities.
Priority: Medium
Organization: National labs and government agencies for the R&D. ISO/TC 261 & ASTM F42 for the standards work.
v2 Status of Progress: Green. Gap partially closed in relation to standards with the publication of ISO/ASTM 52910-17.
v2 Update: The gap statement and recommendation have been updated in light of the publication of ISO/ASTM 52910-17.
Updates Since v2 was Published:

New Published Standards	New In-Development Standards
10/17/2019, LY: Paul Witherell, NIST, comment: Updated release of ISO/ASTM 52910-18, *Additive manufacturing — Design — Requirements, guidelines and recommendations*.	**3/31/2021, JM:** Per presentation by David Rosen, ASTM F42/ISO/TC 261 JG54: ASTM WK64190, *Additive Manufacturing Design - Decision Guide* **10/17/2019, LY**: Paul Witherell, NIST, comment: ISO TC261/ASTM F42 JG54 is in development of PWI 52923 Additive Manufacturing - Design Decision Support to provide support for process selection, including the identification of trade-off criteria.

Commented [A1]: Text changes needed based on publication of 2018 version?

Commented [A2]: 3/31/2021, JM: Mentioned in David Rosen presentation is **Standard Guide for Principles of Design Rules for AM WK54586**

Commented [A3]: 3/31/2021, JM: P. Witherell presentation refers to this as Data Packages for AM Parts — PWI 52923

[Back to Top]

<table>
<tr><td colspan="2">Gap D3: Process-Specific Design Guidelines. There are no available AM process-specific design guidelines. The design guidelines currently being developed by JG57 are process-specific design guidelines under joint development by ASTM F42 and ISO/TC 261. ASTM and ISO identify 7 types of AM processes, meaning that 6 AM processes do not have guidelines under development.</td></tr>
<tr><td colspan="2">R&D Needed: No, for the guidelines on PBF. Not yet determined for the other six processes.</td></tr>
<tr><td colspan="2">Recommendation: Complete work on the ISO/ASTM JG57 design guidelines for PBF. Develop guidelines for the six other AM processes defined in ISO/ASTM 52900:2015, Additive manufacturing -- General principles – Terminology.</td></tr>
<tr><td colspan="2">Priority: Medium</td></tr>
<tr><td colspan="2">Organization: insert text editable by staff only</td></tr>
<tr><td colspan="2">v2 Status of Progress: Green (ISO/ASTM) for PBF. Green (AWS) for PBF and DED. Not Started for the other processes defined in ISO/ASTM 52900.</td></tr>
<tr><td colspan="2">v2 Update: As noted in the text, ISO/ASTM JG57 design guidelines are being developed for PBF-L for metals and polymers. Work on electron beam continues. ~~AWS D20.1 will address PBF and DED, as noted in the text.~~</td></tr>
<tr><td colspan="2">Updates Since v2 was Published:
8/5/2020, MW: ASTM AMCOE Strategic Roadmap for Research & Development (April 2020) notes that AMCOE Project 1905 (WK62867, F3413-19 (WK62946) addresses AMSC Gap D3.
3/17/2020, JM: Jessica Coughlin, AWS D20, comments: “AWS D20.1 does have a design clause, but I'm not sure it lines up with the intentions of this gap. It does not provide any guidance on how to design parts for AM fabrication. Rather, it discusses mechanical property design values, provides requirements for including witness specimens in the build model, and lists the items that the Engineer must specify to the Contractor.”</td></tr>
<tr><td>New Published Standards
4/6/2020, JM: ASTM F3413-19, Guide for Additive Manufacturing — Design — Directed Energy Deposition has been published.
10/17/2019, LY: Paul Witherell, NIST, comment: JG57 standards have been published as:
ISO/ASTM 52911-1-19, Additive manufacturing — Design — Part 1: Laser-based powder bed fusion of metals has been published.
ISO/ASTM 52911-2-19, Additive manufacturing — Design — Part 2: Laser-based powder bed fusion of polymers has been published.</td><td>New In-Development Standards
3/31/2021, JM: Per presentation by David Rosen, ASTM F42/ISO/TC 261: JG57, WK62876, WK62946
8/21/2020, JM: ISO/ASTM DIS 52900, Additive manufacturing — General principles — Fundamentals and vocabulary is being revised.
8/19/2020, JM:
ASTM WK62867, Additive Manufacturing - General Principles - Guide for Design for Material Extrusion Processes
ASTM WK72938, Additive manufacturing -- Design -- Part 3: Electron-based powder bed fusion of metals
ASTM WK69732, Additive Manufacturing -- Wire Arc Additive Manufacturing</td></tr>
</table>

Commented [A4]: 4/2/2021, JM: Added per 12/09/20 NRC presentation by Mohsen Seifi.

Commented [A5]: 3/31/2021, JM: D. Rosen presentation also refers to as (ISO 52922)

Commented [A6]: 3/31/2021, JM: These are not yet listed on ISO or ASTM websites.

Commented [A7]: 3/31/2021, JM, JG55? Another work item listed in D. Rosen presentation: **Guide for Design for Binder Jetting**
Began in 2020. Is this ISO/ASTM PWI 52914 referenced in 12/09/20 presentation by Mohsen Seifi? Not on ISO's website.

Commented [A8]: **3/31/2021, JM:** Is this the same as what is listed in D Rosen presentation as ISO/ASTM AWI 52911-3, Additive Manufacturing — Design — Part 3: Electron beam powder bed fusion of metals?

[Back to Top]

Gap D4: Design Guides for Specific Applications. As industry fields mature in particular AM applications, best practices should be recorded.
R&D Needed: TBD
Recommendation: It is recommended that any application-specific design guides extend available process-independent and process-specific design guides. However, application-specific design guidelines may also need to be developed by their respective communities, and in such cases these guidelines may fall under respective societies or SDOs. For instance, a design guideline for printed electronics may be best suited for an organization such as IEEE or IPC.
Priority: High
Organization: ASME, SAE, ASTM F42/ISO TC 261, and potentially other SDOs et al. (e.g., manufacturers, industry consortia)
v2 Status of Progress: Green
v2 Update: ASME is working on design guides for pressure retaining equipment (e.g., pressure vessels). Other SDOs need to consult with their committees. Some of the SAE process specifications may address this.
Updates Since v2 was Published:

3/31/2021, JM: Per presentation by David Rosen, ASTM F42/ISO/TC 261: No applications specified. Medical? **11/13/2020, MW**: Steve Weinman, ASME, comment: For the ASME draft specification for pressure retaining metallic components using additive manufacturing the construction method used is powder bed fusion additive manufacturing. Both laser beam and electron beam energy sources are permitted by this guideline. Hybrid construction incorporating AM components joined (welded or brazed) to non-AM components is acceptable. Design and fabrication of additive manufactured components joined to other AM components or non-AM components would follow the requirements for the applicable ASME construction code or standard. The Additive Manufacturer and the Powder Supplier maintain a quality program as defined by the construction code. The latest draft of the proposed Criteria will be distributed shortly for review and comment by the Special Committee, and a Peer Review Group. The target date for publication as an ASME product is December 31, 2020. **4/9/2020, MW:** Steve Weinman, ASME, comment: An ASME Special Committee is reviewing a draft specification for pressure retaining metallic components using additive manufacturing. The construction method used is powder bed fusion additive manufacturing, but laser beam and electron beam processes are also included. ASME Code parts to be joined to additive manufactured parts will follow the requirements for the appropriate ASME construction code for the applicable scope. Use of material in the creep regime will not be permitted. It is anticipated that this guideline will serve as the technical baseline to support development of proposed Code Cases for Boiler and Pressure Vessel Section III and VIII construction using AM. **10/17/2019, LY:** Paul Witherell, NIST, comment: ASTM F42.07 Applications has been formed to begin to address application-specific needs, including design.

New Published Standards	**New In-Development Standards**
	3/31/2021, JM: Per presentation by George Rawls, the ASME Special Committee has produced a final draft document providing Criteria for Pressure Retaining Metallic Components Using Additive Manufacturing. The intent is to publish this as a Pressure Technology Book (PTB) for use as a reference document for additive manufacturing Code Cases or incorporation of additive manufacturing into construction codes. ASME has submitted a Project Initiation Notification with ANSI stating that they will develop a standard for additively manufactured pressure equipment. Section V is developing a new article for the 2021 edition for computed tomography. Savannah River National Lab has started a collaborative project with the University of Michigan to evaluate fatigue design criteria for additively manufactured pressure equipment.

Back to Top

Gap D5: Support for Customizable Guidelines. Producing the same part on different machines from different manufacturers and often the same manufacturer will return different results. While process and application guidelines will provide meaningful insight, additional tailoring may be needed for specific instantiations. Guidelines on how to extend process and application guidelines would allow users to further adapt and specify to fit individual needs.
R&D Needed: Yes. Customizable guidelines require understanding process/machine/design characteristics and subsequent tradeoffs.
Recommendation: As machines are benchmarked and calibrated (see Gap PC2), designers should have mechanisms available to them that will provide operational constraints on their available AM processes. Designers should understand what geometric and process liberties might be taken for their particular implementation.
Priority: Medium
Organization: ISO/ASTM
v2 Status of Progress: Green
v2 Update: ASTM WK54856, *New Guide for Principles of Design Rules in Additive Manufacturing*, has an expected release date of late 2018/early 2019.
Updates Since v2 was Published: **3/31/2021, JM:** Per presentation by David Rosen, ASTM F42/ISO/TC 261: Operational guidance for specific parts? **10/17/2019, LY**: Paul Witherell, NIST, comment: Expected release date of Early 2020.

Commented [A9]: Has this been published? See also Gap D6

New Published Standards	New In-Development Standards

Back to Top

Gap D6: Software-encodable/Machine-readable Guidelines. In addition to design guidelines, complementary efforts have been initiated under ASTM Committee F42 on Additive Manufacturing Technologies (F42) to support the development of standardized design rules. Guidelines that are in development rely heavily on graphics/drawings and narrative through natural language, leaving often subjective interpretations. ASTM WK54856, *New Guide for Principles of Design Rules in Additive Manufacturing,* under development in ASTM F42, aims to provide explicit constructs from which explicit design rules can be developed and customized. These constructs will also provide a machine interpretable language that will support software implementation. The standard has an expected release date of late 2018/early 2019.
R&D Needed: Yes. The identification of fundamental constructs should mirror key characteristics and decision criteria for designs, materials, and processes.
Recommendation: Standardize a language that can be interpreted by both humans and machines so that design for AM can be simplified and communicated across platforms, and constraints can be encoded into design software.
Priority: Medium
Organization: ASTM, ISO, ASME, IEEE-ISTO PWG
v2 Status of Progress: Green
v2 Update: This gap is being addressed by ASTM WK54856.
Updates Since v2 was Published:

New Published Standards	New In-Development Standards
	3/31/2021, JM: Per presentation by David Rosen, ASTM F42/ISO/TC 261: WK54856 is start

Commented [A10]: Has this been published?

Back to Top

Gap D7: Design Guide for Post-processing. There is a need for a design guide for post-processing.
R&D Needed: Yes.
Recommendation: Develop a design guide for post processing
Priority: Medium
Organization: ASME B46, ASTM F42/ISO TC 261
v2 Status of Progress: Not Started
v2 Update: ASME is not working on a design guide but ASME B46 Committee is working on measurement and characterization methods for AM surface finish. ISO/ASTM 52910-17, *Standard Guidelines for Design for Additive Manufacturing* has been published and includes a high-level discussion of design considerations for post-processing but more detailed design guides addressing specific AM processes, materials, and applications are needed.
Updates Since v2 was Published: **3/31/2021, JM:** Per presentation by David Rosen, ASTM F42/ISO/TC 261: ASTM COE project **8/5/2020, MW**: ASTM AMCOE *Strategic Roadmap for Research & Development* (April 2020) notes that AMCOE Projects 1802 (WK66682) and 1904 (WK73444) address AMSC Gap D7.

New Published Standards	New In-Development Standards
	3/31/2021, JM: NRC presentation of 12/09/20 by Mohsen Seifi noted these ASTM work items: ASTM WK66682, *Evaluating Post-processing and Characterization Techniques for AM Part Surfaces* ASTM WK73444, *Additive Manufacturing -- Design -- Post-Processing*

Commented [A11]: An updated release was published in 2018 ISO/ASTM 52910-18, *Additive manufacturing — Design — Requirements, guidelines and recommendations*.. Does it apply or should the reference be removed given the specific new work item on design for post-processing.?

Back to Top

Gap D8: Machine Input and Capability Report. A standard for reporting machine input requirements and the associated AM machine capabilities is required to support new design tools which will be able to determine

manufacturing feasibility, optimize manufacturing solutions, and identify AM equipment which would be able to manufacture the part.
R&D Needed: No
Recommendation: Develop a standard for reporting machine inputs such as printing parameters, laser track, etc. and machine capabilities such as dimensional accuracy, surface finish, material properties, geometry constraints (over hang angle requirements), size, porosity, etc. These reports would be used by software to accomplish the following: 1. Topology Optimization 2. Optimize manufacturing solutions 3. Identification of suitable AM equipment 4. Build Simulation 5. Lattice structure generation 6. Spatial comparisons (e.g., common standard grid) See also Gap D20 on neutral build format.
Priority: Medium
Organization: Consortium of industry, ISO/ASTM, IEEE-ISTO PWG
v2 Status of Progress: Not Started
v2 Update: ASTM has a guide for storage of technical build cycle data which may address some of this.
Updates Since v2 was Published:

New Published Standards	**New In-Development Standards**
	3/31/2021, JM: Per presentation by David Rosen, ASTM F42/ISO/TC 261: JG73 is start; Good idea, but detailed info?

Commented [A12]: 3/31/2021, JM: Paul Witherell presentation refers to JG73 as digital product definition and data management

Back to Top

Gap D9: AM Simulation Benchmark Model/Part Requirement. A standard for a process-specific AM benchmark model/part is needed to enable verification and validation (V&V) of applicable process simulation tools.
R&D Needed: Yes. R&D is needed for characterizing processes using consistent, measurable and precise techniques.
Recommendation: Develop a standardized design for AM process chain that specifies and integrates the key AM considerations and suggested design tools in each generic design stage. The process chain can be expanded from ISO/ASTM 52910-2017, *Standard Guidelines for Design for Additive Manufacturing* stages and complimented with design tools to address specific AM needs for each task within the stages. The standardized design for AM process chain can be used by various industries to roll out site-specific DFAM process and digitalization implementation.
Priority: Low
Organization: NIST, America Makes, ASME V&V, ISO/ASTM
v2 Status of Progress: Yellow
v2 Update: An AM Bench Consortium led by NIST has been started.
Updates Since v2 was Published: **8/5/2020, MW**: ASTM AMCOE *Strategic Roadmap for Research & Development* (April 2020) notes that AMCOE Project 1801 (ISO/ASTM AWI 52909) addresses AMSC Gap D9. **10/17/2019, LY**: Paul Witherell, NIST, comment: AM Bench 2018 was hosted by NIST. All related data used for testing models and simulation tools can be found here: https://www.nist.gov/ambench and here: https://ammd.nist.gov. A future AM Bench is in planning.

New Published Standards	**New In-Development Standards**
	3/31/2021, JM: NRC presentation of 12/09/20 by Mohsen Seifi noted these ASTM work items: ISO/ASTM AWI 52909, *Additive manufacturing Finished part properties — Orientation and location dependence of mechanical properties for metal powder bed fusion*

Commented [A13]: An updated release was published in 2018 ISO/ASTM 52910-18, *Additive manufacturing — Design — Requirements, guidelines and recommendations*.. Does it apply or should the reference be removed?

Back to Top

Gap D10: Design for As-built Assembly. Guidelines do not exist for AM design for as-built assembly which is the ability of an AM process to create an assembly with multiple parts with relative motion capabilities in a single build.

Design for Manufacture and Assembly (DFMA) practices do not account for considerations of single build AM assemblies and assemblies constructed from individual AM parts. Design approaches may need to account for complexity of support structures, removal times, post-processing complexity, and manufacturing time/quality using different parameter sets. In regard to parameters sets, factors of interest could include feed rate and diameters for Directed Energy Deposition (DED), layer thickness and laser scan speed for PBF. Furthermore, how these all factors interact must also be considered.
R&D Needed: Yes. Additional research is needed related to individual AM part definition, including tolerances, and non-contact measurement and inspection methods for AM assemblies. If AM design for as-built assembly is to become a viable alternative for creating functioning assemblies, there needs to be rigorous academic research, practical pilot projects, and real industry use cases. These are critical elements in identifying the gaps that will result in the tailoring of existing standards and the development of new standards for AM design for as-built assembly.
Recommendation: ISO 8887-1:2017 and other DFMA standards can be reviewed and further developed to address AM related issues.
Priority: Medium
Organization: R&D: Academia, industry, national laboratories. Standards: ISO, ASTM, AAMI, NEMA/MITA
v2 Status of Progress: New
v2 Update: None provided
Updates Since v2 was Published:

New Published Standards	**New In-Development Standards**

Back to Top

Gap D11: Design for 3D Printed Electronics. There is a need to develop standards on design for 3D printed electronics.
R&D Needed: No
Recommendation: Complete work on IPC-2292, *Design Standard for Printed Electronics on Flexible Substrates*.
Priority: Medium
Organization: IPC
v2 Status of Progress: **Closed**, with the publication of IPC 2292
v2 Update: IPC 2292 was published in March 2018. The IPC D-66A, 3D Printed Electronics Processes Task Group is in the early stages of developing a table of contents for a process guideline standard. This activity will take a considerable amount of time because there are so many processes, variables, materials, technologies, equipment, process environments, etc., to consider. With respect to the development of a design standard like IPC-2292, the group is of the view that it is far too early in the maturation of this technology to develop design requirements, but they will revisit this topic at future meetings. See also Gap D4.
Updates Since v2 was Published: **3/31/2021, JM:** Per presentation by David Rosen, ASTM F42/ISO/TC 261: Closed: IPC

New Published Standards	**New In-Development Standards**

Back to Top

Gap D12: Imaging Consistency. There are currently no standard best practices for creation of protocols and validation procedures to ensure that medical imaging data can be consistently and accurately transformed into a 3D printed object. Individual companies have developed internal best practices, training programs and site qualification procedures. The details of a device's individual imaging and validation plan is developed specifically for each process or product. However, a set of consensus best practices for developing these plans and key validation metrics could reduce the overhead in developing them and reduce the burden on imaging sites. This framework should rely on input from clinical experts to ensure that it accounts for and defers to clinical best practices where appropriate.
R&D Needed: No. The information is housed within individual institutions and could be combined through participation in clinical associations, consortiums or standards development organizations.
Recommendation: Develop a set of best practices for the development and qualification of imaging protocols and imaging sites that provide inputs to patient-matched devices. The focus should be on validation metrics and standard reference parts (phantoms) that can either be simple geometric patterns, or more appropriately designed

to mimic the shape and density of natural anatomy so that the fidelity of an imaging sequence can be measured and calibrated.	
Priority: Medium	
Organization: RSNA (Radiological Society of North America), ASTM F42/ISO TC 261 JG70, DICOM	
v2 Status of Progress: Green	
v2 Update: An RSNA 3D Special Interest Group (SIG) is working on best practices, not a standard. ISO/ASTM NP 52916, *Additive manufacturing -- Data formats -- Standard specification for optimized medical image data* from ISO/TC 261 JG70 deals with imaging quality. This is a secondary priority for the DICOM WG.	
Updates Since v2 was Published:	
New Published Standards	**New In-Development Standards** **3/31/2021, JM:** Per presentation by David Rosen, ASTM F42/ISO/TC 261: JG70 (medical imaging) **9/1/2020, MW:** ASTM WK74006, *New Specification for (Additive manufacturing -- Data formats -- Specification for optimized medical image data* **10/17/2019, LY**: Paul Witherell, NIST, comment: ISO/IEC JTC1 WG12 for "3D Printing and Scanning" has been established. The WG is developing a work item "Information Technology— Requirements of Image Processing for covering cranial defect" to address medical image processing.

Back to Top

Gap D13: Image Processing and 2D to 3D Conversion. Data acquired as a stack of 2D images is converted to a 3D model that could be a device by itself or be a template to build the device on. Tissues such as bone, soft tissue and vascular structures are isolated by the process of segmentation. Variability of the output depends on factors such as spatial and grey scale resolution of the images which in turn are driven by other factors such as the x-ray dosage, MRI protocol, operator capability, and reconstruction algorithms. Computational modeling groups, software developers, research laboratories, and the FDA have investigated methods of validating segmentation processes. However, the wide variety of patient geometries, frequent inability to identify a ground truth due to imaging constraints, and variability in the manual aspects of imaging have caused validation procedures to be developed by individual entities.	
R&D Needed: Yes. Data to develop protocols exists but there is still a need for standardized, physiologically relevant imaging phantoms that can be used to challenge many segmentation techniques.	
Recommendation: 1) Develop a standard test method to use biomimetic imaging phantoms to validate a segmentation technique. Round robin testing of this type of test method is highly recommended. Best practices may include capturing enough information to set accurate threshold values and understand geometric norms for a data set of interest. 2) Develop training standards that operators must meet to ensure that they are able to adequately reproduce a validated image processing pipeline.	
Priority: Medium	
Organization: Methods: NEMA/MITA, ASME V&V 40, ASTM F4, ASTM F42/ISO TC 261. Phantoms: NIST, FDA, RSNA	
v2 Status of Progress: Green	
v2 Update: On the R&D side, FDA research groups are developing phantoms but haven't yet interfaced with SDOs. On the standards side, ISO/ASTM NP 52916, *Additive manufacturing -- Data formats -- Standard specification for optimized medical image data* from ISO/TC 261 JG70 covers this gap. An RSNA SIG is also looking at this.	
Updates Since v2 was Published: **3/31/2021, JM:** Per presentation by David Rosen, ASTM F42/ISO/TC 261: ??	
New Published Standards	**New In-Development Standards** **9/1/2020, MW:** ASTM WK74006, *New Specification for (Additive manufacturing -- Data formats -- Specification for optimized medical image data* **10/17/2019, LY**: Paul Witherell, NIST, comment: ISO/IEC JTC1 WG12 for "3D Printing and Scanning" has been established. The WG is developing a work item "Information Technology— Requirements of Image Processing for covering cranial defect" to address medical image processing.

Back to Top

Gap D14: Designing to be Cleaned. Currently there are no design guidelines for medical devices to assure cleanability after production. When designing a medical device, cleanability must be evaluated at different stages for a number of reasons: 1. To ensure manufacturing residues/contact materials encountered during the manufacturing process can be removed 2. To ensure that unmelted/unsintered AM material from the manufacturing process can be removed 3. For devices that are to be sterilized prior to use, to ensure that a sterilization test soil can be placed at the most difficult location to sterilize so that the validation will accurately show if foreign bodies picked up during the manufacturing process can either be killed or removed from the device prior to sterilization 4. For reusable devices, to ensure the device can be adequately cleaned and sterilized prior to subsequent uses 5. For reusable devices, to ensure that the device materials can be maintained for the specified number of cleaning cycles
R&D Needed: Yes, in terms of ways to determine what parts are likely to be cleanable before they are made
Recommendation: Develop design guidelines to provide general design limits and recommendations that achieve both needed surface structure and allow adequate cleaning. See also Gap FMP3 and Gap QC15.
Priority: Medium
Organization: AAMI, ASTM F4, ASTM F42/ISO TC 261, ISO/TC 198, ASME (surface metrology), FDA
v2 Status of Progress: Not Started
v2 Update: AAMI and ASTM have an interest and are meeting. FDA is also looking at this.
Updates Since v2 was Published: **3/31/2021, JM:** Per presentation by David Rosen, ASTM F42/ISO/TC 261: Good idea

New Published Standards	New In-Development Standards
3/31/2021, JM: Per 12/09/20 NRC presentation by Mohsen Seifi, ASTM standards: F3335-20, Standard Guide for Assessing the Removal of Additive Manufacturing Residues in Medical Devices Fabricated by Powder Bed Fusion, developed by F04.15	

Back to Top

Gap D15: Design of Test Coupons. No standards are available for the design of test coupons for additively-manufactured porous structures.
R&D Needed: Yes. Effects on what is in the build and how well can you replicate your feature of interest.
Recommendation: Standards are needed for the design of test coupons for additively-manufactured porous structures.
Priority: Low
Organization: ASTM F4 and F42
v2 Status of Progress: Green
v2 Update: ASTM F4 is looking at this.
Updates Since v2 was Published: **4/9/2020, MW:** Steve Weinman, ASME, comment: On the R&D side, FDA research groups are developing phantoms but haven't yet interfaced with SDOs. ASME V&V 40 Subcommittee on Verification and Validation in Computational Modeling of Medical Devices is working to form a working group on this item.

New Published Standards	New In-Development Standards

Back to Top

Gap D16: Verifying Functionally Graded Materials (FGM). Functionally graded materials are materials with variation in the composition or structure in order to vary the material properties (e.g., stiffness, density, thermal conductivity, etc.). Standard methods of specifying and verifying functionally graded materials currently do not exist. Furthermore, there are no guidelines on considerations when validating their performance.
R&D Needed: Yes
Recommendation: Update existing test guidelines for metals and polymers with considerations for materials that have graded properties. If the grade itself needs to be verified versus only its performance, new test methods may be needed. This is a broad topic however and depends on what is being evaluated.

Priority: Low	
Organization: ASTM F4 and F42, SAE AMS-AM, ASME, ISO/TC 261 JG67	
v2 Status of Progress: Not Started	
v2 Update: ASME Y14.46 discusses the specification of functionally graded materials. New efforts are focusing on verification of lattice FGM specifications.	
Updates Since v2 was Published:	
New Published Standards	**New In-Development Standards** **10/17/2019, LY**: Paul Witherell, NIST, comment: ISO TC261/ASTM F42 JG67 is developing a technical report that addresses design opportunities and challenges of functionally graded materials, ASTM CD TR 52912, *Additive manufacturing - Design - Functionally graded additive manufacturing*.

Back to Top

Gap D17: Contents of a TDP. The contents of a TDP that is sufficiently complete such that it could be provided to a vendor and result in components that are identical in physical and performance characteristics has not been defined.	
R&D Needed: Yes	
Recommendation: Develop a standard (or revise MIL-STD-31000A, *Technical Data Packages*) to describe all required portions of a TDP and adopt them into a formal standard. The standard should address at a minimum: • Performance/functional requirements (form, fit assembly) • Qualification requirements • Definition of "as-designed" part, versus "as-printed" part, versus "finished" part • Post-processing requirements (including finishing, removal of parts from AM machine such as separation from build plate) • Applicable AM process • Tailorable and non-tailorable build parameters • Cybersecurity requirements (if necessary) • Long term archival and retrieval process (including acquisition)	
Priority: High	
Organization: ASME Y14.46, ASME Y14.47, ASTM F2/ISO TC 261, AWS, DoD AFRL, NIST, SAE G-33	
v2 Status of Progress: Green	
v2 Update: NIST has been involved in developing a number of component standards with various SDOs. DoD is pushing for a standard that defines the contents of a TDP to cover DoD products. DoD is in the process of updating 31000A2 revision B. ASME Y14.47:2019, *Model Organization ~~Schema~~ Practices,* is based on Appendix B of MIL-STD-31000A. ~~It should be available by the second quarter of 2018.~~ DoD representatives are involved in the development of Y14.47 and Y14.46, which has a section specific to AM data packages. SAE G-33's SAE EIA649C, *Configuration Management Standard*, targeted for publication in the third quarter of 2018, provides guidance on specification control. There is a joint WG for digital product definition and data management under ASTM/ISO (JG73).	
Updates Since v2 was Published: **11/13/2020, MW**: Steve Weinman, ASME, comment: ASME has been working with DoD representatives to discuss MIL-STD-31000A and to prepare a strategy. **8/5/2020, MW**: ASTM AMCOE *Strategic Roadmap for Research & Development* (April 2020) notes that AMCOE Project 1901 (WK71395) addresses AMSC Gap D17. **3/17/2020, MW**: Jessica Coughlin, AWS D20, comment: AWS D20.1 (paragraph 4.4) lists the items that the Engineer is required to define and provide to the Contractor, including component classification, final required dimensions (including surface finish), material type and property requirements, allowable AM processes, post-processing requirements, and inspection requirements	
New Published Standards **7/18/2019, LY:** ASME Y14.47 was published in February 2019. **5/8/2019, LY:** SAE's G-33 Configuration Management Committee released *SAE EIA649C, Configuration Management Standard* in February 2019. **4/4/2019, LY:** MIL-STD-31000A has been revised; MIL-STD-31000B is the latest version and was released on 31 Oct 2018.	**New In-Development Standards** **3/31/2021, JM:** NRC presentation of 12/09/20 by Mohsen Seifi noted these ASTM work items: ASTM WK71395, *Additive manufacturing -- accelerated quality inspection of build health for laser beam powder bed fusion process* **3/31/2021, JM:** Per presentation by David Rosen, ASTM F42/ISO/TC 261: JG73

4/4/2019, LY: The AWS recently published a new standard on AM, *AWS D20.1/D20.1M:2019 Specification for Fabrication of Metal Components using Additive Manufacturing*.	**10/17/2019, LY**: Paul Witherell, NIST, comment: ISO TC261/ASTM F42 JG73 is actively developing PWI 52951 "Additive manufacturing — Data packages for AM parts" and has an early draft to be balloted in 2020.

Back to Top

Gap D18: New Dimensioning and Tolerancing Requirements. Although ASME Y14.41, *Digital Product Definition Data Practices* and other standards provide some capability in addressing some of the challenges in documenting AM designs, significant gaps still remain. ASME Y14.46 will address these gaps.	
R&D Needed: No	
Recommendation: Complete work on ASME Y14.46. See also Gap D26 on measurement of AM features/verifying the designs of features such as lattices, etc.	
Priority: High	
Organization: ASME Y14.46, ASME Y14.48, NIST	
v2 Status of Progress: Green	
v2 Update: ASME Y14.46-2017, *Product Definition for Additive Manufacturing [Draft Standard for Trial Use]* has been published and items within the standard related to this gap are still under development pending final approval. ASME Y14.48 on Universal Direction may also be relevant but that will not be available for another year or two. NIST provides a vice chair of the Y14 subcommittee 46.	
Updates Since v2 was Published: **3/31/2021, JM:** Per presentation by David Rosen, ASTM F42/ISO/TC 261: leave for ASME **10/17/2019, LY**: Paul Witherell, NIST, comment: ASME Y14.46 is transitioning out of draft status. Use cases have been explored to identify gaps in the standard and new material is being developed for incorporation into future version. See D26.	
New Published Standards	**New In-Development Standards**

Back to Top

Gap D19: Organization Schema Requirement and Design Configuration Control. AM parts are intrinsically tied to their digital definition. In the event of a design modification, proper methods of configuration and parameter curation are needed for verification. This could include verification of the digital material parameters, process parameters, or software version, if applicable. A comprehensive schema for organizing related information in an AM digital product definition data set will provide traceable, consistent data content and structure to consumers of the data.	
R&D Needed: No	
Recommendation: ASME Y14.47-2019, *Model Organization Schema Practices*, formerly known as Y14.41.1 may partially address this gap but AM related aspects need to be further developed. This standard should be available by the second quarter of 2018. ASME Y14.47 is based on Appendix B of MIL-STD-31000A. ASME could also consider multiple schemas (e.g., scan data) that are not currently under consideration within Y14.47. ASME Y14.47 and ISO/TC 10 could incorporate the digital configuration control into their developing standards if they have not already. SAE's G-33 Configuration Management Committee is developing SAE EIA649C, *Configuration Management Standard*, which is targeted for publication by the third quarter of 2018.	
Priority: High	
Organization: ASME Y14.47, ISO/TC 10, ASTM F42/ISO TC 261 JG73, AWS NIST, SAE G-33	
v2 Status of Progress: Green	
v2 Update: As noted in the recommendation.	
Updates Since v2 was Published: **8/5/2020, MW**: ASTM AMCOE *Strategic Roadmap for Research & Development* (April 2020) notes that AMCOE Project 1902 (WK72172) addresses AMSC Gap D19. **3/17/2020, MW**: Jessica Coughlin, AWS D20, comment: AWS D20.1 (paragraph 7.2) requires that Contractor have a Digital Control Plan in place and defines the items that must be included in such a plan.	
New Published Standards **7/15/2019, LY**: The revision to *Technical Data Packages,* MIL-STD-31000B, has since been published.	**New In-Development Standards** **3/31/2021, JM:** NRC presentation of 12/09/20 by Mohsen Seifi noted these ASTM work items: ASTM WK72172, Additive manufacturing -- General principles -- Overview of data pedigree

5/23/2019, LY: ASME Y14.47 was published in February 2019. **5/9/2019, LY:** SAE's G-33 Configuration Management Committee released *SAE EIA649C, Configuration Management Standard* in February 2019. **4/4/2019, LY:** The AWS recently published a new standard on AM, *AWS D20.1/D20.1M:2019 Specification for Fabrication of Metal Components using Additive Manufacturing*.	**3/31/2021, JM:** Per presentation by David Rosen, ASTM F42/ISO/TC 261: JG73?? **10/17/2019, LY**: Paul Witherell, NIST, comment: ISO TC261/ASTM F42 JG73 is actively developing PWI 52951 "Additive manufacturing — Data packages for AM parts" and has an early draft to be balloted in 2020. This effort addresses configuration of data packages to support different levels of control.

Back to Top

Gap D20: Neutral Build File Format. No published or in development standards or specifications have been identified that incorporate build path or feedstock into a neutral file format. Further, many other parameters remain unsupported. Ideally, the same file could be used as the input into an AM machine regardless of the vendor of the machine and provide for a uniform output. Industry should work to coalesce around one industry standard for AM file format, which will help to better enable qualification of a design. However, the unique technologies of the different vendors could make such an effort challenging.	
R&D Needed: Yes	
Recommendation: Develop a new standard for the computer-interpretable representation and exchange of additive manufacturing product information that can represent all of the applicable slice files, build path, and feedstock, as well as the other applicable parameters into a single file format. This file would be used to exchange data between AM vendors and have the capability to be used instead of both the job files and material perimeter sets. This file format could make use of standard image formats and capture enough information to facilitate size, orientation and color normalization in post-processing of data. See also Gap D8 on machine input and capability report.	
Priority: Low	
Organization: ISO/TC 184/SC4, ISO/TC 261/ASTM F42, consortium of industry, IEEE-ISTO PWG	
v2 Status of Progress: Not Started, or Unknown	
v2 Update: None provided	
Updates Since v2 was Published:	
New Published Standards **8/20/2020, JM:** ISO/ASTM 52915:2020, *Specification for additive manufacturing file format (AMF) Version 1.2.* According to an ASTM tracker alert of 8/20/20, it has been revised to F2915-20 developed by Committee F42.04.	**New In-Development Standards** **3/31/2021, JM:** *ASTM WK48549 AMF Support for Solid Modeling: Voxel Information, Constructive Solid Geometry Representations and Solid Texturing* **8/19/2020, JM:** ISO/ASTM CD TR 52918, Additive manufacturing — Data formats — File format support, ecosystem and evolutions

Commented [A14]: Being done by JG64

Back to Top

Gap D21: New Terminology in Design Documentation. While some AM terminology standards already exist, they do not include certain terms referred to in design documentation. Terminology in a TDP needs to be clear.	
R&D Needed: No	
Recommendation: ASME Y14.46 has identified terms for design documentation that are not defined in existing AM terminology standards. Once this work is completed, it should be referred to ISO/TC 261 and ASTM F42 for inclusion in existing standards such as ISO/ASTM 52900:2015, *Additive manufacturing -- General principles – Terminology*.	
Priority: Medium	
Organization: ASME, ISO/ASTM	
v2 Status of Progress: Green	
v2 Update: ASME Y14.46-2017, *Product Definition for Additive Manufacturing [Draft Standard for Trial Use]* has been published. ASME Y14.46 references ISO/ASTM AM terminology standards (ISO/ASTM 52900 and ISO/ASTM 52921) as much as possible but also had to create new AM terminology specific to AM Product Definition. The ASME Y14.46 AM-related terms were sent to ASTM. Since Y14.46 is a draft standard for trial use, comments are being accepted and there may be significant changes to the draft standard.	
Updates Since v2 was Published:	
New Published Standards	**New In-Development Standards**

2/9/21, JM: ISO/ASTM52950:2021 - Additive manufacturing — General principles — Overview of data processing is a new standard, now available. F3436-21 developed by Committee F42.04, ASTM BOS Volume 10.04. **10/31/2019, JM:** ISO/ASTM52921-13(2019), Standard Terminology for Additive Manufacturing—Coordinate Systems and Test Methodologies, was reapproved.	**3/31/2021, JM:** Per presentation by Paul Witherell, ASTM WK72172, Additive manufacturing -- General principles -- Overview of data pedigree **3/31/2021, JM:** Per presentation by David Rosen, ASTM F42/ISO/TC 261: 52900 incomplete? **8/21/2020, JM:** ISO/ASTM DIS 52900, *Additive manufacturing — General principles — Fundamentals and vocabulary* is being revised. **8/21/2020, JM:** A revision to ISO/ASTM DIS 52921, *Additive manufacturing — General principles — Standard practice for part positioning, coordinates and orientation is under development* is under development **10/17/2019, LY**: Paul Witherell, NIST, comment: NIST and Pennsylvania State University are leading an AM Data Management working group. This working group is developing a Common Data Dictionary to facilitate the exchange of AM data. ISO TC261/ASTM F42 JG73 efforts with PWI 52951 include the explicit identification of parameters to be controlled in different configurations of the data package.

Commented [A15]: 3/31/2021, JM, This is a revision of ISO 17296-4:2014

Back to Top

Gap D22: In-Process Monitoring. There is a lack of standards for validated physics- and properties-based predictive models for AM that incorporate geometric accuracy, material properties, defects, surface characteristics, residual stress, microstructure properties, and other characteristics (NIST, 2013). No standardized data models or documentation have been identified for in-process monitoring and analytics. Given the current state of the technology, this is not surprising.	
R&D Needed: Yes. R&D is needed to understand what in-process monitoring data is needed for verification and validation of the part. Research efforts have been undertaken that are devoted to the development of predictive computational models and simulations to understand the dynamics and complexity of heat and phase transformations. Although computational models and simulations are promising tools to understand the physics of the process, lack of quantitative representation of their prediction accuracy hinders further application in process control and optimization. Due to this reason, it is very challenging to select suitable models for the intended purpose. Therefore, it is important to study and investigate the degree of accuracy and uncertainty associated with AM models.	
Recommendation: Develop standards for predictive computational modeling and simulation tools that link measured in-process monitoring data with product properties, quality, and consistency, as an important aspect of innovative structural design (NIST, 2013). See also Gap PC16 on in-process monitoring to obtain a layer-by-layer (3D) file or quality record showing the as-built part is defect-free or contains no critical flaws, or exhibits an in-family (nominal) response when interrogated during the build.	
Priority: Medium	
Organization: ASTM F42, ASME, IEEE-ISTO PWG	
v2 Status of Progress: Green	
v2 Update: Office of Naval Research (ONR) is also researching this through their Quality Made program. NIST is developing a publically available schema for metals that may apply.	
Updates Since v2 was Published: **3/31/2021, JM:** Per presentation by David Rosen, ASTM F42/ISO/TC 261: Validate predictive models **8/5/2020, MW**: ASTM AMCOE *Strategic Roadmap for Research & Development* (April 2020) notes that AMCOE Project 1906 (WK74390) addresses AMSC Gap D22.	
New Published Standards	**New In-Development Standards** **3/31/2021, JM:** Per presentation by Paul Witherell, ASTM WK72172, Additive manufacturing -- General principles -- Overview of data pedigree **3/19/21, JM:** *ASTM* WK74390, *Additive Manufacturing of Metals -- Data -- File structure for in-process monitoring of powder bed fusion* **10/17/2019, LY**: Paul Witherell, NIST, comment: (In addition to ONR Quality Made Program) NIST and Pennsylvania State University are leading an AM Data Management working group. This working group is developing a Common Data Dictionary to facilitate the

Commented [A16]: 4/2/2021, JM: Per 12/9/20 NRC presentation by Mohsen Seifi

Commented [A17]: The draft standard indicates it is being developed specifically to address gap PC16.

	exchange of AM data, including process monitoring information. Data models for process monitoring and simulation can be found here: https://ammd.nist.gov and here: https://www.nist.gov/ambench.

Back to Top

Gap D23: Documentation of New Functional and Complex Surface Features. There is a need for a specification on design documentation for intentionally introducing new bulk or surface geometries which can be created through AM.	
R&D Needed: No	
Recommendation: ASME Y14.46 should consider an annex describing a method to document functional and complex geometric features.	
Priority: Low	
Organization: ASME	
v2 Status of Progress: Green	
v2 Update: As noted in the recommendation. ASME Y14.46-2017, *Product Definition for Additive Manufacturing [Draft Standard for Trial Use]* has been published.	
Updates Since v2 was Published:	
New Published Standards	**New In-Development Standards** **11/13/2020, MW:** Steve Weinman, ASME, comment: Y14 Committee continuing to work to finalize Y14.46 standard. **10/17/2019, LY**: Paul Witherell, NIST, comment: ASME Y14.46 is transitioning out of draft status. Use cases have been explored to identify gaps in the standard and new material is being developed for incorporation into future version.

Back to Top

Gap D24: An Acquisition Specification. A specification is needed to procure AM parts from third parties.	
R&D Needed: No	
Recommendation: ASTM should complete work on WK51282, New Guide for Additive Manufacturing, General Principles, Requirements for Purchased AM Parts.	
Priority: Medium	
Organization: ISO/ASME	
v2 Status of Progress: Closed	
v2 Update: ISO/ASTM 52901, *Additive manufacturing - General Principles - Requirements for Purchased AM Parts* was published in 2017. WK51282 was the earlier ASTM work item	
Updates Since v2 was Published: **3/31/2021, JM:** Per presentation by David Rosen, ASTM F42/ISO/TC 261: Closed PAMP	
New Published Standards **11/20/20, JM:** Bill Bihlman, SAE Comment: Published: • SAE AMS7004, *Titanium Alloy Preforms from Plasma Arc Directed Energy Deposition Additive Manufacturing on Substrate, Ti-6Al-4V, Stress Relieved* (Jan 2019) • SAE AMS7008, *Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 47.5Ni - 22Cr - 1.5Co - 9.0Mo - 0.60W - 18.5Fe* (March 2019) • SAE AMS7012, *Precipitation Hardenable Steel Alloy, Corrosion and Heat-Resistant Powder for Additive Manufacturing 16.0Cr - 4.0Ni - 4.0Cu - 0.30Nb* (Nov 2019)	**New In-Development Standards**

• SAE AMS7013, *Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 60Ni - 22Cr - 2.0Mo - 14W - 0.35Al - 0.03La* (Jan 2019) • SAE AMS7014, *Titanium Alloy, High Temperature Applications, Powder for Additive Manufacturing, Ti - 6.0Al - 2.0Sn - 4.0Zr - 2.0Mo* (Mar 2019) • SAE AMS7018, Aluminum Alloy Powder 10.0Si – 0.35Mg (May 2020) • *SAE AMS7021, Stainless Steel Powder, 15-5PH Alloy* (Nov 2020) • SAE AMS7101, Fused Filament Fabrication, Material for (Oct 2019)	

Back to Top

Gap D26: Design for Measurement of AM Features/Verifying the Designs of Features such as Lattices, etc. As noted in Gap D18, working groups are currently developing methods to standardize the geometric dimensioning and tolerancing (GD&T) of AM parts. As these mature, existing V&V methods of checking part conformance to GD&T specifications must be investigated for their compatibility with AM. As part of the design process for AM, the availability of methods to measure and verify AM-unique features must be considered, especially to meet critical performance requirements. This may result in adapting existing NDE methods or creating new methods. This will likely be relevant when measuring AM features such as helixes or other complex shapes, or internal features that are not compatible with common methods such as Go/NoGo gauges or coordinate measuring machines (CMM). Especially in the case of internal features, assessing the ability of ultrasonic or radiographic methods to validate high tolerances will be required.	
R&D Needed: Yes, investigation of high resolution radiographic and ultrasonic methods and the maximum achievable resolution and accuracy for GD&T of complex AM designs.	
Recommendation: As GD&T standards continue to develop, perform parallel investigations of validation methods to ensure V&V is possible. See also Gap NDE4, Dimensional Metrology of Internal Features.	
Priority: Medium	
Organization: ISO/TC 261/ASTM F42, ASTM E07.01, ASTM E07.02, ASME B89, ASME Y14.46, ISO/TC 10	
v2 Status of Progress: Not Started	
v2 Update: A standard on methods to verify that complex AM parts meet design requirements is needed. ASME Y14.46-2017, *Product Definition for Additive Manufacturing [Draft Standard for Trial Use]* will address how to document AM-unique design features, but not how to inspect/verify the design. Y14.46 included a non-mandatory appendix with guidance on quality assurance (QA) parameters and references that may be used to develop design validation methods. ASME B89 (dimensional metrology) is working jointly with Y14.46. ISO/ASTM 52910-17, *Standard Guidelines for Design for Additive Manufacturing* provides guidance for AM designers to "work with their quality groups to ascertain if appropriate inspection and qualification processes are available or need to be developed for the types of parts that they are designing."	
Updates Since v2 was Published: **3/31/2021, JM:** Per presentation by David Rosen, ASTM F42/ISO/TC 261: Good idea **8/5/2020, MW**: ASTM AMCOE *Strategic Roadmap for Research & Development* (April 2020) notes that AMCOE Project 1901 (WK71395) addresses AMSC Gap D26.	
New Published Standards	**New In-Development Standards** **3/31/2021, JM:** NRC presentation of 12/09/20 by Mohsen Seifi noted these ASTM work items: ASTM WK71395, *Additive manufacturing -- accelerated quality inspection of build health for laser beam powder bed fusion process* **11/13/2020, MW:** Steve Weinman, ASME, comment: The ASME B46 Task Group is working on changes and/or a new standard or guideline to further address surface texture Additive Manufacturing needs. **10/17/2019, LY**: Paul Witherell, NIST, comment: ASME Y14.46 is transitioning out of draft status. Use cases have been explored to identify gaps in the standard and new material is being developed for incorporation into future version, including challenges with inspection. See D18.

Commented [A18]: An updated release was published in 2018 ISO/ASTM 52910-18, *Additive manufacturing — Design — Requirements, guidelines and recommendations*. Does it apply or should the reference be removed?

Back to Top

New Gap D27: Standardized Design for Additive Manufacturing (DFAM) Process Chain. A standardized design is needed for AM process chain integrating key AM considerations/design tools in each design stage.
R&D Needed: Yes
Recommendation: Develop a standardized design for AM process chain that specifies and integrates the key AM considerations and suggested design tools in each generic design stage. The process chain can be expanded from ISO/ASTM 52910-2017, *Standard Guidelines for Design for Additive Manufacturing* stages and complimented with design tools to address specific AM needs for each task within the stages. The standardized design for AM process chain can be used by various industries to roll out site-specific DFAM process and digitalization implementation.
Priority: Medium
Organization: ASTM F42/ISO TC 261 JG73, NIST
v2 Status of Progress: New
v2 Update: None provided
Updates Since v2 was Published:

New Published Standards	**New In-Development Standards**
	3/31/2021, JM: Per presentation by David Rosen, ASTM F42/ISO/TC 261: JG73++ **10/17/2019, LY:** Paul Witherell, NIST, comment: ISO TC261/ASTM F42 JG73 efforts with PWI 52951 will address file formats and the integration and preservation of information across the process chain.

Commented [A19]: An updated release was published in 2018 ISO/ASTM 52910-18, *Additive manufacturing — Design — Requirements, guidelines and recommendations*.. Does it apply or should the reference be removed?

Back to Top

New Gap D28: Specification of Surface Finish. There is a need for a specification on desired surface finishes of AM parts that can later be measured and validated against. Current surface finish metrics, such as Ra, do not adequately specify surface finish requirements.
R&D Needed: Yes
Recommendation: ASME should continue its work to develop ASME B46.1-2009, *Surface Texture (Surface Roughness, Waviness, and Lay),* to address specification requirements of AM surface finishes.
Priority: Medium
Organization: ASME
v2 Status of Progress: New
v2 Update: None provided
Updates Since v2 was Published: **3/31/2021, JM:** Per presentation by David Rosen, ASTM F42/ISO/TC 261: Leave for ASME? **8/5/2020, MW**: ASTM AMCOE *Strategic Roadmap for Research & Development* (April 2020) notes that AMCOE Projects 1802 (WK66682) and 1804/1907 (WK65937, WK65929) address AMSC Gap D28. **4/9/2020, JM**: Steve Weinman, ASME, comments: The ASME B46 committee has added a section to Appendix B of the standard regarding surface texture of AM parts. This is currently a generalized section with several references to ISO, ASTM, and ANSI standards or guides. The section was approved by the committee as part of the latest revision of the standard (B46.1-2019). We expect to have B46.1-2019 published by July 2020. In the future, the section will be expanded upon, possibly moving to a section within the standard, as opposed to being an appendix.

New Published Standards	**New In-Development Standards**
6/30/2020, JM: It appears that B46.1 was published on/about June 30, 2020.	**3/31/2021, JM:** NRC presentation of 12/09/20 by Mohsen Seifi noted these ASTM work items: • ASTM WK66682, *Evaluating Post-processing and Characterization Techniques for AM Part Surfaces* • ASTM WK65937, *Additive Manufacturing -- Space Application -- Flight Hardware made by Laser Beam Powder Bed Fusion Process* • ASTM WK65929, *Additive Manufacturing-Finished Part Properties and Post Processing - Additively Manufactured Spaceflight Hardware by Laser Beam Powder Bed Fusion In Metals* **11/13/2020, MW**: Steve Weinman, ASME, comment: The ASME B46 Task Group is working on changes and/or a

	new standard or guideline to further address surface texture Additive Manufacturing needs.

Back to Top

Other Design Activity – Relevance to Gaps Not Yet Determined

New Published Standards

New In-Development Standards
ASTM WK71507, *Additive manufacturing -- General principles -- Overview of data processing*
ASTM WK73978, Additive Manufacturing -- Data Registration
ASTM WK75158, Additive Manufacturing -- Data -- Common exchange format for particle size analysis by light scattering

Commented [A20]: These are being developed under F42.08 on data rather than F42.04 on design. *ASTM AMCOE Strategic Guide: Additive Manufacturing Data Management and Schema* is a resource.

Back to Top

Chapter 2.2.1. Precursor Materials

High Priority

- **Gap PM5: Metal Powder Feedstock Sampling (11/20/2020)**

Medium Priority

- **Gap PM1: Flowability (11/20/2020)**
- **Gap PM2: Spreadability (3/31/2021)**
- **Gap PM3: Particle Size and Particle Size Distribution (3/31/2021)**
- **Gap PM7: AM Process-Specific Metal Powder Specifications (3/31/2021)**

Low Priority

- **Gap PM4: Particle Morphology (3/31/2021)**
- **Gap PM6: Hollow Particles and Hollow Particles with Entrapped Gas (2/20/2020)**
- **New Gap PM8: Use of Recycled Polymer Precursor Materials (11/13/2020)**
- **New Gap PM9: Characterization of Material Extrusion Feedstock (Filaments & Pellets) (4/2020)**
- **New Gap PM10: Sampling of Open Liquid Feedstock System**

Back to Top

Gap PM1: Flowability. Existing standards for flowability do not account for the range of conditions that a powder may encounter during shipment, storage, and the AM process.
R&D Needed: Yes. R&D is needed to measure and quantify flowability, especially with powder bed processing.
Recommendation: Standards are needed to address test methods which encompass the variety of flow regimes encountered in AM processes. Recommend completion of ASTM WK55610, *New Test Methods for the Characterization of Powder Flow Properties for Additive Manufacturing Applications*, (not specific to metal powders) which addresses dynamic flow, aeration, permeability, consolidation and compressibility test procedures using, for example, a powder rheometer. Recommend also completion of ISO/ASTM DIS 52907, *Additive Manufacturing Technical Specifications on Metal Powder*, which points to published standards for flowability tests along with consideration of how the state of the powder would affect the flowability measurement. See also Gap PC12 on precursor material flow monitoring.
Priority: Medium
Organization: ASTM F42/ISO TC 261, NIST, ASTM B09, ASTM E29
v2 Status of Progress: Green
v2 Update: As noted in the text, ASTM WK55610 and ISO/ASTM DIS 52907 are in development. Completion of those work items may partially but not fully address the gap.

Updates Since v2 was Published: **8/5/2020, MW**: ASTM AMCOE *Strategic Roadmap for Research & Development* (April 2020) notes that AMCOE Project 1803 (WK66030) addresses AMSC Gap PM1.

New Published Standards	New In-Development Standards
11/20/2020, MW: Bill Bihlman, SAE, Comment: • SAE AMS7008, *Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 47.5Ni - 22Cr - 1.5Co - 9.0Mo - 0.60W - 18.5Fe* (March 2019) • SAE AMS7012, *Precipitation Hardenable Steel Alloy, Corrosion and Heat-Resistant Powder for Additive Manufacturing 16.0Cr - 4.0Ni - 4.0Cu - 0.30Nb* (Nov 2019) • SAE AMS7013, *Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 60Ni - 22Cr - 2.0Mo - 14W - 0.35Al - 0.03La* (Jan 2019) • SAE AMS7014, *Titanium Alloy, High Temperature Applications, Powder for Additive Manufacturing, Ti - 6.0Al - 2.0Sn - 4.0Zr - 2.0Mo* (Mar 2019) • SAE AMS7018, Aluminum Alloy Powder 10.0Si – 0.35Mg (May 2020) • *SAE AMS7021, Stainless Steel Powder, 15-5PH Alloy* (Nov 2020) **2/20/2020, JM:** ISO/ASTM 52907:2019, *Additive manufacturing – Feedstock materials – Methods to characterize metal powder*, was published in November 2019.	**3/31/2021, JM:** NRC presentation of 12/09/20 by Mohsen Seifi noted these ASTM work items: *WK66030 Quality Assessment of Metal Powder Feedstock Characterization Data for Additive Manufacturing* **11/20/2020, MW**: Bill Bihlman, SAE, Comment: • *SAE GAAM-M20A, Aluminum Alloy Powder Template* (Apr 2020) • *SAE GAAM-M20B, Cobalt, Iron, or Nickel Alloy Powder Template* (Apr 2020) • *SAE GAAM-M20C, Titanium Powder Template* (Apr 2020) **8/19/2020, JM:** ASTM WK62190, Additive manufacturing Feedstock materials Technical specifications on metal powder

Commented [A21]: Does ISO/ASTM PWI 52913, Characterization of powder flow properties also belong here?

Back to Top

Gap PM2: Spreadability. There is no known description of spreadability or standard for how to quantitatively assess powder spreadability.
R&D Needed: Yes. R&D is needed to measure and quantify spreadability, as well as to correlate powder characteristics with spreadability.
Recommendation: A standard should be created that guides the measurement of a powder's spreadability. This standard may be comprised of a series of tests that together describe a powder's spreading performance.
Priority: Medium
Organization: ASTM F42/ISO TC 261, NIST, universities, ASTM B09, ASTM E29
v2 Status of Progress: Not Started, Or Unknown
v2 Update: There are no ASTM standard test methods for spreadability.
Updates Since v2 was Published: **8/5/2020, MW**: ASTM AMCOE *Strategic Roadmap for Research & Development* (April 2020) notes that AMCOE Projects 1803 (WK66030) and 1903 (WK71393) addresses AMSC Gap PM2.

New Published Standards	New In-Development Standards
11/20/2020, MW: Bill Bihlman, SAE, Comment: • SAE AMS7008, *Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 47.5Ni - 22Cr - 1.5Co - 9.0Mo - 0.60W - 18.5Fe* (March 2019) • SAE AMS7012, *Precipitation Hardenable Steel Alloy, Corrosion and Heat-Resistant Powder for Additive Manufacturing 16.0Cr - 4.0Ni - 4.0Cu - 0.30Nb* (Nov 2019) • SAE AMS7013, *Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 60Ni - 22Cr - 2.0Mo - 14W - 0.35Al - 0.03La* (Jan 2019)	**3/31/2021, JM:** NRC presentation of 12/09/20 by Mohsen Seifi noted these ASTM work items: • *WK66030 Quality Assessment of Metal Powder Feedstock Characterization Data for Additive Manufacturing* • WK71393, *Additive manufacturing -- assessment of powder spreadability for powder bed fusion (PBF) processes* **11/20/2020, MW**: Bill Bihlman, SAE, Comment: • *SAE GAAM-M20A, Aluminum Alloy Powder Template* (Apr 2020)

• SAE AMS7014, *Titanium Alloy, High Temperature Applications, Powder for Additive Manufacturing, Ti - 6.0Al - 2.0Sn - 4.0Zr - 2.0Mo* (Mar 2019) • SAE AMS7018, Aluminum Alloy Powder 10.0Si – 0.35Mg (May 2020) • *SAE AMS7021, Stainless Steel Powder, 15-5PH Alloy* (Nov 2020)	• *SAE GAAM-M20B, Cobalt, Iron, or Nickel Alloy Powder Template* (Apr 2020) • *SAE GAAM-M20C, Titanium Powder Template* (Apr 2020)

Back to Top

<table>
<tr><td colspan="2">Gap PM3: Particle Size and Particle Size Distribution. While current standards for measurement of particle size and particle size distribution exist for powder metallurgy and can be leveraged for AM powders, the reliability and repeatability of different testing methodologies is currently unacceptable.</td></tr>
<tr><td colspan="2">R&D Needed: Yes. Validation of various measurement techniques for reliability, repeatability, and correlation is required, possibly defining best measurement techniques for different build systems.</td></tr>
<tr><td colspan="2">Recommendation: See R&D needed. For metal PBF, recommend completion of ISO/ASTM DIS 52907, Additive Manufacturing Technical Specifications on Metal Powder, which points to published standards for particle size analysis and discusses advantages and limitations of each referenced test method.</td></tr>
<tr><td colspan="2">Priority: Medium</td></tr>
<tr><td colspan="2">Organization: ASTM F42/ISO TC 261 JG66, ASTM B09, ASTM E29</td></tr>
<tr><td colspan="2">v2 Status of Progress: Green</td></tr>
<tr><td colspan="2">v2 Update: As noted, ISO/ASTM DIS 52907 is in development as JG66. Completion of this work item may partially but not fully address the gap.</td></tr>
<tr><td colspan="2">Updates Since v2 was Published:
8/5/2020, MW: ASTM AMCOE Strategic Roadmap for Research & Development (April 2020) notes that AMCOE Project 1803 (WK66030) addresses AMSC Gap PM3.</td></tr>
<tr><td>New Published Standards
11/20/2020, MW: Bill Bihlman, SAE, Comment:
• SAE AMS7008, Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 47.5Ni - 22Cr - 1.5Co - 9.0Mo - 0.60W - 18.5Fe (March 2019)
• SAE AMS7012, Precipitation Hardenable Steel Alloy, Corrosion and Heat-Resistant Powder for Additive Manufacturing 16.0Cr - 4.0Ni - 4.0Cu - 0.30Nb (Nov 2019)
• SAE AMS7013, Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 60Ni - 22Cr - 2.0Mo - 14W - 0.35Al - 0.03La (Jan 2019)
• SAE AMS7014, Titanium Alloy, High Temperature Applications, Powder for Additive Manufacturing, Ti - 6.0Al - 2.0Sn - 4.0Zr - 2.0Mo (Mar 2019)
• SAE AMS7018, Aluminum Alloy Powder 10.0Si – 0.35Mg (May 2020)
• SAE AMS7021, Stainless Steel Powder, 15-5PH Alloy (Nov 2020)

2/20/2020, JM: ISO/ASTM 52907:2019, Additive manufacturing – Feedstock materials – Methods to characterize metal powder, was published in November 2019.</td><td>New In-Development Standards
3/31/2021, JM: NRC presentation of 12/09/20 by Mohsen Seifi noted these ASTM work items:
WK66030 Quality Assessment of Metal Powder Feedstock Characterization Data for Additive Manufacturing
11/20/2020, MW: Bill Bihlman, SAE, Comment:
• SAE GAAM-M20A, Aluminum Alloy Powder Template (Apr 2020)
• SAE GAAM-M20B, Cobalt, Iron, or Nickel Alloy Powder Template (Apr 2020)
• SAE GAAM-M20C, Titanium Powder Template (Apr 2020)

8/19/2020, JM: ASTM WK62190, Additive manufacturing Feedstock materials Technical specifications on metal powder</td></tr>
</table>

Back to Top

Gap PM4: Particle Morphology. No standards exist giving users of AM criteria for use of a particular powder feedstock based on the powder morphology.	
R&D Needed: Yes. R&D is needed to measure and quantify particle morphology.	
Recommendation: Based on the results of R&D, a standard may be needed to define accepted test methods for powder morphology and criteria for determining acceptable powder morphology characteristics. Because powder morphology may affect powder flow, powder spreadability, and density of the AM built object, it could possibly be addressed indirectly by standards governing flow and spreadability requirements for a powder, taking into account the density of the powder. Recommend completion of ISO/ASTM DIS 52907, *Additive Manufacturing Technical Specifications on Metal Powder*, which points to published standards for describing particle morphology.	
Priority: Low	
Organization: NIST, ASTM F42/ISO TC 261 JG66, ASTM B09, ASTM E29	
v2 Status of Progress: Green	
v2 Update: As noted, ISO/ASTM DIS 52907 is in development as JG66.	
Updates Since v2 was Published: **8/5/2020, MW**: ASTM AMCOE *Strategic Roadmap for Research & Development* (April 2020) notes that AMCOE Project 1803 (WK66030) addresses AMSC Gap PM4.	
New Published Standards **11/20/2020, MW**: Bill Bihlman, SAE, Comment: • SAE AMS7008, *Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 47.5Ni - 22Cr - 1.5Co - 9.0Mo - 0.60W - 18.5Fe* (March 2019) • SAE AMS7012, *Precipitation Hardenable Steel Alloy, Corrosion and Heat-Resistant Powder for Additive Manufacturing 16.0Cr - 4.0Ni - 4.0Cu - 0.30Nb* (Nov 2019) • SAE AMS7013, *Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 60Ni - 22Cr - 2.0Mo - 14W - 0.35Al - 0.03La* (Jan 2019) • SAE AMS7014, *Titanium Alloy, High Temperature Applications, Powder for Additive Manufacturing, Ti - 6.0Al - 2.0Sn - 4.0Zr - 2.0Mo* (Mar 2019) • SAE AMS7018, Aluminum Alloy Powder 10.0Si – 0.35Mg (May 2020) • *SAE AMS7021, Stainless Steel Powder, 15-5PH Alloy* (Nov 2020) **2/20/2020, JM:** ISO/ASTM 52907:2019, *Additive manufacturing – Feedstock materials – Methods to characterize metal powder*, was published in November 2019.	**New In-Development Standards** **3/31/2021, JM:** NRC presentation of 12/09/20 by Mohsen Seifi noted these ASTM work items: *WK66030 Quality Assessment of Metal Powder Feedstock Characterization Data for Additive Manufacturing* **11/20/2020, MW**: Bill Bihlman, SAE, Comment: • *SAE GAAM-M20A, Aluminum Alloy Powder Template* (Apr 2020) • *SAE GAAM-M20B, Cobalt, Iron, or Nickel Alloy Powder Template* (Apr 2020) • *SAE GAAM-M20C, Titanium Powder Template* (Apr 2020) **8/19/2020, JM:** ASTM WK62190, Additive manufacturing Feedstock materials Technical specifications on metal powder

Back to Top

Gap PM5: Metal Powder Feedstock Sampling. While existing powder metallurgy standards may be leveraged for AM use, they require tailoring for AM-specific situations. For example, sampling practices for reused powder that has been through an AM build cycle are needed to establish how to collect representative powder samples. These practices should take into account the variation caused by build exposure on powder in multiple locations.
R&D Needed: Yes, with respect to the re-use of powder during the build. See also Gaps PC7, PC10 and PC11.
Recommendation: Standards are needed for sampling of powders used for AM, with considerations for unique aspects of AM not considered in powder sampling standards for general powder metallurgy, including re-use of powder.
Priority: High
Organization: NIST, SAE AMS-AM, ASTM B09, MPIF, ASTM D20 (for polymers), ASTM F42, ASTM E29
v2 Status of Progress: Green
v2 Update: SAE AMS7003, *Laser Powder Bed Fusion Process* was published in June 2018 and addresses this issue. For metals specifically, members of MPIF's Association for Metal Additive Manufacturing (AMAM) technical committee reviewed MPIF Standard Test Method 01, *Method for Sampling Metal Powders (2016)* and noted that challenges with standardizing powder sampling include variations for different powder alloy systems, additive

manufacturing technologies, and the importance of powder purity to the application. ASTM B09 is currently reviewing the MPIF Std. Test Method 01. For polymers, there may be interest from ASTM D20 working in conjunction with ASTM F42.
Updates Since v2 was Published:

New Published Standards	**New In-Development Standards** **11/20/2020, MW**: Bill Bihlman, SAE, Comment: *SAE AMS7003A, Laser Powder Bed Fusion Process* (Jun 2019)

Commented [A22]: Does WK66030 also apply to this gap?

Back to Top

Gap PM6: Hollow Particles and Hollow Particles with Entrapped Gas. No standards exist for measuring how to determine the presence and percentage of hollow particles and hollow particles with entrapped gas or their impact upon part properties and in-service performance.
R&D Needed: Yes. R&D is needed to establish the impact of hollow powder particles, if any.
Recommendation: Dependent upon R&D, a standard may be needed that specifies how to determine the percentage of hollow particles and hollow particles with entrapped gas in lots of metal powders. Testing may be needed to determine the level of hollow particles and hollow particles with entrapped gas that are acceptable without negatively affecting the properties and performance of finished parts. Recommend completion of ISO/ASTM DIS 52907, *Additive Manufacturing Technical Specifications on Metal Powder* and include measurement standards for powder internal porosity.
Priority: Low
Organization: For R&D: NIST, ASTM, America Makes, Oak Ridge National Laboratory, universities. For standards: ASTM F42/ISO TC 261, SAE, ASTM B09, ASTM E29
v2 Status of Progress: Unknown
v2 Update: None provided
Updates Since v2 was Published:

New Published Standards	**New In-Development Standards**
2/20/2020, JM: ISO/ASTM 52907:2019, *Additive manufacturing – Feedstock materials – Methods to characterize metal powder*, was published in November 2019.	

Back to Top

Gap PM7: AM Process-Specific Metal Powder Specifications. There is a need to develop AM process-specific metal powder specifications to ensure that a competitive supply of metal powder is available for procurement purposes. Further, vendors should be encouraged to use these industry powder specifications when testing their equipment and advertising final material properties.
R&D Needed: Yes. R&D is needed to determine the effect of powder parameters/characteristics on final part properties and on the suitability of a given powder for use in a given AM machine. Some of these powder parameters may include: 1) Particle Size Distribution 2) Particle Morphology 3) Flow Rate 4) Tap Density 5) Angle of Repose 6) Shear Stress 7) Chemistry 8) Specific Surface Area
Recommendation: Develop AM process-specific metal powder specifications to facilitate procurement of metal powders for use in AM machines. These specifications should describe the acceptable ranges of all relevant powder parameters that would impact the suitability of a given powder to be used in a given AM machine, and the effect it would have on final material properties.
Priority: Medium
Organization: ISO/ASTM, SAE AMS-AM, AWS, industry OEMs
v2 Status of Progress: Green

v2 Update: ASTM WK58219, *New Guide for Additive Manufacturing - Feedstock Materials-Creating Feedstock Specifications for Metal Powder Bed Fusion*, is in development. SAE AMS7001, *Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 62Ni - 21.5Cr - 9.0Mo - 3.65 Nb* has some of the parameters defined and was published in June 2018.
Updates Since v2 was Published: **8/5/2020, MW**: ASTM AMCOE *Strategic Roadmap for Research & Development* (April 2020) notes that AMCOE Project 1803 (WK66030) addresses AMSC Gap PM7.

Commented [A23]: Broken link and can't find reference to this standard

New Published Standards	New In-Development Standards
11/20/2020, MW: Bill Bihlman, SAE, Comment: • SAE AMS7008, *Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 47.5Ni - 22Cr - 1.5Co - 9.0Mo - 0.60W - 18.5Fe* (March 2019) • SAE AMS7012, *Precipitation Hardenable Steel Alloy, Corrosion and Heat-Resistant Powder for Additive Manufacturing 16.0Cr - 4.0Ni - 4.0Cu - 0.30Nb* (Nov 2019) • SAE AMS7013, *Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 60Ni - 22Cr - 2.0Mo - 14W - 0.35Al - 0.03La* (Jan 2019) • SAE AMS7014, *Titanium Alloy, High Temperature Applications, Powder for Additive Manufacturing, Ti - 6.0Al - 2.0Sn - 4.0Zr - 2.0Mo* (Mar 2019) • SAE AMS7018, Aluminum Alloy Powder 10.0Si – 0.35Mg (May 2020) • *SAE AMS7021, Stainless Steel Powder, 15-5PH Alloy* (Nov 2020) **4/2020, JM:** ISO/ASTM 52903-1:2020, *Additive manufacturing – Material extrusion-based additive manufacturing of plastic materials – Part 1: Feedstock materials* **5/8/2019, LY:** SAE has published the following metal powder material specifications for aerospace applications: • SAE AMS7001, *Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 62Ni - 21.5Cr - 9.0Mo - 3.65 Nb (June 2018)* • *SAE AMS7002, Process Requirements for Production of Metal Powder Feedstock for Use in Additive Manufacturing of Aerospace Parts* (June 2018) • SAE AMS7008, *Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 47.5Ni - 22Cr - 1.5Co - 9.0Mo - 0.60W - 18.5Fe* (March 2019)	**3/31/2021, JM:** NRC presentation of 12/09/20 by Mohsen Seifi noted these ASTM work items: *WK66030 Quality Assessment of Metal Powder Feedstock Characterization Data for Additive Manufacturing* **11/20/2020, MW**: Bill Bihlman, SAE, Comment: • *SAE AMS7002A, Process Requirements for Production of Metal Powder Feedstock for Use in Additive Manufacturing of Aerospace Parts* (Aug 2018) • *SAE AMS7012A, Precipitation Hardenable Steel Alloy, Corrosion and Heat-Resistant Powder for Additive Manufacturing 16.0Cr - 4.0Ni - 4.0Cu - 0.30Nb* (Mar 2020) • *SAE AMS7015 - Ti-6Al-4V, Powder For Additive Manufacturing* (Sep 2018) • SAE AMS7017, *Titanium 6-Aluminum 4-Vanadium Powder for Additive Manufacturing, ELI Grade* (Feb 2019) • *SAE AMS7020, Aluminum Alloy Powder, F357 Alloy* (May 2019) • *SAE AMS7023, Gamma Titanium Aluminide Powder for Additive Manufacturing, Ti-48Al-2Nb-2Cr* (May 2019) • *SAE AMS7025, Metal Powder Feedstock Size Classifications for Additive Manufacturing* (Jun 2019) • *SAE AMS7026, Powder Titanium 5553* (Jan 2020) • *SAE AMS7031, Process Requirements for Recovery and Recycling of Metal Powder Feedstock for Use in Additive Manufacturing of Aerospace Parts* (Apr 2020) • *SAE AMS7033, Aluminum Alloy Powder A205 (AlCuTiBAgMg)* (May 2020) • *SAE AMS7035 - Precipitation Hardenable Steel Alloy, Corrosion and Heat-Resistant, Powder for Binder Jet Additive Manufacturing, 16.0Cr – 4.0Ni – 4.0Cu - 0.30Nb* (Sep 2020) • *SAE GAAM-M20A, Aluminum Alloy Powder Template* (Apr 2020) • *SAE GAAM-M20B, Cobalt, Iron, or Nickel Alloy Powder Template* (Apr 2020) • *SAE GAAM-M20C, Titanium Powder Template* (Apr 2020) **8/19/2020, JM:** ASTM WK62190, Additive manufacturing Feedstock materials Technical specifications on metal powder **5/8/2019, LY:** The following SAE metal powder specifications for aerospace applications are under development: • AMS7006, *Alloy 718 Powder* • AMS7012, *17-4PH Powder for Additive Manufacturing*

Back to Top

New Gap PM8: Use of Recycled Polymer Precursor Materials. Feedstock/precursor material can be sourced from either virgin polymer resin, recycled polymer resin, or a combination of the two. Recycled resin can be obtained from a number of different sources including in-house processed product of the same material which may not have met all the requirements when initially produced but is still functional, commercial recyclate from commercial sources, and post-consumer recyclate. Recycled feedstock, depending on its source and usage level, can introduce problems in the printing or end-use application due to the recyclate's thermal/mechanical history, consistency and composition.
R&D Needed: Yes, to determine the acceptable limits and other constraints of incorporating reprocessed materials. This may be machine, material, and/or application specific.
Recommendation: Develop a general guidance document to address best practices in regard to sources, handling, and characterization of recycled materials. In some cases, such as medical and aerospace applications, more stringent guidelines may need to be developed such as identification of recycled material use.
Priority: Low
Organization: ASTM F42/D20, SAE AMS-AM
v2 Status of Progress: New
v2 Update: None provided
Updates Since v2 was Published: **11/13/2020, MW**: Steve Weinman, ASME, comment: ASME forming a Working Group to work on this gap.

New Published Standards	**New In-Development Standards**
	8/19/2020, JM: ASTM WK67583*, Additive Manufacturing -- Feedstock Materials -- Powder Reuse Schema in Powder Bed Fusion Processes for Medical Applications*

Back to Top

New Gap PM9: Characterization of Material Extrusion Feedstock (Filaments & Pellets). There are many classification systems and test procedures that are available and applicable to characterizing the feedstocks used for filaments or pellets. However, these are based on "conventional" processes and requirements and, in many cases, will need to be adapted to AM requirements and, in some cases, new, more specific systems and procedures may be required.
R&D Needed: Yes, to define the specific requirements and evaluate if these can be addressed by existing systems and procedures and, if not, to develop new ones.
Recommendation: Since this will be very dependent on specific materials and process requirements, existing documents need to be evaluated on a case-by-case basis, and, if necessary, new documents need to be developed. This is another aspect that needs to be considered by a possible ASTM F42 and D20 collaboration.
Priority: Low
Organization: ASTM F42/D20, SAE AMS-AM
v2 Status of Progress: New
v2 Update: None provided
Updates Since v2 was Published:

New Published Standards	**New In-Development Standards**
4/2020, JM: ISO/ASTM 52903-1:2020*, Additive manufacturing – Material extrusion-based additive manufacturing of plastic materials – Part 1: Feedstock materials*	

Back to Top

New Gap PM10: Sampling of Open Liquid Feedstock System. There is a need to develop a standard for monitoring and sampling open liquid feedstock systems to ensure the consistent chemical composition and mechanical properties in the final AM part.
R&D Needed: Yes. R&D is needed to determine how much the viscosity can change before having a significant effect on the mechanical and chemical properties of the final AM part, how fast the change can happen and the frequency and method for sampling the open liquid feedstock system.

Recommendation: Develop a process-specific standard to indicate how often the liquid feedstock viscosity must be monitored throughout the feedstock's lifetime (both in storage and in an open system).	
Priority: Low	
Organization: ISO/ASTM, Industry OEMs	
v2 Status of Progress: New	
v2 Update: None provided	
Updates Since v2 was Published:	
New Published Standards	**New In-Development Standards**

Back to Top

Other Precursor Materials Activity - Relevance to Gaps Not Yet Determined

New Published Standards

New In-Development Standards

ASTM WK69730, *Additive Manufacturing -- Wire for Directed Energy Deposition (DED) Processes in Additive Manufacturing*
SAE AMS7103 - Material for High Performance Laser Sintering (Jan 2019)

Back to Top

Chapter 2.2.2. Process Control

High Priority

- **Gap PC2: Machine Calibration and Preventative Maintenance (3/31/2021)**
- **Gap PC7: Recycle & Re-use of Materials (3/31/2021)**
- **Gap PC9: Environmental Conditions: Effects on Materials (3/31/2021)**
- **Gap PC14: Environmental Health and Safety: Protection of Machine Operators (8/19/2020)**

Medium Priority

- **Gap PC1: Digital Format and Digital System Control (3/17/2020)**
- **Gap PC4: Machine Qualification (3/31/2021)**
- **Gap PC5: Parameter Control (3/31/2021)**
- **Gap PC8: Stratification (11/20/2020)**
- **Gap PC10. Re-use of Material that Has Not Been Processed (11/20/2020)**
- **Gap PC12: Precursor Material Flow Monitoring**
- **Gap PC15. Configuration Management: Cybersecurity**
- **Gap PC16: In-Process Monitoring (4/2/2021)**

Low Priority

- **Gap PC3: Machine Health Monitoring (3/31/2021)**
- **Gap PC6: Adverse Machine Environmental Conditions: Effect on Component Quality (11/20/2020)**
- **Gap PC11: Re-use of Material that Has Been Processed (11/20/2020)**
- **Gap PC13: Flow Parameters for Material Jetting**

Back to Top

Gap PC1: Digital Format and Digital System Control. Existing process control standards do not adequately address digital format and digital system control.

R&D Needed: Yes.
Recommendation: Leverage NIST research and work with SDOs to ensure that AM process control standards include digital format and digital system control.
Priority: Medium
Organization: NIST, ISO/ASTM JG56, SAE, IEEE-ISTO PWG, AWS
v2 Status of Progress: Green
v2 Update: The ISO/TC 261/ASTM F42 JG56 standard in development addresses digital data configuration control.
Updates Since v2 was Published: **3/17/2020, MW:** Jessica Coughlin, AWS D20, comment: AWS D20.1 (paragraph 7.2) requires that Contractor have a Digital Control Plan in place and defines the items that must be included in such a plan.

New Published Standards	New In-Development Standards

Back to Top

Gap PC2: Machine Calibration and Preventative Maintenance. There are no known industry standards addressing machine calibration and preventative maintenance for additive manufacturing. Current users may not have established best practices or their own internal standards and may assume that the OEM maintenance procedures are sufficient to start/restart production. Additionally, AM machines have many mechanical components that are similar to conventional subtractive machinery. The motion control components are trusted to provide accurate positioning and it is currently unknown how errors in these systems affect the output quality. This is important during machine qualification and could be addressed in a standard.
R&D Needed: Research is required to determine how errors in machine components affect output quality so that tolerances can be developed for machine calibration and preventative maintenance checks
Recommendation: Complete work on standards in development addressing machine calibration and preventative maintenance. In addition, OEM and end user best practices should ensure adequate and recommended calibration and maintenance intervals that have been documented with data for different processes and machines. OEMs and SDOs should develop technical reports that incorporate case studies related to machine restart after maintenance. Standards should account for motion control components that guide measurement and remediation of error in positioning systems where possible in AM machines. OEMs should also take this into account when designing AM machines.
Priority: High. There is an urgent need to develop guidelines on day-to-day machine calibration checks.
Organization: AWS D20, ASTM F42/ISO TC 261, SAE AMS-AM, NIST, OEMs, end users, experts in machine metrology
v2 Status of Progress: Green
v2 Update: As noted in the text. **8/5/2020, MW**: ASTM AMCOE *Strategic Roadmap for Research & Development* (April 2020) notes that AMCOE Projects 1804/1907 (WK65937, WK65929), and 1901 (WK71395) address AMSC Gap PC2. **3/17/2020, MW:** Jessica Coughlin, AWS D20, comment: AWS D20.1 has a section on AM systems (7.3) that requires use of a pre-production maintenance checklist and a calibration control plan. Examples of items that are required to be addressed by these are provided.
Updates Since v2 was Published:

New Published Standards	New In-Development Standards
	3/31/2021, JM: NRC presentation of 12/09/20 by Mohsen Seifi noted these ASTM work items: • ASTM WK65937, *Additive Manufacturing -- Space Application -- Flight Hardware made by Laser Beam Powder Bed Fusion Process* • ASTM WK65929, *Additive Manufacturing-Finished Part Properties and Post Processing - Additively Manufactured Spaceflight Hardware by Laser Beam Powder Bed Fusion In Metals* • ASTM WK71395, *Additive manufacturing -- accelerated quality inspection of build health for laser beam powder bed fusion process* **11/20/2020, MW**: Bill Bihlman, SAE, Comment:

	[SAE AMS7032, *Additive Manufacturing Machine Qualification*]

Back to Top

Gap PC3: Machine Health Monitoring. There are no known industry standards addressing AM machine health monitoring. Machine health monitoring is a process of observing the machinery to identify changes that may indicate a fault. The use of a machine health monitoring system allows maintenance to be scheduled in a timely manner so as to prevent system failure.
R&D Needed: Yes
Recommendation: Adapt existing health monitoring (diagnostics and prognosis) standards for use in the additive manufacturing industry. Examples of such standards are the semiconductor industry "Interface A" collection of standards and ISO 13379-1:2012, *Condition monitoring and diagnostics of machines - Data interpretation and diagnostics techniques - Part 1: General guidelines* and ISO 13381-1:2015, *Condition monitoring and diagnostics of machines - Prognostics - Part 1: General guidelines*. Additional information can be found in NISTIR 8012, *Standards Related to Prognostics and Health Management (PHM) for Manufacturing*.[1] Further research/guidelines/specifications may be needed. For example, NIST may be able to identify critical indicators that need to be documented or controlled to assist end users with quality assurance. See also Gap M6, Tracking Maintenance.
Priority: Low
Organization: NIST, ISO, ASTM, AWS, IEEE-ISTO PWG, ASME
v2 Status of Progress: Not Started, or Unknown
v2 Update: ASME has a non AM-specific project concerning Advanced Monitoring, Diagnostics, and Prognostics for Manufacturing Operations.
Updates Since v2 was Published: **8/5/2020, MW**: ASTM AMCOE *Strategic Roadmap for Research & Development* (April 2020) notes that AMCOE Project 1901 (WK71395) addresses AMSC Gap PC3. **3/17/2020, JM:** Jessica Coughlin, AWS D20, comments: "Would the testing of witness specimens fall under this category? AWS D20.1 addresses this topic (8.3.1.2)."

New Published Standards	New In-Development Standards
	3/31/2021, JM: NRC presentation of 12/09/20 by Mohsen Seifi noted these ASTM work items: ASTM WK71395, *Additive manufacturing -- accelerated quality inspection of build health for laser beam powder bed fusion process* **11/13/2020, MW**: Steve Weinman, ASME, comment: The Committee is about 75% complete with a draft, with the intention to proceed to subcommittee balloting in December 2020. The draft guideline is an extension of the white paper and will cover: Baseline Metrics and identification of pain points, PHM readiness characterization, where to deploy and improve existing PHM deployments, and the determination of a PHM business case for manufacturing systems. **4/9/2020, MW**: Steve Weinman, ASME, comment: ASME has a non AM-specific project concerning Advanced Monitoring, Diagnostics, and Prognostics for Manufacturing Operations which is being conducted by the ASME PHM Subcommittee. Current efforts of this Subcommittee are focused on the development of guidelines that manufacturers can use to identify opportunities and implement advanced monitoring, diagnostic, and prognostic technologies within their facilities. The guidelines are being written in an agnostic manner such that they could be applied to operations involving subtractive machine tools, robotics, or additive processes.

[1] http://dx.doi.org/10.6028/NIST.IR.8012

Back to Top

Gap PC4: Machine Qualification. Current users may not have considered the influence of machine control on resulting product quality and material properties beyond form and fit, including machine-to-machine variation (even between machines of the same make and model). While guidelines for machine qualification can be developed, a broader view of part-specific, process-specific, material-specific, and application-specific recommended practices is needed.

R&D Needed: Yes

Recommendation: SDOs should develop qualification standards for AM machines to pass in order to provide a level of confidence that these machines can produce parts with the required material properties. In addition, SDOs should develop guidelines or technical reports that incorporate case studies of various part types and applications across materials. Additional research may be needed in relation to machine-to-machine variation and on key parameters.

Priority: Medium

Organization: NIST, AWS, SAE AMS-AM, ASTM F42, NAVSEA, NASA MFSC

v2 Status of Progress: Green

v2 Update: As noted in the text.

Updates Since v2 was Published:
8/5/2020, MW: ASTM AMCOE *Strategic Roadmap for Research & Development* (April 2020) notes that AMCOE Projects 1804/1907 (WK65937, WK65929), and 1901 (WK71395) address AMSC Gap PC4.
3/17/2020, MW: Jessica Coughlin, AWS D20, comment: AWS D20.1 provides detailed requirements for the qualification of AM machines. These involve the testing of material built throughout the volume of the machine, at different thicknesses and orientations. See Clause 5.

New Published Standards

11/26/20, JM: ISO/ASTM52941 - Additive manufacturing — System performance and reliability — Acceptance tests for laser metal powder-bed fusion machines for metallic materials for aerospace application is a new standard, now available. F3472-20 developed by Committee F42.07, ASTM BOS Volume 10.04

10/27/2020, MW: ASTM ISO/ASTM52903-2-20, *Additive manufacturing — Material extrusion-based additive manufacturing of plastic materials — Part 2: Process equipment* is a new standard, now available. F3475-20 developed by Committee F42.05, ASTM BOS Volume 10.04.

8/13/2020, JM: ASTM F3434-20, *Guide for Additive manufacturing – Installation/Operation and Performance Qualification (IQ/OQ/PQ) of Laser-Beam Powder Bed Fusion Equipment for Production Manufacturing* is a new standard, now available. F3434-20 developed by Committee *F42.05*, ASTM BOS Volume *10.04*.

1/21/20, JM: ISO/ASTM 52904:2019, *Additive manufacturing – Process characteristics and performance – Practice for metal powder bed fusion process to meet critical applications* was published

New In-Development Standards

3/31/2021, JM: NRC presentation of 12/09/20 by Mohsen Seifi noted these ASTM work items:

- ASTM WK65937, *Additive Manufacturing -- Space Application -- Flight Hardware made by Laser Beam Powder Bed Fusion Process*
- ASTM WK65929, *Additive Manufacturing-Finished Part Properties and Post Processing - Additively Manufactured Spaceflight Hardware by Laser Beam Powder Bed Fusion In Metals*
- ASTM WK71395, *Additive manufacturing -- accelerated quality inspection of build health for laser beam powder bed fusion process*

8/19/2020, JM:

- ASTM WK73688, New Specification for Additive manufacturing -- Qualification principles -- Generic machine evaluation and KPI Definition for LPBF-M Processes in Automotive Applications
- ISO/ASTM PRF TS 52930, *Guideline for Installation — Operation — Performance Qualification (IQ/OQ/PQ) of laser-beam powder bed fusion equipment for production manufacturing*
- ASTM WK65420, *Additive manufacturing Guideline for Installation, Operation and Performance Qualification (IQ/OQ/PQ) of Laser-Beam Powder Bed Fusion Equipment for Production Manufacturing*
- ASTM WK73231, *Additive manufacturing -- System performance and reliability -- Acceptance tests for laser metal powder-bed fusion machines for metallic materials for aerospace application*

5/14/20, JM: *SAE AMS7032, Additive Manufacturing Machine Qualification* is in development

Commented [A24]: This will replace F3434-20

Commented [A25]: Looks the same as 52930 but doesn't appear in F42.05 list

Back to Top

Gap PC5: Parameter Control. As a result of the many sources of variability within and among AM parts, and because a complete understanding of the specific effects of so many build process parameters on AM part performance is not currently available in the AM industry, standards are needed to identify requirements for demonstrating that a set of build process parameters produces an acceptable part, and for ensuring that those build process parameters remain consistent from build to build.
R&D Needed: Yes. Develop and establish one verifiable key process parameter that combines both material and process parameters (such as power absorption coefficient or power ratio parameter, verifiable by melt pool geometry, as shown in the research) that is independent of material and machine brand. R&D is needed to verify the concept of power ratio as the single controlling parameter and its applicability to all materials and machine brands.
Recommendation: Develop a standard that identifies key build process parameters for AM machines, taking into account the different processes, materials, industry-specific applications, and machines involved. Complete work on AWS D20.1. See also Gap QC3 on harmonizing Q&C terminology for process parameters.
Priority: Medium
Organization: AWS D20, ASTM F42, SAE AMS-AM, OEMs, IEEE-ISTO PWG
v2 Status of Progress: Green
v2 Update: As noted in the text, AWS D20.1 has been drafted. ASTM F42 process and materials standards cover the parameters for PBF and Inconel 625 but not the values. SAE AMS7100 is trying to address FDM process control including setting parameters for the aerospace industry. SAE AMS7003 includes an appendix on PBF-L process characteristics but contains no values.
Updates Since v2 was Published: **8/5/2020, MW**: ASTM AMCOE *Strategic Roadmap for Research & Development* (April 2020) notes that AMCOE Projects 1804/1907 (WK65937, WK65929) address AMSC Gap PC5. **3/17/2020, MW**: Jessica Coughlin, AWS D20, comment: AWS D20.1 [published in 2019] provides a listing of important process parameters in Table 5.2 (PBF) and Table 5.3 (DED), referred to as "qualification variables." These include variables related to build design, material, machine, environment, heat source characteristics, deposition characteristics, and post-build processing. AWS D20.1 provides requirements for qualifying an AM procedure, after which full or partial requalification is required for any changes beyond the qualified limits identified in Table 5.2 or Table 5.3 for each parameter.

New Published Standards	**New In-Development Standards**
11/20/2020, MW: Bill Bihlman, SAE, Comment • SAE AMS7004, *Titanium Alloy Preforms from Plasma Arc Directed Energy Deposition Additive Manufacturing on Substrate, Ti-6Al-4V, Stress Relieved* (Jan 2019) • SAE AMS7008, *Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 47.5Ni - 22Cr - 1.5Co - 9.0Mo - 0.60W - 18.5Fe* (March 2019) • SAE AMS7012, *Precipitation Hardenable Steel Alloy, Corrosion and Heat-Resistant Powder for Additive Manufacturing 16.0Cr - 4.0Ni - 4.0Cu - 0.30Nb* (Nov 2019) • SAE AMS7013, *Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 60Ni - 22Cr - 2.0Mo - 14W - 0.35Al - 0.03La* (Jan 2019) • SAE AMS7014, *Titanium Alloy, High Temperature Applications, Powder for Additive Manufacturing, Ti - 6.0Al - 2.0Sn - 4.0Zr - 2.0Mo* (Mar 2019) • SAE AMS7018, Aluminum Alloy Powder 10.0Si – 0.35Mg (May 2020) • *SAE AMS7021, Stainless Steel Powder, 15-5PH Alloy* **11/20/2020, JM:** *SAE AMS7100, Fused Filament Fabrication, Process Specification for* (Oct 2019) **10/27/2020, MW**: ASTM ISO/ASTM52903-2-20, *Additive manufacturing — Material extrusion-based*	**3/31/2021, JM:** NRC presentation of 12/09/20 by Mohsen Seifi noted these ASTM work items: • ASTM WK65937, *Additive Manufacturing -- Space Application -- Flight Hardware made by Laser Beam Powder Bed Fusion Process* • ASTM WK65929, *Additive Manufacturing-Finished Part Properties and Post Processing - Additively Manufactured Spaceflight Hardware by Laser Beam Powder Bed Fusion In Metals* **11/20/2020, MW**: Bill Bihlman, SAE, Comment: • *SAE AMS7000A, Laser-Powder Bed Fusion (L-PBF) Produced Parts, Nickel Alloy, Corrosion and Heat-Resistant, 62Ni - 21.5Cr - 9.0Mo - 3.65Nb Stress Relieved, Hot Isostatic Pressed and Solution Annealed* (Feb 2020) • *SAE AMS7012A, Precipitation Hardenable Steel Alloy, Corrosion and Heat-Resistant Powder for Additive Manufacturing 16.0Cr - 4.0Ni - 4.0Cu - 0.30Nb* (Mar 2020) • *SAE AMS7015 - Ti-6Al-4V, Powder For Additive Manufacturing* (Sep 2018) • *SAE AMS7016, Laser-Powder Bed Fusion (L-PBF) Produced Parts, 17-4PH H1025 Alloy* (Oct 2018) • SAE AMS7017, *Titanium 6-Aluminum 4-Vanadium Powder for Additive Manufacturing, ELI Grade* (Feb 2019) • *SAE AMS7020, Aluminum Alloy Powder, F357 Alloy* (May 2019)

additive manufacturing of plastic materials — Part 2: Process equipment is a new standard, now available. F3475-20 developed by Committee F42.05, ASTM BOS Volume 10.04. **1/21/20, JM:** ISO/ASTM 52904:2019, *Additive manufacturing – Process characteristics and performance – Practice for metal powder bed fusion process to meet critical applications* was published **4/4/2019, LY:** The AWS recently published a new standard on AM, *AWS D20.1/D20.1M:2019 Specification for Fabrication of Metal Components using Additive Manufacturing*.	• *SAE AMS7023, Gamma Titanium Aluminide Powder for Additive Manufacturing, Ti-48Al-2Nb-2Cr* (May 2019) • *SAE AMS7024, Inconel 718 L-PBF Material specification* (Jun 2019) • *SAE AMS7025, Metal Powder Feedstock Size Classifications for Additive Manufacturing* (Jun 2019) • *SAE AMS7026, Powder Titanium 5553* (Jan 2020) • *SAE AMS7028, Laser-Powder Bed Fusion (L-PBF) Produced Parts, Titanium Alloy, Ti-6Al-4V Stress Relieved, and Hot Isostatic Pressed* (Jan 2020) • *SAE AMS7030, Laser- Powder Bed Fusion (L-PBF) Produced Parts of AlSi10Mg* (Feb 2020) • *SAE AMS7033, Aluminum Alloy Powder A205 (AlCuTiBAgMg)* (May 2020) • *SAE AMS7035 - Precipitation Hardenable Steel Alloy, Corrosion and Heat-Resistant, Powder for Binder Jet Additive Manufacturing, 16.0Cr – 4.0Ni – 4.0Cu - 0.30Nb* (Sep 2020)

Back to Top

Gap PC6: Adverse Machine Environmental Conditions: Effect on Component Quality. There is a need for more research as well as standards or specifications that address AM machines being able to work in adverse environmental conditions.	
R&D Needed: Yes.	
Recommendation: Develop standards and specifications to address external environmental factors that could negatively impact component quality.	
Priority: Low	
Organization: OEMs, DoD for military-specific operational environments, ASTM	
v2 Status of Progress: Unknown	
v2 Update: None provided	
Updates Since v2 was Published:	
New Published Standards **11/20/2020, MW**: Bill Bihlman, SAE, Comment: • *SAE AMS7005, Wire Fed Plasma Arc Directed Energy Deposition Additive Manufacturing Process* (Jan 2019) • SAE AMS7007, *Electron Beam Powder Bed Fusion Process* (Jul 2020) • SAE AMS7010, *Wire Fed Laser Directed Energy Deposition Additive Manufacturing Process (L-DED-wire)* (Jan 2020) • *SAE AMS7022, Binder Jetting Process* (Nov 2020) • *SAE AMS7027, Electron Beam Wire Fusion Process* (Nov 2020)	**New In-Development Standards** **11/20/2020, MW**: Bill Bihlman, SAE, Comment: • *SAE AMS7002A, Process Requirements for Production of Metal Powder Feedstock for Use in Additive Manufacturing of Aerospace Parts* (Aug 2018) • *SAE AMS7003A, Laser Powder Bed Fusion Process* (Jun 2019) • *SAE AMS7010A, Wire Fed Laser Directed Energy Deposition Additive Manufacturing Process (L-DED-wire)* (Jan 2020) • *SAE AMS7029, Cold Metal Transfer Directed Energy Deposition (CMT-DED) Process* (Feb 2020) • *SAE AMS7031, Process Requirements for Recovery and Recycling of Metal Powder Feedstock for Use in Additive Manufacturing of Aerospace Parts* (Apr 2020) • *SAE AMS7034 - Hybrid Laser Arc Directed Energy Deposition (HLA-DED) (Aug 2020)*

Back to Top

Gap PC7: Recycle & Re-use of Materials. There are many practices in the materials industry of how to recycle, re-use, and revert materials in production. They are also highly material dependent. End users need to understand best practices for how to qualify their various precursor material streams.
R&D Needed: Yes. Research should be conducted to understand the effects of mixing ratios of reused to virgin material.
Recommendation: Develop guidance as to how reused materials may be quantified and how their history should be tracked (e.g., number of re-uses, number of exposure hours [for a laser system], or some other metric). Guidelines for sieving reused powder prior to mixing must be created.
Priority: High
Organization: ASTM F42/ISO TC 261, ASTM D20, AWS, MPIF, NIST, SAE, trusted end user-group
v2 Status of Progress: Green
v2 Update: SAE is looking at it on the aerospace side. NIST has published one study on the subject on metals but more R&D is needed before you can build parts to be qualified.
Updates Since v2 was Published: **3/17/2020, MW**: Jessica Coughlin, AWS D20, comment: AWS D20.1 (paragraph 7.4.2.3) provides requirements for re-testing powder to ensure that it is still acceptable for use following certain events such as recycling, blending, mixing, reconditioning, or extended storage.

New Published Standards	**New In-Development Standards**
11/20/2020, MW: Bill Bihlman, SAE, Comment: • *SAE AMS7005, Wire Fed Plasma Arc Directed Energy Deposition Additive Manufacturing Process* (Jan 2019) • SAE AMS7007, *Electron Beam Powder Bed Fusion Process* (Jul 2020) • SAE AMS7010, *Wire Fed Laser Directed Energy Deposition Additive Manufacturing Process (L-DED-wire)* (Jan 2020) • *SAE AMS7022, Binder Jetting Process* (Nov 2020) • *SAE AMS7027, Electron Beam Wire Fusion Process* (Nov 2020)	**3/31/2021, JM:** ISO/ASTM AWI 52928, *Additive manufacturing — Feedstock materials — Powder life cycle management* **11/20/2020, MW**: Bill Bihlman, SAE, Comment: • *SAE AMS7002A, Process Requirements for Production of Metal Powder Feedstock for Use in Additive Manufacturing of Aerospace Parts* (Aug 2018) • *SAE AMS7003A, Laser Powder Bed Fusion Process* (Jun 2019) • *SAE AMS7010A, Wire Fed Laser Directed Energy Deposition Additive Manufacturing Process (L-DED-wire)* (Jan 2020) • *SAE AMS7029, Cold Metal Transfer Directed Energy Deposition (CMT-DED) Process* (Feb 2020) • *SAE AMS7031, Process Requirements for Recovery and Recycling of Metal Powder Feedstock for Use in Additive Manufacturing of Aerospace Parts* (Apr 2020) • *SAE AMS7034 - Hybrid Laser Arc Directed Energy Deposition (HLA-DED) (Aug 2020)*

Back to Top

Gap PC8: Stratification. Powders used in additive manufacturing are composed of a distribution of particle sizes. Stratification may take place during container filling, transportation, or handling before and after being received by a user of powder. Users must know what conditioning is appropriate to ensure that the powder's particle size distribution is consistent and acceptable for the specific process. There is currently a lack of guidance in this area.
R&D Needed: Yes. Research should be conducted to understand the effect of stratification on particle size distribution of as-received powder and mixed powder prior to being put into service. The results from this work can be used to guide the re-blending of powder before being put into service.
Recommendation: Develop guidelines on how to maintain OEM characteristics in new use and re-use powder scenarios. There is documented variability in the final part properties in various AM processes; the AM community must either rule out stratification of powder precursor material or provide guidelines for mixing of lots to achieve acceptable particle size distribution.
Priority: Medium
Organization: NIST, trusted end user-group, ASTM
v2 Status of Progress: Unknown
v2 Update: None provided
Updates Since v2 was Published:

New Published Standards	**New In-Development Standards**

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11/20/2020, MW: Bill Bihlman, SAE, Comment: • SAE AMS7008, *Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 47.5Ni - 22Cr - 1.5Co - 9.0Mo - 0.60W - 18.5Fe* (March 2019) • SAE AMS7012, *Precipitation Hardenable Steel Alloy, Corrosion and Heat-Resistant Powder for Additive Manufacturing 16.0Cr - 4.0Ni - 4.0Cu - 0.30Nb* (Nov 2019) • SAE AMS7013, *Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 60Ni - 22Cr - 2.0Mo - 14W - 0.35Al - 0.03La* (Jan 2019) • SAE AMS7014, *Titanium Alloy, High Temperature Applications, Powder for Additive Manufacturing, Ti - 6.0Al - 2.0Sn - 4.0Zr - 2.0Mo* (Mar 2019) • SAE AMS7018, Aluminum Alloy Powder 10.0Si – 0.35Mg (May 2020) • *SAE AMS7021, Stainless Steel Powder, 15-5PH Alloy*	**11/20/2020, MW**: Bill Bihlman, SAE, Comment: • *SAE AMS7012A, Precipitation Hardenable Steel Alloy, Corrosion and Heat-Resistant Powder for Additive Manufacturing 16.0Cr - 4.0Ni - 4.0Cu - 0.30Nb* (Mar 2020) • *SAE AMS7015 - Ti-6Al-4V, Powder For Additive Manufacturing* (Sep 2018) • SAE AMS7017, *Titanium 6-Aluminum 4-Vanadium Powder for Additive Manufacturing, ELI Grade* (Feb 2019) • *SAE AMS7020, Aluminum Alloy Powder, F357 Alloy* (May 2019) • *SAE AMS7023, Gamma Titanium Aluminide Powder for Additive Manufacturing, Ti-48Al-2Nb-2Cr* (May 2019) • *SAE AMS7025, Metal Powder Feedstock Size Classifications for Additive Manufacturing* (Jun 2019) • *SAE AMS7026, Powder Titanium 5553* (Jan 2020) • *SAE AMS7033, Aluminum Alloy Powder A205 (AlCuTiBAgMg)* (May 2020) • *SAE AMS7035 - Precipitation Hardenable Steel Alloy, Corrosion and Heat-Resistant, Powder for Binder Jet Additive Manufacturing, 16.0Cr – 4.0Ni – 4.0Cu - 0.30Nb* (Sep 2020) • *SAE GAAM-M20A, Aluminum Alloy Powder Template* (Apr 2020) • *SAE GAAM-M20B, Cobalt, Iron, or Nickel Alloy Powder Template* (Apr 2020) • *SAE GAAM-M20C, Titanium Powder Template* (Apr 2020)

Back to Top

Gap PC9: Environmental Conditions: Effects on Materials. AM materials can be sensitive to changes in environmental conditions including temperature, humidity, and ultraviolet radiation. Therefore, general guidance must be provided to ensure the environmental conditions in which the material is used and stored remain within acceptable ranges for all material types. Specific material packaging requirements are addressed in Section 2.2.1.3.9. No standards or specifications have been identified regarding this topic.	
R&D Needed: Yes.	
Recommendation: Develop guidance on the storage of AM materials so that AM materials are stored and used in environments with acceptable conditions. Research should be conducted to identify these ranges.	
Priority: High	
Organization: ASTM F42/ISO TC 261, NIST, SAE, UL, Powder Manufacturers/Suppliers	
v2 Status of Progress: Green	
v2 Update: UL 3400, *Outline of Investigation for Additive Manufacturing Facility Safety Management*, is a document for the evaluation and certification of any additive manufacturing facility that uses powder as the initial form of feedstock material to print parts. It identifies the potential hazards within an AM facility, which includes environmental conditions. It does not provide specific reference to acceptable ranges for material storage within a facility. The effect of environmental conditions on AM materials can be dependent on a number of factors, which can vary by facility. UL 3400 provides guidance based on the requirements and conditions of the facility being evaluated. ASTM F42.06 is looking at environmental conditions for storage via work item ASTM WK59813, *New Guide for Hazard Risk Ranking and Safety Defense*. SAE AMS7003, *Laser Powder Bed Fusion Process*, contains requirements for feedstock powder handling and storage plans.	
Updates Since v2 was Published: **7/18/19 JM:** ASTM WK59813 was deleted due to lack of activity.	
New Published Standards	**New In-Development Standards**

11/20/2020, MW: Bill Bihlman, SAE, Comment: • *SAE AMS7005, Wire Fed Plasma Arc Directed Energy Deposition Additive Manufacturing Process* (Jan 2019) • SAE AMS7007, *Electron Beam Powder Bed Fusion Process* (Jul 2020) • SAE AMS7010, *Wire Fed Laser Directed Energy Deposition Additive Manufacturing Process (L-DED-wire)* (Jan 2020) • *SAE AMS7022, Binder Jetting Process* (Nov 2020) • *SAE AMS7027, Electron Beam Wire Fusion Process* (Nov 2020)	**3/31/2021, JM:** ISO/ASTM AWI 52928**,** *Additive manufacturing — Feedstock materials — Powder life cycle management* **11/20/2020, MW**: Bill Bihlman, SAE, Comment: • *SAE AMS7002A, Process Requirements for Production of Metal Powder Feedstock for Use in Additive Manufacturing of Aerospace Parts* (Aug 2018) • *SAE AMS7003A, Laser Powder Bed Fusion Process* (Jun 2019) • *SAE AMS7010A, Wire Fed Laser Directed Energy Deposition Additive Manufacturing Process (L-DED-wire)* (Jan 2020) • *SAE AMS7029, Cold Metal Transfer Directed Energy Deposition (CMT-DED) Process* (Feb 2020) • *SAE AMS7031, Process Requirements for Recovery and Recycling of Metal Powder Feedstock for Use in Additive Manufacturing of Aerospace Parts* (Apr 2020) • *SAE AMS7034 - Hybrid Laser Arc Directed Energy Deposition (HLA-DED)* (Aug 2020) **8/19/2020, JM:** ASTM WK73227, Additive Manufacturing -- Investigation for Additive Manufacturing (AM) Facility Safety Management

Back to Top

Gap PC10. Re-use of Material that Has Not Been Processed. There is a lack of industry guidance on the re-use of material that has not been processed.	
R&D Needed: Yes.	
Recommendation: Develop a standard for the re-use of material that was not processed but is already within the system (e.g., for inkjet it can be in the plumbing, the reservoirs, the printing heads, etc.).	
Priority: Medium	
Organization: ISO/ASTM	
v2 Status of Progress: Unknown	
v2 Update: None provided	
Updates Since v2 was Published:	
New Published Standards	**New In-Development Standards** **11/20/2020, MW**: Bill Bihlman, SAE, Comment: *SAE AMS7031, Process Requirements for Recovery and Recycling of Metal Powder Feedstock for Use in Additive Manufacturing of Aerospace Parts* (Apr 2020)

Back to Top

Gap PC11: Re-use of Material that Has Been Processed. There is a lack of industry guidance on the re-use of material that was already processed.
R&D Needed: Yes.
Recommendation: Develop a standard for re-use of material that was already processed and cannot be reused as precursor material. For inkjet, there are two concerns: Material that was jetted but not polymerized and material that was polymerized to some extent (waste from each processed layer or the actual support material). Example: non-polymerized material that was jetted can be reused as material to fill bulky areas of the model (by filtering, re-jetting, and polymerizing).
Priority: Low
Organization: ASTM
v2 Status of Progress: Unknown
v2 Update: None provided
Updates Since v2 was Published:

11/13/2020, MW: Steve Weinman, ASME, comment: ASME is forming a Working Group to address this for use of recycled polymers.	
New Published Standards	**New In-Development Standards** **11/20/2020, MW**: Bill Bihlman, SAE, Comment: *SAE AMS7031, Process Requirements for Recovery and Recycling of Metal Powder Feedstock for Use in Additive Manufacturing of Aerospace Parts* (Apr 2020)

Back to Top

Gap PC12: Precursor Material Flow Monitoring. There is no known standard for defining: • Method of DED process powder flow monitoring • Location of monitoring • Accuracy of flow monitoring • Standardized calibration process of flow	
R&D Needed: Yes.	
Recommendation: Develop a standard for DED process powder flow monitoring so that operators/users will have a way to ensure the powder flow is coming out consistently and with minimal fluctuations so as to not alter the desired build and its properties. See also Gap PM1 on flowability.	
Priority: Medium	
Organization: NIST, ISO/ASTM	
v2 Status of Progress: Unknown	
v2 Update: None provided	
Updates Since v2 was Published:	
New Published Standards	**New In-Development Standards**

Back to Top

Gap PC13: Flow Parameters for Material Jetting. No published standards or standards in development have been identified for monitoring and control of all flow related parameters for material jetting.	
R&D Needed: Yes.	
Recommendation: Develop a standard for monitoring and controlling all flow parameters for material jetting such as flow rate, temperature, viscosity, pressure level, wetting of the orifice plate, etc. This standard should include: • Monitoring and controlling similar flow in different material feeding channels. This is needed to allow multi-material printing while minimizing cross talk or non-uniformity between channels keeping quality of all printed materials. • Controlling the thickness of the printed layer. In material jetting, the material flows to the surface and controlling the thickness of each layer is clearly critical to maintain quality. The layer thickness can be controlled by controlling the material flow within the system and within the printing heads as well as by direct measurement after deposition. • Expanding the performance envelope to enable more degrees of freedom for the flow of material. For example, to enable a wider range of temperatures, humidity control, oxygen level control, ink recirculation in the print heads, etc. All this can allow using more viscous materials, with larger filler particles and exotic materials that might not be compatible with the print head materials in a standard environment.	
Priority: Low	
Organization: NIST, OEMs, ASTM, IEEE-ISTO PWG	
v2 Status of Progress: Unknown	
v2 Update: None provided	
Updates Since v2 was Published:	
New Published Standards	**New In-Development Standards**

Back to Top

Gap PC14: Environmental Health and Safety: Protection of Machine Operators. There is a need for standards to address environmental health and safety (EHS) in the AM process. Typical hazards to be addressed include:

guarding from moving parts that are not protected from contact; chemical handling (liquids, powders, wires); air emissions (dusts, vapors, fumes); noise (cleaning apparatus); electrical (water wash systems, electro-static systems); flammable/combustible cleaning materials; solid waste; laser use (sintering processes); and UV light (may require eye and skin protection based on design). See Gaps P5 and P6 in section 2.2.3.6 related to health and safety, specifically to toxic gases/vapors from polymers.
R&D Needed: Yes.
Recommendation: Recommend creating a standard addressing EHS issues relative to additive machines (power, laser, handling, air quality, etc.). Physical measurement of operator exposure to AM materials is one of the most critical needs and can be leveraged from existing industry standards. As noted in the text, research is underway.
Priority: High
Organization: ASTM F42/ISO TC 261, UL, ASSP, B11, LIA (Z136), ISO/TC 262
v2 Status of Progress: Green
v2 Update: UL has published UL 3400, *Outline of Investigation for Additive Manufacturing Facility Safety Management*, for the evaluation and certification of any additive manufacturing facility that uses powder feedstock to print parts. ASTM WK59813, *New Guide for Hazard Risk Ranking and Safety Defense*, is being developed to cover risks associated with different types of AM technologies and the recommended PPE and safety measures. ISO/TC 261 has a Working Group on *Environment, health and safety* (ISO/TC 261/WG 6), and two Joint Groups with ASTM F42 on AM: *EH&S for 3D printers* (ISO/TC 261/JG68) and *EH&S for use of metallic materials* (ISO/TC 261/JG69).
Updates Since v2 was Published: **7/18/19 JM:** ASTM WK59813 was deleted due to lack of activity.

New Published Standards	**New In-Development Standards**
	8/19/2020, JM: • ASTM WK73227, Additive Manufacturing -- Investigation for Additive Manufacturing (AM) Facility Safety Management • ASTM WK72391, *Additive manufacturing -- Environment, health and safety -- Standard guideline for use of metallic materials*

Back to Top

Gap PC15. Configuration Management: Cybersecurity. Best practices for maintaining and controlling the programming environment for additive processes are needed to ensure repeatable product quality.
R&D Needed: Yes.
Recommendation: Develop best practices to protect digital files used in the AM process. See also Gap M7 on cybersecurity for maintenance.
Priority: Medium
Organization: America Makes, NIST, UL, IEEE-ISTO PWG
v2 Status of Progress: Unknown
v2 Update: None provided
Updates Since v2 was Published:

New Published Standards	**New In-Development Standards**

Back to Top

Gap PC16: In-Process Monitoring. No published standards have been identified that address 1) the conversion of in-process monitoring data into an accurate 3D file representing the part manufactured, or 2) the use of in-process monitoring data to self-monitor and self-calibrate processing equipment. More than likely, there will be no "one size fits all" standard for any given additive process, piece of equipment, or material. It would be highly dependent on end user analytics of OEM or internally developed sensing systems. A standard guide is being developed in ASTM E07 (WK62181) that covers conversion of in-process monitoring data into an accurate 3D file representing the part manufactured, based on real-time measurement of part dimensions, surface finish, density, hot spots, or defect state during the build. Ideally, the information gathered during in-process monitoring is used to evaluate part acceptance, as a go/no-go before expensive post-processing operations are performed, and/or to guide NDE performed on the part after build.

R&D Needed: Yes. Seamless incorporation of sensor-based monitoring techniques into the build without interfering with the build is nontrivial. While commercial based systems have been developed (for example, visible-spectrum layer-wise imaging; co-axial melt pool monitoring (visible or near-infrared); infrared, off-axis thermography; single-point, and off-axis pyrometry and/or photodetectors), other techniques (for example, spectroscopic measurements of plume; high speed visible-spectrum imaging (stationary view); single-point surface profilometry; and in-situ laser ultrasonic or AE monitoring) are lower TRL and warrant additional R&D.	
Recommendation: Issue standards on in-process monitoring of the feedstock (supply ratios and other metrics), process conditions (atmosphere, humidity), process parameters (beam diagnostics such as location, laser power, scan width, scan rate), and the part during build (dimensions, surface finish, density, hot spots, defect state). See also Gap D22 on the use of physics-based models and simulation tools (analytics).	
Priority: Medium, given the relatively low TRL state of the art	
Organization: ASTM E07.10	
v2 Status of Progress: Yellow	
v2 Update: ASTM E7.10 is developing a draft guide WK62181 on in-process monitoring covering commercial based systems (visible-spectrum layer-wise imaging; co-axial melt pool monitoring (visible or near-infrared); infrared, off-axis thermography; single-point, off-axis pyrometry and/or photodetectors). Potentially, other techniques that show promise will be included (spectroscopic measurements of plume; high speed visible-spectrum imaging (stationary view); single-point surface profilometry; and in-situ laser ultrasonic or AE monitoring). The goal of WK62181 is to obtain a layer-by-layer (3D) file or quality record showing the as-built part is defect-free or contains no critical flaws, or exhibits an in-family (nominal) response when interrogated during the build. WK62181 does not address control of equipment functions such as feedstock supply, process conditions, or process parameters (no known gap), or physics-based models or simulation tools used in prognostics or diagnostics (see Gap D22).	
Updates Since v2 was Published: **8/5/2020, MW**: ASTM AMCOE *Strategic Roadmap for Research & Development* (April 2020) notes that AMCOE Project 1906 (WK74390) addresses AMSC Gap PC16.	
New Published Standards	**New In-Development Standards** **3/19/21, JM:** *ASTM* WK74390, *Additive Manufacturing of Metals -- Data -- File structure for in-process monitoring of powder bed fusion*

Commented [A26]: 4/2/2021, JM: Per 12/9/20 NRC presentation by Mohsen Seifi

Commented [A27]: The draft standard indicates it is being developed specifically to address gap PC16.

Back to Top

Other Process Control Activity - Relevance to Gaps Not Yet Determined

New Published Standards

New In-Development Standards

ISO/ASTM PWI 52927, Additive manufacturing — Process characteristics and performance - Test methods

ISO/ASTM CD 52931, *Additive manufacturing — Environmental health and safety — Standard guideline for use of metallic materials*

ISO/ASTM CD 52932, *Additive manufacturing — Environmental health and safety — Standard test method for determination of particle emission rates from desktop 3D printers using material extrusion*

ASTM WK66473, *Additive Manufacturing Environment, Health, and Safety Test Method for Determination of Particle and Chemical Emission Rates From Desktop 3D Printer Material Extrusion*

ASTM WK70918, *Additive manufacturing -- Environment, Health, and Safety -- Test method for the hazardous substances emitted from ME- type 3D printers in non-industrial places*

ISO/ASTM WD 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 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

Commented [A28]: 3/31/2021, JM: Noted in 12/09/20 NRC presentation by Mohsen Seifi

Commented [A29]: 3/31/2021, JM: List of preliminary work items found here https://committee.iso.org/sites/tc261/home/projects/ongoing/ongoing-1.html

ISO/ASTM PWI 52944
Additive manufacturing — Process characteristics and performance — Standard specification for powder bed processes in aerospace applications
ISO/ASTM WD 52917, Additive manufacturing — Round Robin Testing — Guidance for conducting Round Robin studies
ASTM WK72317, Additive Manufacturing -- Powder Bed Fusion -- Multiple Energy Sources
SAE AMS7102 - High Performance Laser Sintering Process for Thermoplastic Parts for Aerospace Applications (Jan 2019)

Back to Top

Chapter 2.2.3. Post-processing

Medium Priority

- **Gap P1: Post-processing Qualification and Production Builds (11/20/2020)**
- **Gap P2: Heat Treatment (HT)-Metals (11/20/2020)**
- **Gap P3: Hot Isostatic Pressing (HIP) (11/20/2020)**
- **Gap P4: Surface Finish (3/31/2021)**

Low Priority

- **Gap P5: Use of Post-cure to Reduce Toxic Gases from Uncured Polymer Feedstock**
- **Gap P6: Guidelines for Post-curing AM Plastics to Address Outgassing and Offgassing**
- **NEW Gap P7: Heat Treatment (HT)-Polymers**

Back to Top

Gap P1. Post-processing Qualification and Production Builds. No known standards have been issued that require consistent post-processing to be applied for qualification and production builds.	
R&D Needed: Yes.	
Recommendation: Guideline standards should be issued that require consistent post-processing for the various AM processes to be applied for qualification and production builds. These standards should be process and material specific and should seek to define minimum best practices for qualification and production builds, along with reporting requirements.	
Priority: Medium	
Organization: AWS D20, ASTM F42/ISO TC 261 JG55, SAE	
v2 Status of Progress: Green	
v2 Update: For metals, AWS D20.1 is in development and SAE AMS7000 was published in June 2018. For polymers, ASTM F42/ISO TC 261 JG55 is in development for material extrusion.	
Updates Since v2 was Published: **3/17/2020, MW**: Jessica Coughlin, AWS D20, comment: AWS D20.1 requires that the same post-processing operations that will be performed on the production component be performed on the qualification builds (5.2.1.4 - PBF, 5.2.2.4 - DED). Post-build processing parameters are listed as qualification variables in Table 5.2 (PBF) and Table 5.3 (DED).	
New Published Standards **11/20/2020, MW**: Bill Bihlman, SAE, Comment: SAE AMS7004, *Titanium Alloy Preforms from Plasma Arc Directed Energy Deposition Additive Manufacturing on Substrate, Ti-6Al-4V, Stress Relieved* (Jan 2019) **4/4/2019, LY:** The AWS recently published a new standard on AM, *AWS D20.1/D20.1M:2019 Specification for Fabrication of Metal Components using Additive Manufacturing*.	**New In-Development Standards** **11/20/2020, MW**: Bill Bihlman, SAE, Comment: • *SAE AMS7000A, Laser-Powder Bed Fusion (L-PBF) Produced Parts, Nickel Alloy, Corrosion and Heat-Resistant, 62Ni - 21.5Cr - 9.0Mo - 3.65Nb Stress Relieved, Hot Isostatic Pressed and Solution Annealed* (Feb 2020) • *SAE AMS7016, Laser-Powder Bed Fusion (L-PBF) Produced Parts, 17-4PH H1025 Alloy* (Oct 2018) • *SAE AMS7024, Inconel 718 L-PBF Material specification* (Jun 2019)

	• *SAE AMS7028, Laser-Powder Bed Fusion (L-PBF) Produced Parts, Titanium Alloy, Ti-6Al-4V Stress Relieved, and Hot Isostatic Pressed* (Jan 2020) • *SAE AMS7030, Laser- Powder Bed Fusion (L-PBF) Produced Parts of AlSi10Mg* (Feb 2020)

Back to Top

Gap P2: Heat Treatment (HT)-Metals. The existing and in-development ASTM standards for HT of metals built using PBF state the requirements for a specific metal within the standard, but not all metals have been addressed, and stress relief heat treatments in these standards may not be optimized for AM. In addition, differences between laser-based and electron beam-based PBF processes are insufficiently addressed in the existing standards. In this example, both processes are considered to be the same regarding HT requirements, when in reality PBF-EB is performed at much higher temperature and may not require residual stress relief and produce a more uniform microstructure. Heat treatment requirements for metals made with non-powder processes such as directed energy deposition using wire feedstock, sheet lamination, etc., are currently not addressed in any standards except for titanium-6Al-4V via DED. There are currently no standards on heat treatments designed to reduce anisotropy in properties. In cases where AM materials requires HIP processing, the process may be modified to meet HT requirements as well, negating the need for additional HT standards.
R&D Needed: Yes. R&D is needed to determine the optimized heat treatments for AM materials as a function of materials and process.
Recommendation: As the need arises for new metals, new standards will have to be written for each one, containing specific HT information. Also, as differences are found in required HT for laser versus electron beam processes, these differences should be added to the existing standard for that metal. Standards for metals made with non-powder processes need to be developed that contain HT requirements specific to that metal and optimized for the appropriate production process. As heat treatments are found to reduce anisotropy in properties for particular metals, these should be added to the existing standards for those metals.
Priority: Medium
Organization: R&D: universities, OEMs, government research labs, and others. Standards development: ASTM F42, SAE AMS-AM.
v2 Status of Progress: Green
v2 Update: *SAE AMS7000, Laser-Powder Bed Fusion (L-PBF) Produced Parts, Nickel Alloy, Corrosion and Heat-Resistant, 62Ni - 21.5Cr - 9.0Mo - 3.65Nb Stress Relieved, Hot Isostatic Pressed and Solution Annealed*, states that several thermal processing steps (stress relief and solution annealing) need to be performed in accordance with SAE AMS2774E, *Heat Treatment, Wrought Nickel Alloy and Cobalt Alloy Parts*. ASTM F3301-18a, *Standard for Additive Manufacturing – Post Processing Methods – Standard Specification for Thermal Post-Processing Metal Parts Made Via Powder Bed Fusion* (formerly WK58233) addresses this.
Updates Since v2 was Published:

New Published Standards	**New In-Development Standards**
11/20/2020, MW: Bill Bihlman, SAE, Comment: SAE AMS7004, *Titanium Alloy Preforms from Plasma Arc Directed Energy Deposition Additive Manufacturing on Substrate, Ti-6Al-4V, Stress Relieved* (Jan 2019)	**11/20/2020, MW**: Bill Bihlman, SAE, Comment: • *SAE AMS7000A, Laser-Powder Bed Fusion (L-PBF) Produced Parts, Nickel Alloy, Corrosion and Heat-Resistant, 62Ni - 21.5Cr - 9.0Mo - 3.65Nb Stress Relieved, Hot Isostatic Pressed and Solution Annealed* (Feb 2020) • *SAE AMS7016, Laser-Powder Bed Fusion (L-PBF) Produced Parts, 17-4PH H1025 Alloy* (Oct 2018) • *SAE AMS7024, Inconel 718 L-PBF Material specification* (Jun 2019) • *SAE AMS7028, Laser-Powder Bed Fusion (L-PBF) Produced Parts, Titanium Alloy, Ti-6Al-4V Stress Relieved, and Hot Isostatic Pressed* (Jan 2020) • *SAE AMS7030, Laser- Powder Bed Fusion (L-PBF) Produced Parts of AlSi10Mg* (Feb 2020)

Back to Top

<table>
<tr><td colspan="2">Gap P3: Hot Isostatic Pressing (HIP). Just as for heat treatment and Gap P2, the existing HIP standards do not fully address AM material-related issues such as: slow cooling rate and its effect on formation of prior particle boundaries and carbide precipitation at grain boundaries, as well as the effect of thermal exposure on excessive grain growth, carbide size, incipient melting, and the effect of removing the part from the base plate before HIP. The HIP parameters in the existing AM standards are often developed for castings, forgings and sintered parts and may not be optimal for AM material since the thermal history, as-printed microstructure and property requirements often is a lot different from materials processed with the conventional manufacturing methods. Generally, the existing standards provide guidance for interpretation of processing parameters, tolerances, and conformance to industry accepted practices such as pyrometry, cleanliness, traceability, etc.</td></tr>
<tr><td colspan="2">R&D Needed: Yes</td></tr>
<tr><td colspan="2">Recommendation: Develop material specific standards based on R&D defined HIP parameters for AM with acceptance criteria for internal discontinuities. Some examples include the following:
• Effect of max thermal exposure on microstructure evolution (X temperature for more than X hours)
• Effect of cooling rate
• Discontinuities extended to the surface
• Incipient melting with and without voids
• Discontinuities larger than X inches depending on location
• Lack of fusion
• Interconnected porosity
• Nonmetallic contamination
• Cross contamination due to processing of different customer parts in commercial HIP vessels
• Grain morphology
• Material dependent microstructure (e.g., in 718 laves phase, delta phase morphology, etc.)
• Number of discontinuities larger than X in per certain view area (e.g., within 1 sq. inch)
• Number of discontinuities in subsurface area (X microns from the surface) larger than X inch
• Linear formation of discontinuities (other than interconnected porosity) and minimum distance of X inches between adjacent discontinuities.</td></tr>
<tr><td colspan="2">Priority: Medium</td></tr>
<tr><td colspan="2">Organization: R&D: various entities. Standards: ASTM F42, SAE AMS-AM, possibly SAE AMEC</td></tr>
<tr><td colspan="2">v2 Status of Progress: Green</td></tr>
<tr><td colspan="2">v2 Update: Some R&D is taking place in the commercial sector and at the university level. In terms of standards development, the referenced ASTM F42 work items may address the gap. SAE AMS7000 was published in June 2018 and SAE AMS AMEC is working on a HIP spec.</td></tr>
<tr><td colspan="2">Updates Since v2 was Published:</td></tr>
<tr><td>New Published Standards
11/20/2020, MW: Bill Bihlman, SAE, Comment:
SAE AMS7004, Titanium Alloy Preforms from Plasma Arc Directed Energy Deposition Additive Manufacturing on Substrate, Ti-6Al-4V, Stress Relieved (Jan 2019)</td><td>New In-Development Standards
11/20/2020, MW: Bill Bihlman, SAE, Comment:
• SAE AMS7000A, Laser-Powder Bed Fusion (L-PBF) Produced Parts, Nickel Alloy, Corrosion and Heat-Resistant, 62Ni - 21.5Cr - 9.0Mo - 3.65Nb Stress Relieved, Hot Isostatic Pressed and Solution Annealed (Feb 2020)
• SAE AMS7016, Laser-Powder Bed Fusion (L-PBF) Produced Parts, 17-4PH H1025 Alloy (Oct 2018)
• SAE AMS7024, Inconel 718 L-PBF Material specification (Jun 2019)
• SAE AMS7028, Laser-Powder Bed Fusion (L-PBF) Produced Parts, Titanium Alloy, Ti-6Al-4V Stress Relieved, and Hot Isostatic Pressed (Jan 2020)
• SAE AMS7030, Laser- Powder Bed Fusion (L-PBF) Produced Parts of AlSi10Mg (Feb 2020)</td></tr>
</table>

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Back to Top

Gap P4: Surface Finish. Unique features, such as helixes, spirals, lattice structures, and internal surfaces and cavities, can be manufactured using AM versus subtractive machining. However, the applicability of current measurement methods to the surface of these features is not clear or captured in standards. For example, features such as helixes or lattices may produce wire-like structures that are not as easily measured using stylus instruments as flat surfaces.
Also, the suitability of current specification methods must be investigated for AM.
• ~~ANSI/~~ASME Y14.36-2018~~M-1996 (R2008)~~, *Surface Texture Symbols* may be sufficient, but further investigation is required to determine if AM-specific symbols are necessary (e.g., to control stair-stepping or allowable surface porosity).
• Furthermore, although there are methods available for finishing AM materials, many lack standard practices. Some methods require material removal, such as micro-machining or abrasive techniques, and it is not known at this time how to accommodate this in AM product specifications in a standard form. Other methods require the addition of material, such as electroplating and coatings but it is also unknown how to accommodate these into AM standards.
• Lastly, as the effects of surface finish on performance become more apparent, material specification recommendations must go beyond "supplier and purchaser agreement," specifically for as-built, non-machined surfaces.

R&D Needed: Yes
• Standards for reliable NDT, such as XCT, for evaluation of internal passages
• Guidance for validation of surface finish on complex features (such as wires or non-planar surfaces)
• Investigation of mechanical techniques such as shot peening or media blasting and their effect on fatigue life for AM materials

Recommendation: Verify if there are certain measurement methods more appropriate to AM-unique features than a stylus approach such as laser or white light 3D scanning. If so, they should be reviewed for their use on AM materials and appropriate standards written.
• The applicability of existing surface texture symbols to AM materials should be investigated.
• Available finishing methods should be reviewed for their effects on final material properties, and improved with standardized practices or guidelines where none exist.

Priority: Medium

Organization: ISO/ASTM; ASME (B46 new project team 53 on surface finish), IEEE-ISTO PWG, NIST

v2 Status of Progress: Green for R&D (metals). Unknown for Standards (metals and polymers).

v2 Update: In terms of R&D for metals, NIST is currently investigating several research topics related to surface texture of parts produced via laser powder bed fusion. Current research is focused on process-structure relationships and the identification of complex structures that result from the AM process in anticipation that better identification and definition of as-built surfaces will lead to stronger functional correlations for AM parts. To this end, current topic areas include: investigation of surface texture parameters beyond Ra (including both areal and profile parameters) to better define AM parts, variability of as-built surface texture (i.e., methods for describing changes in the as-built surface texture as position and orientation within the build chamber change), and use of XCT for determining surface texture.

Updates Since v2 was Published:
8/5/2020, MW: ASTM AMCOE *Strategic Roadmap for Research & Development* (April 2020) notes that AMCOE Project 1802 (WK66682) addresses AMSC Gap P4.
4/9/2020, MW: Steve Weinman, ASME, comment: In addition to the research being performed at NIST, the ASME B46 committee also has a project team (PT 53 – Surface Finish for Additive Manufacturing) looking at different kinds of measurement methods, different parameters, etc. There are a number of questions still to answer, such as what instruments are able to measure the natural porous structures of AM parts, what parameters are important for the functionality of AM parts, how do you define a reference for geometric measurements of internal structures, etc. The project team is working on these issues and will ultimately have guidance for the B46 committee, possibly incorporating these ideas into a future revision of the B46.1 standard or a separate B46 standard.

New Published Standards	New In-Development Standards
	3/31/2021, JM: NRC presentation of 12/09/20 by Mohsen Seifi noted these ASTM work items: ASTM WK66682, *Evaluating Post-processing and Characterization Techniques for AM Part Surfaces*

Back to Top

Gap P5: Use of Post-cure to Reduce Toxic Gases from Uncured Polymer Feedstock. An evaluation of the toxic gases resulting from uncured reagents in liquid resins used during processes such as Vat Photopolymerization (e.g., SLA) would be warranted to ensure product and environmental safety during and after production.

Commented [A31]: Per 11/13/20 changes from Steve Weinman, ASME

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R&D Needed: No	
Recommendation: Augment existing standards with AM-specific recommendations for processes that utilize liquid resins. Evolved gas analysis, an analytical method by which the amount and characteristics of the volatile products released by an AM-built part under controlled temperature variation, is recommended for finished product safety and toxicity. To analyze evolved gas quantitatively, parameters such as sample chamber volume, thermal/vacuum conditions for releasing/analyzing the volatiles and the techniques for the analysis need to be specified.	
Priority: Low	
Organization: ASTM D20, ISO/TC 261/ASTM F42	
v2 Status of Progress: Not Started, or Unknown	
v2 Update: None provided	
Updates Since v2 was Published:	
New Published Standards	**New In-Development Standards**

Back to Top

Gap P6: Guidelines for Post-curing AM Plastics to Address Outgassing and Offgassing. Guidelines for evaluating the outgassing and offgassing properties and the effects of post-polymerization treatments have not been evaluated, specifically for AM materials. The voids and entrapments that can form in this case warrant some method of evaluating AM plastics over traditional methods.	
R&D Needed: Yes, R&D may be needed to look at environmental conditions and health and safety aspects. Outgassing (thermal vacuum stability) and offgassing (toxicity) performance data for some materials may be archived in NASA's Materials and Processes Technical Information System (MAPTIS). In space systems, materials typically undergo outgassing testing for use in external environments and offgassing testing for use in crewed environments.	
Recommendation: Extend existing methods with AM-specific recommendations.	
Priority: Low	
Organization: ASTM E21.05, ASTM D20, ISO/TC 138, ISO/TC 261/ASTM F42	
v2 Status of Progress: Not Started, or Unknown	
v2 Update: None provided	
Updates Since v2 was Published:	
New Published Standards	**New In-Development Standards**

Back to Top

Gap P7: Heat Treatment (HT)-Polymers. Heat treatment is an effective method to modify the properties of AM built polymer parts. Presence of fillers, as in the case of composites, can alter the nucleation rate causing significant increase in tensile strength and hardness of the finished part. It also becomes essential to consider the variation of morphology of the polymer parts and layers because of the difference in the cooling rate from the surface to the center. The outer surface could end up less crystalline due to a rapid solidification rate and result in less resistance to wear. The contraction of volume due to crystallization in the bulk could increase the residual stresses at the interface. There are currently no standards on specific heat treatments (heating and cooling rates, anneal conditions) which could guide the AM practitioners to arrive at an optimum anisotropic structure and properties for the polymer parts.
R&D Needed: Yes. R&D is needed to determine the conditions for optimized heat treatments of AM built parts as a function of materials (semi-crystalline polymers, composites, etc.) and AM post process parameters.
Recommendation: As AM expands to include new and high performance semi-crystalline polymers, polymer nanocomposites and thermosets, advanced machine design and processing, the standards for the measurement of mechanical properties will have to describe specific HT information on the test samples. These HT requirements (slow cooled vs. quenched vs. gradient cooled) will be specific to the polymer and the production process. A guideline on HT treatment procedures followed by sampling for testing would enable achieving optimum polymer microstructure and properties.
Priority: Low
Organization: R&D: NIST, universities, OEMs, government research labs, and others. Standards development: ASTM F42, SAE AMS-AM.
v2 Status of Progress: New
v2 Update: None provided

Updates Since v2 was Published:	
New Published Standards	**New In-Development Standards**

Back to Top

Other Post-processing Activity - Relevance to Gaps Not Yet Determined

New Published Standards

New In-Development Standards
ISO/ASTM AWI 52908, *Additive manufacturing — Post-processing methods — Standard specification for quality assurance and post processing of powder bed fusion metallic parts*
ASTM WK69371, *Standard practice for generating mechanical performance debits*

Back to Top

Chapter 2.2.4. Finished Material Properties

High Priority

- **Gap FMP1: Material Properties (3/31/2021)**
- **Gap FMP3: Cleanliness of Medical AM Parts**
- **Gap FMP4: Design Allowables (3/31/2021)**

Medium Priority

- **Gap FMP5: Microstructure (3/31/2021)**

Back to Top

Gap FMP1: Material Properties. Many machine manufacturers offer general values for parts made from select materials in their machines. However, these values are not statistically validated and do not have the pedigree required for material design. Standards for thermal properties and minimum mechanical properties that also contain qualification procedures cannot currently be produced for AM materials, given the current state of knowledge, for the reasons stated above. Testing standards modified for use with AM parts that are designed/built to be inhomogeneous are also not available at this time.
R&D Needed: Yes.
Recommendation: Develop standards that identify the means to establish minimum mechanical properties (i.e., AM procedure qualification requirements) for metals and polymers made by a given AM system using a given set of AM parameters for a given AM build design. Developing these standards will require generating data that currently doesn't exist or is not in the public arena. Qualification requirements to establish minimum mechanical properties for AM parts, both homogeneous and deliberately inhomogeneous, need to be developed.
Priority: High (Metals, Polymers); Low (Ceramics)
Organization: ASTM F42/ISO TC 261, SAE AMS-AM, ~~AWS D20,~~ CMH-17, MMPDS, NIST
v2 Status of Progress: Green
v2 Update: Work in progress is noted in the text.
Updates Since v2 was Published: **11/13/2020, MW:** Rachael Andrulonis, WSU NIAR, comment: The National Center for Advanced Materials Performance (NCAMP) at Wichita State University released public specifications and a material property database of ULTEM 9085/Fortus 900MC in 2018. (https://www.wichita.edu/research/NIAR/Research/ultem9085.php). Other public qualifications for non-metallic and metallic materials are in progress at NCAMP.

Commented [A32]: Strike this based on J. Coughlin comment

CMH-17 Non-Metallic Additive Manufacturing Coordination Group was formed in October 2018. A CMH-17 committee is currently drafting tables of material properties to be included in this first release of the handbook. Properties are based on NCAMP qualification of ULTEM 9085. **11/13/2020, MW**: Steve Weinman, ASME, comment: ASME is working to form a Working Group on this topic for polymers **8/5/2020, MW**: ASTM AMCOE *Strategic Roadmap for Research & Development* (April 2020) notes that AMCOE Projects 1801 (ISO/ASTM AWI 52909), 1804/1907 (WK65937, WK65929), 1805 (WK66029, WK71391), 1901 (WK71395), 1908 (TBD) and 1909 (WK73340) address AMSC Gap FMP1. **3/17/2020, JM**: Jessica Coughlin, AWS D20 comments: "References to AWS D20 should be removed from this item. AWS D20 does not have any plans to provide guidelines or requirements for establishing AM material properties. Instead, the Engineer is relied upon to specify the functional requirements of the component and the standard is then used to ensure that those requirements can be consistently met."

New Published Standards	**New In-Development Standards**
3/31/2021, JM: Per 12/09/20 presentation from Mohsen Seifi, new ASTM standards: • *F3318-18 Standard for Additive Manufacturing – Finished Part Properties – Specification for AlSi10Mg with Powder Bed Fusion – Laser Beam* • *F3302-18 Standard for Additive Manufacturing – Finished Part Properties – Standard Specification for Titanium Alloys via Powder Bed Fusion* **11/20/2020, MW**: Bill Bihlman, SAE, Comment: SAE AMS7004, *Titanium Alloy Preforms from Plasma Arc Directed Energy Deposition Additive Manufacturing on Substrate, Ti-6Al-4V, Stress Relieved* (Jan 2019) **5/8/2019, LY:** SAE has published the following specifications which contain statistically based minimum properties for lot acceptance: *SAE AMS7000, Laser-Powder Bed Fusion (L-PBF) Produced Parts, Nickel Alloy, Corrosion and Heat-Resistant, 62Ni - 21.5Cr - 9.0Mo - 3.65Nb Stress Relieved, Hot Isostatic Pressed and Solution Annealed* (Jun 2018)	**3/31/2021, JM:** NRC presentation of 12/09/20 by Mohsen Seifi noted these ASTM work items: • ISO/ASTM AWI 52909, *Additive manufacturing Finished part properties — Orientation and location dependence of mechanical properties for metal powder bed fusion* • ASTM WK65937, *Additive Manufacturing -- Space Application -- Flight Hardware made by Laser Beam Powder Bed Fusion Process* • ASTM WK65929, *Additive Manufacturing-Finished Part Properties and Post Processing - Additively Manufactured Spaceflight Hardware by Laser Beam Powder Bed Fusion In Metals* • ASTM WK66029, *Mechanical Testing of Polymer Additively Manufactured Materials* • ASTM WK71391, *New Guide for Additive Manufacturing -- Static Properties for Polymer AM (Continuation)* • ASTM WK71395, *Additive manufacturing -- accelerated quality inspection of build health for laser beam powder bed fusion process* • ASTM WK73340, *Additive Manufacturing -- Static Properties of Polymer Additive Manufacturing* **11/20/2020, MW**: Bill Bihlman, SAE, Comment: • *SAE AMS7000A, Laser-Powder Bed Fusion (L-PBF) Produced Parts, Nickel Alloy, Corrosion and Heat-Resistant, 62Ni - 21.5Cr - 9.0Mo - 3.65Nb Stress Relieved, Hot Isostatic Pressed and Solution Annealed* (Feb 2020) • *SAE AMS7016, Laser-Powder Bed Fusion (L-PBF) Produced Parts, 17-4PH H1025 Alloy* (Oct 2018) • *SAE AMS7024, Inconel 718 L-PBF Material specification* (Jun 2019) • *SAE AMS7028, Laser-Powder Bed Fusion (L-PBF) Produced Parts, Titanium Alloy, Ti-6Al-4V Stress Relieved, and Hot Isostatic Pressed* (Jan 2020) • *SAE AMS7030, Laser- Powder Bed Fusion (L-PBF) Produced Parts of AlSi10Mg* (Feb 2020) **8/19/2020, JM:** • ASTM WK66637, *Additive Manufacturing -- Finished Part Properties -- Specification for 4340 Steel via Laser Beam Powder Bed Fusion for Transportation and Heavy Equipment Industries*

Commented [A33]: This appears to be the same as ASTM WK49229

	• ASTM WK70164, *Additive Manufacturing -- Finished Part Properties -- Standard Practice for Assigning Part Classifications for Metallic Materials* **5/8/2019, LY:** Two metals specifications are under development which will contain statistically based minimum properties for lot acceptance: • AMS7011, *Additive manufacture of aerospace parts from T-6Al-4V using the Electron Beam powder bed fusion EB-PBF) process*. • AMS7016, *Laser-Powder Bed Fusion (L-PBF) Produced Parts, 17-4PH H1025 Alloy*

Back to Top

Gap FMP3: Cleanliness of Medical AM Parts. Like many medical devices, medical AM parts must be cleaned of manufacturing residues and contact materials prior to packaging or final use. For patient-contacting (both direct and indirect) devices this cleaning must allow the device to pass tests for biological reactivity such as cytotoxicity and inflammation as described in ISO 10993. They should also ensure that AM materials such as powder are removed before use. Residues left on the parts may include but are not limited to cooling fluids or AM materials (powder or uncured monomer), that may be stuck within small geometric features or lattice structures. There are no standardized protocols or acceptance criteria to reproducibly measure and evaluate the cleanliness of a part with relevant, risk-based acceptance criteria.	
R&D Needed: Yes. R&D is needed to establish standards which discern clean from uncleaned parts; specifically, to reliably distinguish unsintered, unmelted, and uncured material from the intended part	
Recommendation: Develop standard test methods, metrics, and acceptance criteria for measuring cleanliness of complex 3D geometries that are based on existing standards but focus on AM-specific considerations. ASTM F04 already has work in progress.	
Priority: High	
Organization: AAMI, ASTM F04, ASTM F42/ISO TC 261, ISO, ISO/TC 150, ISO/TC 194	
v2 Status of Progress: Green	
v2 Update: As noted, ASTM F04.15 is working on WK53082 and WK60265.	
Updates Since v2 was Published:	
New Published Standards	**New In-Development Standards**

Back to Top

Gap FMP4: Design Allowables. Current standards and underlying infrastructure/technology are not mature enough to support the development of design allowables. For metallic additively manufactured material, a guideline was published by the MMPDS Coordination Committee describing an exploratory study for developing a metallic design allowable entitled "11-40. Guidelines for Emerging Materials and Technologies." This guideline includes potential procedures to publish design allowables in a handbook and illuminates the gaps that would need to be addressed before AM could be included. For polymer based additively manufactured materials, an FAA sponsored research program is currently developing statistical procedures for allowables that will eventually be submitted to CMH-17 for consideration to be published in a new volume.
R&D Needed: Yes. Recommended R&D required to fill this gap includes the generation of a set of initial seed data and subsequent statistical analyses. The initial data may be developed via round robin testing and procedures to capture the multiple sources of variability inherent in AM materials and processes. These data should result from programs through public-private partnerships or government laboratories to ensure the sharing of information. Separate test programs must be developed for different material types as the distributions may not be the same across all materials (i.e., metallic, polymer, etc.). The generation of data and subsequent analyses will help define the minimum requirements and statistical methods necessary for additive materials.
Recommendation: Multiple developments must take place prior to generation and acceptance of design allowables for additive materials. 1. Material specifications: SDOs involved in developing and publishing material specifications should continue their efforts to adequately capture the relevant material parameters and minimum mechanical properties required for a specification. These specifications can be used in the future to support testing that will lead to the level of data

needed to support design allowable basis values. Currently, the SAE AMS-AM Committee is actively developing specifications for lot acceptance of metallic and polymer additive materials. ASTM F42.05 may also have interest.
2. Data requirements and statistical analyses: Established organizations, such as MMPDS and CMH-17, should be involved in establishing the methodology required for deriving the allowables through a statistical process that takes into account the variability and parameters associated with additively manufactured materials. The MMPDS General Coordinating Committee, CMH-17 Executive Group, and/or other steering groups of organizations familiar with curating design allowable databases should develop guidelines on minimum data requirements and statistical processes. Although the key material/process parameters affecting allowables and in some cases the required test methods will differ, it is recommended to start with the currently available statistical analysis methods for metals and polymer composites as a baseline.
3. Test methods: Test standards organizations, such as ASTM/ISO, should provide recommendations on established test methods with special considerations for AM materials. If necessary, new coupon or component test methods should be developed.

Priority: High (Material Specifications); Medium (Data Requirements and Statistical Analyses): Medium (Test Methods)

Organization: ASTM F42/ISO TC 261, SAE AMS-AM, AWS, NASA, ASME BPVC, MMPDS, CMH-17, NIST

v2 Status of Progress: Green

v2 Update: At this time, no publicly available methodology for design allowables of additively manufactured materials has been identified. However, the three sections listed above (Material Specifications, Data Requirements and Statistical Analyses, and Test Methods) are all being addressed throughout multiple SDOs and other programs. Material specifications are being generated by multiple SDOs at this time. SAE has a Data Management Sub-Committee currently defining guidelines to generate specifications minimum values for both metals and polymers. In addition to the work in progress noted in the text and gap statement, ASME's BPVC committee is looking at this. Regarding characterization methods for metals, the MMPDS coordinating committee has concerns that existing data requirements and statistical analysis methods are not sufficient. Their primary concern is the level of maturity of standards and specifications needed to ensure consistent properties. Polymer AM material test methods have similar issues; methods can either be adopted from plastic or polymer matrix composites methods, both of which may need modification.

Updates Since v2 was Published:
11/13/2020, MW: Rachael Andrulonis, WSU NIAR, comment: The National Center for Advanced Materials Performance (NCAMP) at Wichita State University released public specifications and a material property database of ULTEM 9085/Fortus 900MC in 2018. (https://www.wichita.edu/research/NIAR/Research/ultem9085.php). Other public qualifications for non-metallic and metallic materials are in progress at NCAMP.
11/13/2020, MW: Rachael Andrulonis, WSU NIAR, comment: CMH-17 Non-Metallic Additive Manufacturing Coordination Group was formed in October 2018. A CMH-17 committee is currently drafting tables of material properties to be included in this first release of the handbook. Properties are based on NCAMP qualification of ULTEM 9085.
8/5/2020, MW: ASTM AMCOE *Strategic Roadmap for Research & Development* (April 2020) notes that AMCOE Projects 1801 (ISO/ASTM AWI 52909), 1804/1907 (WK65937, WK65929), 1805 (WK66029, WK71391), 1908 (TBD) and 1909 (WK73340) address AMSC Gap FMP4.
4/4/2019, JM: The CMH-17 Volume for Additive Manufacturing kicked off in October 2018 in conjunction with the FAA. The new volume will cover non-metallic AM. A Coordination Group was formed to guide this activity with Working Groups in the areas of Testing, Data Review, Design & Analysis, and Materials & Processes. This volume, when published, will include design allowables for non-metallic AM materials. The first data set that will be reviewed for inclusion in this new volume is ULTEM 9085. Test Standards for Polymer AM – F42 has started a new work item for a standard guide that addresses recommendations for mechanical test methods for polymer AM. The guide is being developed this year in conjunction with the ASTM AM Center of Excellence and draws upon research conducted through America Makes and the FAA.

New Published Standards

11/20/2020, MW: Bill Bihlman, SAE, Comment: SAE AMS7004, *Titanium Alloy Preforms from Plasma Arc Directed Energy Deposition Additive Manufacturing on Substrate, Ti-6Al-4V, Stress Relieved* (Jan 2019)

4/4/2019, JM: In late Jan/early Feb 2019, SAE International released a finished material specification, as well as the associated process specification, *SAE AMS7005, Wire Fed Plasma Arc Directed Energy Deposition Additive Manufacturing Process* (Jan 2019)
SAE AMS7013, *Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 60Ni - 22Cr - 2.0Mo - 14W - 0.35Al - 0.03La* (Jan 2019)

New In-Development Standards

3/31/2021, JM: NRC presentation of 12/09/20 by Mohsen Seifi noted these ASTM work items:

- ISO/ASTM AWI 52909, *Additive manufacturing Finished part properties — Orientation and location dependence of mechanical properties for metal powder bed fusion*
- ASTM WK65937, *Additive Manufacturing -- Space Application -- Flight Hardware made by Laser Beam Powder Bed Fusion Process*
- ASTM WK65929, *Additive Manufacturing-Finished Part Properties and Post Processing - Additively Manufactured Spaceflight Hardware by Laser Beam Powder Bed Fusion In Metals*

	• ASTM WK66029, *Mechanical Testing of Polymer Additively Manufactured Materials* • ASTM WK71391, *New Guide for Additive Manufacturing -- Static Properties for Polymer AM (Continuation)* • ASTM WK73340, *Additive Manufacturing -- Static Properties of Polymer Additive Manufacturing* **11/20/2020, MW**: Bill Bihlman, SAE, Comment: • *SAE AMS7000A, Laser-Powder Bed Fusion (L-PBF) Produced Parts, Nickel Alloy, Corrosion and Heat-Resistant, 62Ni - 21.5Cr - 9.0Mo - 3.65Nb Stress Relieved, Hot Isostatic Pressed and Solution Annealed* (Feb 2020) • *SAE AMS7016, Laser-Powder Bed Fusion (L-PBF) Produced Parts, 17-4PH H1025 Alloy* (Oct 2018) • *SAE AMS7024, Inconel 718 L-PBF Material specification* (Jun 2019) • *SAE AMS7028, Laser-Powder Bed Fusion (L-PBF) Produced Parts, Titanium Alloy, Ti-6Al-4V Stress Relieved, and Hot Isostatic Pressed* (Jan 2020) • *SAE AMS7030, Laser- Powder Bed Fusion (L-PBF) Produced Parts of AlSi10Mg* (Feb 2020) **5/8/2019, LY:** One non-metals specification under development is tied to an AM qualification program with NCAMP (see MRO Network article, Creating an Easier Qualification Path for 3D Printing, which references *SAE AMS7100, Fused Filament Fabrication, Process Specification for*. SAE AMS7101/1, *Fused Filament Fabrication Feedstock Type 1, Class 1, Group 1, F1.17, Natural* (Sep 2018) FMP4 Recommendation 1 for Material Specifications also encompasses the SAE specifications listed under FMP1

Back to Top

<table>
<tr><td colspan="2">Gap FMP5: Microstructure. There is an inherent heterogeneity in the microstructure of metallic alloys made by AM that requires a standard for identification and quantification of the spatial variability of various microstructure features.</td></tr>
<tr><td colspan="2">R&D Needed: Yes. NIST should help develop Calphad databases suitable for non-equilibrium solidification.</td></tr>
<tr><td colspan="2">Recommendation: ASTM should develop a standard for characterization and acceptance criteria of AM microstructures (both identification and quantification).</td></tr>
<tr><td colspan="2">Priority: Medium</td></tr>
<tr><td colspan="2">Organization: NIST, ASTM</td></tr>
<tr><td colspan="2">v2 Status of Progress: Not Started, or Unknown</td></tr>
<tr><td colspan="2">v2 Update: Nothing started in terms of ASTM work</td></tr>
<tr><td colspan="2">Updates Since v2 was Published:
8/5/2020, MW: ASTM AMCOE Strategic Roadmap for Research & Development (April 2020) notes that AMCOE Projects 1804/1907 (WK65937, WK65929) address AMSC Gap FMP5.</td></tr>
<tr><td>New Published Standards</td><td>New In-Development Standards
3/31/2021, JM: NRC presentation of 12/09/20 by Mohsen Seifi noted these ASTM work items:
• ASTM WK65937, Additive Manufacturing -- Space Application -- Flight Hardware made by Laser Beam Powder Bed Fusion Process</td></tr>
</table>

	• ASTM WK65929, *Additive Manufacturing-Finished Part Properties and Post Processing - Additively Manufactured Spaceflight Hardware by Laser Beam Powder Bed Fusion In Metals*

Back to Top

Other Finished Material Properties Activity - Relevance to Gaps Not Yet Determined

New Published Standards
SAE AIR7352, Additively Manufactured Component Substantiation (Oct 2019)

New In-Development Standards
ISO/ASTM WD 52919-1, *Additive manufacturing — Test method of sand mold for metalcasting — Part 1: Mechanical properties*
ASTM WK70206, *Additive manufacturing -- Test method of sand mold for metal casting -- Part 1: Mechanical properties*
ISO/ASTM WD 52919-2, *Additive manufacturing — Test method of sand mold for metalcasting — Part 2: Physical properties*
ASTM WK70207, *Additive manufacturing -- Test method of sand mold for metal casting -- Part 2: Physical properties*
ASTM WK73550, *Additive manufacturing -- Material extrusion based additive manufacturing of plastic materials -- Part 2: process equipment*

Back to Top

Chapter 2.3. Qualification & Certification

High Priority

- **Gap QC1: Harmonization of AM Q&C Terminology (8/21/2020)**
- **Gap QC2: AM Part Classification System for Consistent Qualification Standards (3/31/2021)**
- **Gap QC9: Personnel Training for Image Data Set Processing**
- **Gap QC10: Verification of 3D Model (4/9/2020)**

Medium Priority

- **Gap QC3: Harmonizing Q&C Terminology for Process Parameters (3/31/2021)**
- **Gap QC4: Process Approval for DoD-procured Parts**
- **Gap QC6: Importing Ultrasound Data (9/1/2020)**
- **Gap QC7: Protocols for Image Accuracy (9/1/2020)**
- **Gap QC8: Phantoms**
- **Gap QC12: Resorbable Materials**
- **Gap QC14: Segmentation (3/17/2020)**
- **NEW Gap QC16: Sterilization of Tissue Engineered Products**

Low Priority

- **Gap QC5: Machine Operator Training and Qualification (9/15/2020)**
- **Gap QC13: Material Control Data and Procedures (11/13/2020)**
- **Gap QC15: Sterilization of Anatomical Models**

Back to Top

Gap QC1: Harmonization of AM Q&C Terminology. One of the challenges in discussing qualification and certification in AM is the ambiguity of the terms qualification, certification, verification, and validation, and how these

terms are used by different industrial sectors when describing Q&C of materials, parts, processes, personnel, and equipment.
R&D Needed: No
Recommendation: Compare how the terms qualification, certification, verification and validation are used by industry sector. Update as needed existing quality management system standards and other terminology standards to harmonize definitions and encourage consistent use of terms across industry sectors with respect to AM.
Priority: High
Organization: ASTM F42/ISO TC 261, AAMI, ASME, SAE
v2 Status of Progress: Green
v2 Update: In discussions between the AMSC advisory group and the SDOs, there was a general sense that relevant AM terminology could be captured in the ISO/ASTM 52900 document to the extent possible. However, that document does not currently address the disparities on Q&C terminology discussed here. As a general matter, ASME has been coordinating AM terminology activity with ASTM. SAE has noted the challenges of coming to consensus on terminology and has been using the ASTM definitions when they exist but coming up with new terms for aerospace applications when a term is not defined. ASTM has offered to convene a virtual meeting with the SDOs and technical experts to discuss terminology. America Makes could help to promote such collaboration. This would be a step forward though it may not solve the issue of getting different sectors to adopt the same terminology.
Updates Since v2 was Published:

New Published Standards	**New In-Development Standards**
	8/21/2020, JM: ISO/ASTM DIS 52900, *Additive manufacturing — General principles — Fundamentals and vocabulary* is being revised. **4/9/2020, MW:** Steve Weinman, ASME, comment: ASME is currently working on a V&V 1 standard which contains terminology that focuses on verification and validation as applied to the computational modeling and simulation phase of the product lifecycle. The ASME Model Based Enterprise Committee has a Terms Working Group working on standardized terminology that can be applied across the product lifecycle.

Back to Top

Gap QC2: AM Part Classification System for Consistent Qualification Standards. A part classification system is used to describe the level of risk associated with a part and may therefore be used as a metric to gauge appropriate qualification requirements. A common classification system for AM parts by industry sector is needed to provide consistent evaluation criteria for AM part risk. This should include a definition of criticality levels. Consistent risk criteria provide the basis for consistent expectations and levels of qualification rigor. Examples of classification systems can be found in NASA's MSFC-STD-3716, *Standard for Additively Manufactured Spaceflight Hardware by Laser Powder Bed Fusion in Metals*, and the draft AWS D20.1 standard, which utilizes the part classification system identified in AWS D17.1/D17.1M:2017-AMD1, *Specification for Fusion Welding of Aerospace Applications*. Any industry requiring rigorous AM part qualification and system certification would benefit from a common part classification system.
R&D Needed: No
Recommendation: A technical report describing existing classification systems for AM parts would be useful. It could include the recommended minimum process and part qualification requirements commensurate with part risk for each classification level.
Priority: High
Organization: ASTM F42/ISO TC 261, AWS, DoD, FAA, NASA, SAE
v2 Status of Progress: Green
v2 Update: ASTM F42.01 will explore developing this technical report. This will require coordination between the SDOs and relevant federal agencies. It may also be application-specific (e.g., spaceflight, military, etc.) This is more a harmonization issue. Procurement and level of testing required need to be addressed. The primary beneficiaries will be industry.
Updates Since v2 was Published: **8/5/2020, MW**: ASTM AMCOE *Strategic Roadmap for Research & Development* (April 2020) notes that AMCOE Projects 1804/1907 (WK65937, WK65929) address AMSC Gap QC2. **3/17/2020, MW**: Jessica Coughlin, AWS D20, comment: The component classifications used by AWS D20.1 (published in 2019) are: Class A - Critical application, Class B - Semi-critical application, and Class C - Noncritical application.

New Published Standards	**New In-Development Standards**

4/4/2019, LY: The AWS recently published a new standard on AM, *AWS D20.1/D20.1M:2019 Specification for Fabrication of Metal Components using Additive Manufacturing*.	**3/31/2021, JM:** NRC presentation of 12/09/20 by Mohsen Seifi noted these ASTM work items: • ASTM WK65937, *Additive Manufacturing -- Space Application -- Flight Hardware made by Laser Beam Powder Bed Fusion Process* • ASTM WK65929, *Additive Manufacturing-Finished Part Properties and Post Processing - Additively Manufactured Spaceflight Hardware by Laser Beam Powder Bed Fusion In Metals* **8/19/2020, JM:** • ISO/ASTM DIS 52924, *Additive manufacturing — Qualification principles — Classification of part properties for additive manufacturing of polymer parts* • ASTM WK73239, *Additive manufacturing -- Qualification principles -- Classification of part properties for additive manufacturing of polymer parts* • ASTM WK70164, *Additive Manufacturing -- Finished Part Properties -- Standard Practice for Assigning Part Classifications for Metallic Materials*

Commented [A34]: These appear to be the same standard

Back to Top

Gap QC3: Harmonizing Q&C Terminology for Process Parameters. In order to enable full understanding of the given processes and to include this type of information in a process-agnostic TDP, and for purposes of qualification and/or certification, there must be standardization of process parameter terminology across machine manufacturers.	
R&D Needed: No	
Recommendation: Develop standardized terminology for process parameters for use across all AM equipment. Potentially, incorporate these into ISO/ASTM 52900:2015, *Additive manufacturing - General principles - Terminology*. See also Gap PC5 on parameter control.	
Priority: Medium	
Organization: ASTM F42/ISO TC 261 JG51, AWS D20, SAE AMS-AM, IEEE-ISTO PWG	
v2 Status of Progress: Green	
v2 Update: As noted in the text.	
Updates Since v2 was Published: **8/5/2020, MW**: ASTM AMCOE *Strategic Roadmap for Research & Development* (April 2020) notes that AMCOE Projects 1804/1907 (WK65937, WK65929) address AMSC Gap QC3. **3/17/2020, MW**: Jessica Coughlin, AWS D20, comments: AWS D20.1 uses the term "Qualification Variables" to describe the process parameters that must be controlled as part of AM machine and procedure qualifications. I believe that SAE AMS-AM uses "Key Process Variables," ASTM F42 refers to "critical attributes," and NASA uses "Control Factors."	
New Published Standards	**New In-Development Standards** **3/31/2021, JM:** NRC presentation of 12/09/20 by Mohsen Seifi noted these ASTM work items: • ASTM WK65937, *Additive Manufacturing -- Space Application -- Flight Hardware made by Laser Beam Powder Bed Fusion Process* • ASTM WK65929, *Additive Manufacturing-Finished Part Properties and Post Processing - Additively Manufactured Spaceflight Hardware by Laser Beam Powder Bed Fusion In Metals* **8/21/2020, JM:** ISO/ASTM DIS 52900, *Additive manufacturing — General principles — Fundamentals and vocabulary* is being revised.

Back to Top

<table>
<tr><td colspan="2">Gap QC4: Process Approval for DoD-procured Parts. As multiple methods of AM continue to mature, and new AM techniques are introduced, the government will need to fully understand the ramifications of each of these techniques, of what they are capable, and how certain AM procedures might lend themselves to some classes of parts and not others. Thus, not only must the government understand the differences, but how they should be assessed and tested, and what additional checks must be made on the end product before it can be qualified for use in a military platform. High pressures, temperatures, and other contained environments could impact the performance or life of safety-critical parts in ways that are not understood. More research is required to determine the delta between traditional and AM methods.</td></tr>
<tr><td colspan="2">R&D Needed: Yes</td></tr>
<tr><td colspan="2">Recommendation: Starting with the most mature technologies, such as laser powder bed, there is a need to develop standards that assess required checks for levels of criticality and safety as part of the DoD procurement process. DoD should participate in the development of such standards and specify the certification requirements needed.</td></tr>
<tr><td colspan="2">Priority: Medium</td></tr>
<tr><td colspan="2">Organization: ASME, ASTM F42/ISO TC 261, DoD, Industry, SAE, Service SYSCOMS</td></tr>
<tr><td colspan="2">v2 Status of Progress: Yellow</td></tr>
<tr><td colspan="2">v2 Update: DoD is holding AM business model workshops, the agenda for which includes developing an AM contracting guide for the Navy/DoD. None provided vis a vis work by the SDOs.</td></tr>
<tr><td colspan="2">Updates Since v2 was Published:</td></tr>
<tr><td>New Published Standards</td><td>New In-Development Standards</td></tr>
</table>

Back to Top

<table>
<tr><td colspan="2">Gap QC5: Machine Operator Training and Qualification. There is a need for standards or guidelines outlining AM training requirements.</td></tr>
<tr><td colspan="2">R&D Needed: No</td></tr>
<tr><td colspan="2">Recommendation: Develop AM operator training and qualification standards or guidelines. Training should cover the various AM materials and processes available in the market and be performance based to ensure consistent AM part quality. Develop additional standards for artisanal levels of competency and experience, delineating an individual’s expertise in the field or subsets of the AM field.</td></tr>
<tr><td colspan="2">Priority: Low</td></tr>
<tr><td colspan="2">Organization: NASA, SAE, AWS, OEMs, UL, ASTM F42/ISO TC 261, AAMI</td></tr>
<tr><td colspan="2">v2 Status of Progress: Green</td></tr>
<tr><td colspan="2">v2 Update: As noted in the text.</td></tr>
<tr><td colspan="2">Updates Since v2 was Published:
9/15/2020, JM: ISO/ASTM52942 - Additive manufacturing — Qualification principles — Qualifying machine operators of laser metal powder bed fusion machines and equipment used in aerospace applications is a new standard, now available. F3471-20 developed by Committee F42.07, ASTM BOS Volume 10.04.
3/17/2020, MW: Jessica Coughlin, AWS D20, comment: AWS D20.1 contains a Clause (6) dedicated to requirements for AM machine operator performance qualification. It requires that the AM machine operator undergo training, written examination, practical examination, and a build demonstration in order to become qualified.</td></tr>
<tr><td>New Published Standards</td><td>New In-Development Standards
8/19/2020, JM:
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</td></tr>
</table>

Commented [A35]: The 10 ISO and ASTM work items listed below appear to be 5 work items with dual listings of the ISO/ASTM number and just an ASTM number.

	ISO/ASTM WD 52926-5, *Additive manufacturing — Qualification principles — Part 5: Qualification of machine operators for metallic parts production for DED-Arc* ASTM WK71375, *Additive Manufacturing Qualification principles Part 1: Qualification of Machine operators for metallic parts production* ASTM WK71376, *Additive manufacturing -- Qualification principles -- Part 2: Qualification of machine operators for metallic parts production for PBF-LB* ASTM WK71377, *Additive manufacturing -- Qualification principles -- Part 3: Qualification of machine operators for metallic parts production for PBF-EB* ASTM WK71378, *Additive manufacturing -- Qualification principles -- Part 4: Qualification of machine operators for metallic parts production for DED-LB* ASTM WK71379, *Additive manufacturing -- Qualification principles -- Part 5: Qualification of machine operators for metallic parts production for DED-Arc* **8/19/2020, JM:** ASTM WK72458, *Additive Manufacturing -- Qualification principles -- Qualification of coordinators for metallic parts production* ASTM WK73236, *Additive Manufacturing -- Qualification principles -- Qualification of coordinators for metallic parts production* ISO/ASTM WD 52935, *Additive manufacturing — Qualification principles — Qualification of coordinators for metallic parts production* **8/19/2020, JM:** ASTM WK73170, *Additive manufacturing -- Qualification principles -- Qualifying machine operators of laser metal powder bed fusion machines and equipment used in aerospace applications* ASTM WK65937, *Additive Manufacturing -- Space Application -- Flight Hardware made by Laser Beam Powder Bed Fusion Process*

Commented [A36]: In some cases there even appear to be more than 1 ASTM WK number as well as an ISO/ASTM number covering the same topic

Back to Top

Gap QC6: Importing Ultrasound Data. The DICOM standard needs to be more widely promoted and may need to be revised to enable data to be imported from any ultrasound equipment similar to the CT scan or MRI data. There is a concern that the data coming from the ultrasound may not be providing adequately detailed images but this cannot be assessed until the interoperability concerns are eliminated.	
R&D Needed: Yes	
Recommendation: Promote and potentially revise the DICOM standard for importing data from ultrasound equipment. Use cases are obstetrics and pre-natal diagnosis. CP 1071 correction proposals should be approved. This relates to codes for cardiac ultrasound data target sites.	
Priority: Medium	
Organization: DICOM, IEEE, ASTM F42/ISO TC 261 JG70	
v2 Status of Progress: Green	
v2 Update: ISO/ASTM NP 52916, *Additive manufacturing -- Data formats -- Standard specification for optimized medical image data*, is being developed by ASTM F42 and ISO/TC 261 as JG70.	
Updates Since v2 was Published: **3/17/20, JM:** Comments on the gap statement from Justin Ryan, Rady Children's Hospital San Diego: "DICOM cannot force vendors to submit their proprietary standards to DICOM. Instead the action item should be for ultrasound vendors to adopt DICOM (and suggest revisions where necessary) or open their proprietary format to enable easy conversations to a standard such as DICOM."	
New Published Standards	**New In-Development Standards**

Commented [A37]: See 3/17/20 comment from Justin Ryan

	9/1/2020, MW: ASTM WK74006, *New Specification for (Additive manufacturing -- Data formats -- Specification for optimized medical image data*

Back to Top

Gap QC7: Protocols for Image Accuracy. Problems associated with data acquisition for 3D modeling either individually or in combination contribute to image inaccuracies that will result in inaccuracies of the 3D model and eventually the final device produced.
R&D Needed: Yes. More R&D is needed on data for image accuracy before a standard can be developed.
Recommendation: Develop standard protocols for acquiring data for 3D modeling to ensure image accuracy. They may make use of standard image formats that capture enough information to facilitate size, orientation and color normalization and/or validation in post-processing of data.
Priority: Medium
Organization: DICOM, IEEE, ASME, ASTM F42/ISO TC 261, RSNA (Radiological Society of North America)
v2 Status of Progress: Green
v2 Update: ISO/ASTM NP 52916, *Additive manufacturing -- Data formats -- Standard specification for optimized medical image data*, is being developed by ASTM F42 and ISO/TC 261 as JG70.
Updates Since v2 was Published: **4/9/2020, MW**: Steve Weinman, ASME, comment: ASME V&V 40 Subcommittee on Verification and Validation in Computational Modeling of Medical Devices is working to form a working group on this item. **3/17/2020, JM:** Comments on the gap statement from Justin Ryan, Rady Children's Hospital San Diego, suggesting removal of DICOM from the list of organizations: "DICOM doesn't create protocol standards for acquisition. Closest element that DICOM could help with is to record which protocol was used."

New Published Standards	**New In-Development Standards**
	9/1/2020, MW: ASTM WK74006, *New Specification for (Additive manufacturing -- Data formats -- Specification for optimized medical image data*

Commented [A38]: Remove based on comment from Justin Ryan?

Back to Top

Gap QC8: Phantoms. Material and process guidelines are needed for phantoms to provide reliable models for imaging experiments and to check the accuracy of the process. These would include which materials and AM process to use, based on what is being imaged and the modality in use (e.g., X-ray vs. ultrasound).
R&D Needed: Yes.
Recommendation: Develop guidelines for creating and using phantoms to include material and process used, based on use. Similar to Gap QC7, they may make use of standard image formats that capture enough information to facilitate size, orientation and color normalization and/or validation in post-processing of data.
Priority: Medium
Organization: Biomedical Engineering Society, NEMA/MITA, ISO, ASTM, RSNA
v2 Status of Progress: Green
v2 Update: The RSNA 3DP Special Interest Group (SIG) is developing best practices for phantoms.
Updates Since v2 was Published:

New Published Standards	**New In-Development Standards**

Back to Top

Gap QC9: Personnel Training for Image Data Set Processing. Currently, there are only limited qualification or certification programs (some are in process of formation) available for training personnel who are handling imaging data and preparing for AM printing.
R&D Needed: No
Recommendation: Develop certification programs for describing the requisite skills, qualification, and certification of personnel responsible for handling imaging data and preparing for printing. The SME organization currently has a program in development.
Priority: High
Organization: SME, RSNA, ASTM F42/ISO TC 261

v2 Status of Progress: Green
v2 Update: The SME AM3DP medical WG has developed competency models and is working on a detailed body of knowledge (BOK) to help recruit skilled workers to the profession, along with training, curriculum development, and a certification program.[2] The FDA is involved with SME and RSNA. There is no separate interest at the federal level; certifications happen at the state level.
Updates Since v2 was Published:

New Published Standards	**New In-Development Standards**

Back to Top

Gap QC10: Verification of 3D Model. There are currently no standards for the final verification of a 3D model before it is approved for AM for the intended purpose (e.g., surgical planning vs. implantation; cranial replacement piece; cutting guides which have a low tolerance for anatomical discrepancy).
R&D Needed: Yes, in terms of tolerances
Recommendation: Develop standards for verification of the 3D model against the initial data. Ideally, they should identify efficient, automatable methods for identifying discrepancies.
Priority: High
Organization: ASTM F42/ISO TC 261, NEMA/MITA, AAMI, ASME, NIST, ACR
v2 Status of Progress: Green
v2 Update: ASTM F42/ISO 261 are looking at image quality as part of the model verification. ~~ASME V&V 40 addresses verification and validation in computational modeling of medical devices~~. This issue requires cooperation between clinical societies, the FDA and industry. It may also be a general, not only medical, concern. The ASME Model Based Enterprise Committee is working on model quality, model capability, and standards conformance.
Updates Since v2 was Published:

New Published Standards	**New In-Development Standards**

Commented [A39]: 4/9/20, JM: Edits proposed by Steve Weinman, ASME

Back to Top

Gap QC12: Resorbable Materials. Testing of degradation of the new resorbable metals/polymers in living tissues cannot be adequately achieved using existing standards.
R&D Needed: Yes, in terms of rate and amount of degradation for new polymers and resorbable metals.
Recommendation: Develop guidance on how to test the degradation of new resorbable metals/polymers to support material selection for AM.
Priority: Medium
Organization: ASTM F4, ISO, ISO/TC 150, ISO/TC 194
v2 Status of Progress: Green
v2 Update: None provided
Updates Since v2 was Published:

New Published Standards	**New In-Development Standards**

Back to Top

Gap QC13: Material Control Data and Procedures. There is a need for well-established material control data and procedures. Materials are primarily manufactured through proprietary methods and, while recommended handling practices exist for each company and each product, standard procedures or standardized considerations are not available.
R&D Needed: Yes
Recommendation: A standard or specification describing a data set for material pedigree, recommended testing, and handling procedures would simplify evaluation of material suitability.

[2] http://sme.org/am3dpjobmodel/

Priority: Low
Organization: Material providers, ASTM
v2 Status of Progress: Unknown
v2 Update: None provided
Updates Since v2 was Published: **11/13/2020, MW**: Steve Weinman, ASME, comment: ASME is in the process of forming a new Standards Committee to address bioprinters. Proposed charter: Develop, review and maintain guidelines and standards for bioprinters hardware requirements. With many different manufacturers and academic researchers developing bioink products, there is a lack of standardization for bioink printers such as nozzle temperature, printing time, dispensing pressure, printing speed, and nozzle diameter, all of which directly influence the precision and accuracy of bioink deposition.

New Published Standards	New In-Development Standards

Back to Top

Gap QC14: Segmentation. There are currently no standards for patient imaging files including the methods from standard-of-care medical images to print-ready files. There is no group or entity that oversees segmentation within a clinical setting. RSNA has a special interest group that may set standards for segmentation and/or 3D printing. DICOM WG 17 also is looking at this.
R&D Needed: No
Recommendation: There is a need to create an augmented file specification for the DICOM file format. Incorporation of 3D files into the DICOM format will facilitate integration of 3D models into standard-of-care medical image databases present at all institutions. 3D models should include enough information to facilitate standardized methods for validation.
Priority: Medium
Organization: RSNA, DICOM, ASTM
v2 Status of Progress: Green
v2 Update: DICOM is addressing most of this. They will have public comment by the end of 2018, with a target for the first update being made by the second quarter of 2019.
Updates Since v2 was Published: **3/17/2020, JM:** Comments on the gap statement from Justin Ryan, Rady Children's Hospital San Diego, suggesting striking "and/or 3D printing. DICOM WG 17 also is looking at this" at the end of the gap statement. Comment also states that "this section is conflating 2 concepts. Quality of Segmentation and how segmentation is saved/archived. DICOM is only facilitating the later. DICOM doesn't set standards for "how" a segmentation is done. My suggestion is to break QC into two categories. Segmentation Protocols/Standards and Segmentation Archiving."

New Published Standards	New In-Development Standards

Commented [A40]: See 3/17/20 comments from Justin Ryan

Back to Top

Gap QC15: Sterilization of Anatomical Models. Anatomical models are frequently made in a healthcare setting and their final use may differ from the initial intended use. For instance, a surgeon may determine that a model patient education may be useful for reference in the operating room during the surgical procedure. If the models enter the sterile field they would require sterilization and the effects of sterilization on the geometric fidelity of the model should be assessed. If they are to come into contact with the patient the effects of sterilization on the materials are especially important. While many standards and industry best practices exist, the healthcare facilities may not have relevant experience.
R&D Needed: No. Procedures and protocols for determining appropriate materials, sterilization cycles, and validation tests are already available but may not be implemented in healthcare settings.
Recommendation: Develop guides and best practices to help identify critical parameters and apply existing standards in a clinical setting.
Priority: Low
Organization: R&D: OEMs. Guidance: AAMI, AOAC International, ASTM, ISO, PDA, USP, RSNA 3DP SIG.
v2 Status of Progress: Unknown
v2 Update: The SME medical group is working on a biocompatibility worksheet for use with both models and surgical guides. This will not be a standard, but a guide of considerations.

Updates Since v2 was Published:	
New Published Standards	**New In-Development Standards**

[Back to Top](#)

[Gap QC16: Sterilization of Tissue Engineered Products](#). Tissue engineered products present a particularly challenging circumstance for sterility assurance. While using a validated aseptic processing protocol for tissue engineered products can maintain sterility, it is not always sufficient or practical. Risk management standards can help decrease the risks of contamination with best practices but not provide defined measures to ensure the sterility or assess contamination in a tissue engineered product.	
R&D Needed: Maybe. A wide variety of aseptic processing and sterilization protocols exist for tissue engineered products, however no standards have been published to address validation and testing of these protocols in tissue engineered products.	
Recommendation: Develop and validate standard methods of sterilizing and verifying the sterility of tissue engineered products, especially those that can be applied in healthcare settings.	
Priority: Medium	
Organization: R&D: OEMs, FDA, BioFabUSA. Standards: AAMI, ISO, ASTM, AATB.	
v2 Status of Progress: New	
v2 Update: None provided	
Updates Since v2 was Published:	
New Published Standards	**New In-Development Standards**

[Back to Top](#)

Other Qualification & Certification Activity - Relevance to Gaps Not Yet Determined

New Published Standards

New In-Development Standards

API Standard 20S, Additively Manufactured Metallic Components for Use in the Petroleum and Natural Gas Industries (has elements applicable to the full lifecycle of producing an AM part)
ASTM WK71269, *Additive manufacturing -- Qualification principles -- Quality requirements for industrial additive manufacturing sites*
ISO/ASTM WD 52920, *Additive manufacturing — Qualification principles — Requirements for industrial additive manufacturing sites*
ASTM WK71616, *Additive manufacturing -- Qualification principles -- Part 2: Requirements for industrial additive manufacturing sites*
ASTM WK72237, *Additive manufacturing -- Qualification principles -- Part 2: Requirements for industrial additive manufacturing sites*
ASTM WK72457, *Additive manufacturing processes -- Laser sintering of polymer parts/laser-based powder bed fusion of polymer parts -- Qualification of materials*
ASTM WK73240, *Additive manufacturing processes -- Laser sintering of polymer parts/laser-based powder bed fusion of polymer parts -- Qualification of materials*
ASTM WK72659, *Guideline for Material Process Validation for Additive Manufacturing of Medical Devices*
ISO/ASTM DIS 52925, *Additive manufacturing processes — Laser sintering of polymer parts/laser-based powder bed fusion of polymer parts — Qualification of materials*
ISO/ASTM CD 52936-1, *Additive manufacturing — Qualification principles — Laser-based powder bed fusion of polymers — Part 1: General principles, preparation of test specimens*
ASTM WK71268, *Additive manufacturing -- Qualification principles -- Laser-based powder bed fusion of polymers -- Part 1: General principles, preparation of test specimens*
ISO/ASTM AWI 52937, Additive Manufacturing of metals — Qualification principles — Qualification of designers

Commented [A41]: May apply to a number of gaps across the AM product life-cycle.

Commented [A42]: 3/31/2021, JM, Noted in Mohsen Seifi NRC presentation of 12/09/20

[Back to Top](#)

Chapter 2.4. Nondestructive Evaluation (NDE)

High Priority

- **Gap NDE1: Terminology for the Identification of AM Flaws Detectable by NDE Methods (8/21/2020)**
- **Gap NDE3: Standard Guide for the Application of NDE to Objects Produced by AM Processes (8/19/2020)**

Medium Priority

- **Gap NDE2: Standard for the Design and Manufacture of Artifacts or Phantoms Appropriate for Demonstrating NDE Capability (8/21/2020)**
- **Gap NDE4: Dimensional Metrology of Internal Features**
- **Gap NDE5: Data Fusion**
- **NEW Gap NDE8: NDE Acceptance Criteria for Fracture Critical AM Parts**

Low Priority

- **NEW Gap NDE6: NDE of Polymers and Other Non-Metallic Materials (11/13/2020)**
- **NEW Gap NDE7: NDE of Counterfeit AM Parts**

Back to Top

<table>
<tr><td colspan="2">Gap NDE1: Terminology for the Identification of AM Flaws Detectable by NDE Methods. An industry driven standard needs to be developed, with input from experts in metallurgy, NDE, and additive manufacturing fabrication, to identify flaws or flaw concentrations with the potential to jeopardize an AM object's intended use. Many flaws have been identified but more effort is needed to agree on flaws terminology, providing appropriate names and descriptions.</td></tr>
<tr><td colspan="2">R&D Needed: No</td></tr>
<tr><td colspan="2">Recommendation: Develop standardized terminology to identify and describe flaws, and typical locations in a build.</td></tr>
<tr><td colspan="2">Priority: High</td></tr>
<tr><td colspan="2">Organization: ASTM E07, ASTM F42/ISO TC 261, SAE AMS K, ASME BPVC, AWS D20, NIST</td></tr>
<tr><td colspan="2">v2 Status of Progress: Green</td></tr>
<tr><td colspan="2">v2 Update: As noted in the text.</td></tr>
<tr><td colspan="2">Updates Since v2 was Published:
2/24/2020, MW: Jess Waller, NASA, comments: The following standards, which have either been adopted (ASTM E3166-20) or are in progress (ISO/ASTM DTR 52905, ASTM WK56649), contain preliminary definitions for AM defects, including pictures of technologically important defects, processing and post-processing factors related to their generation and removal, and applicable NDE methods. The ultimate goal is the ballot vetted definition for AM defects in ISO/ASTM 52900 Additive manufacturing — General principles — Terminology. See below for more info.</td></tr>
<tr><td>New Published Standards
2/24/2020, MW: Per Jess Waller, NASA
ASTM E3166-20, Standard Guide for Nondestructive Examination of Metal Additively Manufactured Aerospace Parts After Build, (formerly WK47031) has been published.
8/9/19, JM: ISO/ASTM52902:2019 - Additive manufacturing — Test artifacts — Geometric capability assessment of additive manufacturing systems is a new standard, now available. F3345-19 developed by Committee F42.01, ASTM BOS Volume 10.04.
4/4/2019, LY: The AWS recently published a new standard on AM, AWS D20.1/D20.1M:2019 Specification for Fabrication of Metal Components using Additive Manufacturing.</td><td>New In-Development Standards
ISO/ASTM AWI 52902, Additive manufacturing — Test artifacts — Geometric capability assessment of additive manufacturing systems
8/21/2020, JM: ISO/ASTM DTR 52906, Additive manufacturing — Non-destructive testing and evaluation — Standard guideline for intentionally seeding flaws in parts is in development.
8/21/2020, JM: ISO/ASTM DIS 52900, Additive manufacturing — General principles — Fundamentals and vocabulary is being revised.
2/24/2020, MW: Per Jess Waller, NASA
ISO/ASTM DTR 52905, Additive manufacturing—General principles—Non-destructive testing of additive manufactured products, is under development.
ASTM WK56649 New Guide for Standard Practice/Guide for Intentionally Seeding Flaws in</td></tr>
</table>

Commented [A44]: This appears to be a revision of the 2019 standard

Commented [A45]: Does ISO/ASTM DTR 52906 replace WK56649 listed below?

Commented [A43]: This came from an ASTM tracker alert. It appears that the designation being used is ISO/ASTM 52902 and not ASTM F3345-19

	Additively Manufactured (AM) Parts, is under development

Back to Top

Gap NDE2: Standard for the Design and Manufacture of Artifacts or Phantoms Appropriate for Demonstrating NDE Capability. ~~No~~ One published standards exists for the design or manufacture of artifacts or phantoms applicable to calibrating NDE equipment or demonstrating detection of naturally occurring flaws (lack of fusion, porosity, etc.), or intentionally added features (watermarks, embedded geometrical features, etc.). Current standards under development, ISO/ASTM CD 52905 JG59 and ASTM WK47031, are partially addressing this with seeded defects and demonstration of NDT detectability. This standard should identify the naturally occurring flaws and intentional features. This standard should also include recommendations regarding the use of existing subtractive machined calibration standards or AM representative artifacts or phantoms.
R&D Needed: No. This may not need R&D but it will require obtaining the knowledge necessary to state requirements and present supporting evidence, much like a round robin activity.
Recommendation: Complete work on applicable ASTM F42/ISO TC 261 standards (JG59 and, JG60), especially ASTM WK56649 and ISO/ASTM DTR 52905 ~~and ASTM WK47031~~.
Priority: Medium
Organization: ASTM F42/ISO TC 261
v2 Status of Progress: Green
v2 Update: As noted in the text.
Updates Since v2 was Published:

New Published Standards	**New In-Development Standards**
2/24/2020, MW: Per Jess Waller, NASA ASTM E3166-20, Standard Guide for Nondestructive Examination of Metal Additively Manufactured Aerospace Parts After Build, (formerly WK47031) has been published.	**8/21/2020, JM:** ISO/ASTM CD TR 52906, *Additive manufacturing — Non-destructive testing and evaluation — Standard guideline for intentionally seeding flaws in parts* is in development. **2/24/2020, MW**: Per Jess Waller, NASA • ISO/ASTM DTR 52905, *Additive manufacturing—General principles—Non-destructive testing of additive manufactured products,* is under development.

Back to Top

Gap NDE3: Standard Guide for the Application of NDE to Objects Produced by AM Processes. There is a need for an industry-driven standard led by nondestructive testing experts and supported by the additive manufacturing community to assess current inspection practices and provide an introduction to nondestructive testing and inspection requirements.
R&D Needed: Yes. Round robin testing is underway on ASTM WK47031 and ISO/ASTM CD 52905. A future need will be a precision and bias statement to generate standard test methods to accept/reject AM parts and in procurement of AM parts.
Recommendation: Complete work on ~~ASTM WK47031, *New Guide for Nondestructive Testing of Additive Manufactured Metal Parts Used in Aerospace Applications* and~~ ISO/ASTM ~~C~~DTR 52905, *Additive Manufacturing — Non-Destructive Testing and Evaluation — Standard Guideline for Defect Detection in Metallic Parts*, proceeding as ISO/TC 261/JG59.
Priority: High
Organization: ASTM E07, ASTM F42/ISO TC 261, ASME, NIST
v2 Status of Progress: Green
v2 Update: ASTM WK47031 and ISO/TC 261/JG59 are in development. ASME is also looking at NDE vis a vis its boiler and pressure vessel code.
Updates Since v2 was Published:

New Published Standards	**New In-Development Standards**
2/24/2020, MW: Per Jess Waller, NASA ASTM E3166-20, Standard Guide for Nondestructive Examination of Metal Additively Manufactured	**8/19/2020, JM:** ASTM WK69731, *Additive Manufacturing -- Non-Destructive Testing (NDT) for Use in Directed Energy Deposition (DED) Additive Manufacturing Processes*

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Commented [A47]: Jess Waller edit

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Commented [A50]: Does this replace WK56649? Same question earlier.

Commented [A51]: Per comments from Jess Waller

Aerospace Parts After Build, (formerly WK47031) has been published.	**2/24/2020, MW**: Per Jess Waller, NASA • ISO/ASTM DTR 52905, *Additive manufacturing—General principles—Non-destructive testing of additive manufactured products,* is under development. • ASME is also looking at NDE vis a vis its boiler and pressure vessel code.

Back to Top

Gap NDE4: Dimensional Metrology of Internal Features. The utility of existing and draft CT standards are needed for the dimensional measurement of AM internal features.	
R&D Needed: Yes.	
Recommendation: ASTM E07 should address the applicability of current and draft CT standards (E1570, E1695, WK61161, and WK61974) for measurement of internal features in additively manufactured parts, especially parts with complex geometry, internal features, and/or embedded features. Current CT metrology state-of-the-art needs to be tailored to evolving AM part inspection requirements. See also Gap D26, Measurement of AM Features/Verifying the designs of features such as lattices, etc.	
Priority: Medium	
Organization: ASTM	
v2 Status of Progress: Green	
v2 Update: As noted in the text.	
Updates Since v2 was Published:	
New Published Standards	**New In-Development Standards**

Back to Top

Gap NDE5: Data Fusion. Since multiple sources and results are combined in data fusion, there is a possible issue of a non-linear data combination that can produce results that can be influenced by the user. Additionally, data fusion may employ statistical techniques that can also introduce some ambiguity in the results. While likely more accurate than non-data fusion techniques, introduction of multiple variables can be problematic. Data fusion techniques also require a certain level of expertise by the user and therefore there might be a need for user certification.	
R&D Needed: No	
Recommendation: The following are needed to address the gap: • Specific industry standards for data fusion in AM NDT techniques • Expert education, training, and certification for AM data fusion in NDT	
Priority: Medium	
Organization: ASTM	
v2 Status of Progress: Unknown	
v2 Update: None provided	
Updates Since v2 was Published:	
New Published Standards	**New In-Development Standards**

Back to Top

Gap NDE6: NDE of Polymers and Other Non-Metallic Materials. No published or in development standards or specifications have been identified for NDE of polymers and other non-metallic materials.
R&D Needed: Yes. Research who uses AM Fused Filaments or pellets with PAI/Torlon and/or carbon fiber reinforced filaments with a high degree of fiber loading to see what they are anticipating for testing requirements for NDE for strength or structural qualities.
Recommendation: There is a need for an industry-driven standard led by nondestructive testing experts and supported by the additive manufacturing community to assess current inspection practices and provide an introduction to nondestructive testing and inspection requirements for structural or load bearing polymers and other non-metallic materials. Use ASTM E2533-17e1 as a guideline when applicable.

Priority: Low	
Organization: ASTM F42/ISO TC 261, ASTM E07, ASTM D20, ASME	
v2 Status of Progress: New	
v2 Update: None provided	
Updates Since v2 was Published: **11/13/2020, MW**: Steve Weinman, ASME, comment: Add ASME to the list of organizations for GAP NDE6	
New Published Standards	**New In-Development Standards**

Back to Top

Gap NDE7: NDE of Counterfeit AM Parts. There are no published or in development NDE standards for methods used to verify anti-counterfeiting methods.	
R&D Needed: Not at this time. Future R&D may be needed if an anti-counterfeiting method is developed which cannot be verified by existing NDE methods or standards.	
Recommendation: Develop NDE methods and standards for anti-counterfeiting that are not addressed by existing methods or standards.	
Priority: Low	
Organization: ASTM F42/ISO TC 261, ASTM E07, SAE AMS-AM	
v2 Status of Progress: New	
v2 Update: None provided	
Updates Since v2 was Published:	
New Published Standards	**New In-Development Standards**

Back to Top

Gap NDE8: NDE Acceptance Criteria for Fracture Critical AM Parts. There is a need for an industry standard that establishes NDE acceptance classes for fracture critical AM parts.	
R&D Needed: Yes. Well-characterized samples should be fabricated with controlled loadings of technologically important AM defects in order to conduct effect-of-defect studies.	
Recommendation: Develop an industry standard that establishes different degrees of flaw concentrations for quality acceptance. Fabricate effect-of-defect samples with the appropriate level of fidelity, i.e., sufficient similarity between the defect state in sacrificial samples (for example, ASTM E8 compliant dogbones) with natural flaws in actual production parts.	
Priority: Medium	
Organization: ASTM F42 / ISO TC 261 JG59, ASTM E07, ASTM E08 on Fracture and Fatigue	
v2 Status of Progress: New	
v2 Update: None provided	
Updates Since v2 was Published:	
New Published Standards	**New In-Development Standards**

Back to Top

Other Nondestructive Evaluation (NDE) Activity - Relevance to Gaps Not Yet Determined

New Published Standards

New In-Development Standards

Back to Top

Chapter 2.5. Maintenance & Repair

Medium Priority

Low Priority

Back to Top

Gap M1: AM Analyses in RCM and CBM. With respect to maintenance and sustainment of AM machines, standards for AM analyses in Reliability Centered Maintenance (RCM) and Conditioned Based Maintenance (CBM+) are needed.	
R&D Needed: No	
Recommendation: Update SAE JA1012, a guide to provide analytics for AM trade-offs in RCM and CBM+.	
Priority: Medium	
Organization: SAE, ISO, ASTM	
v2 Status of Progress: Not Started	
v2 Update: SAE G-11M, Maintainability, Supportability and Logistics Committee, will consider inclusion of analytics for AM trade-offs in the next update of JA1012_201108.	
Updates Since v2 was Published:	
New Published Standards	**New In-Development Standards**

Back to Top

Gap M3: AM Level of Repair Analysis. Standards for AM LORA are needed. In performing a repair versus discard analysis, the use of AM can change the LORA decision due to shifts in factors relating to logistics delay time, spares availability, cost of spares, etc. Trade space would address reduction of time and increase in skill set (e.g., for qualified printer operators).	
R&D Needed: No	
Recommendation: Update SAE AS1390, *Level of Repair Analysis (LORA)*, to include impact of AM on trade space of repairs.	
Priority: Medium	
Organization: SAE LCLS, SAE AMS-B, ISO, ASTM	
v2 Status of Progress: Green	
v2 Update: SAE's LCLS (Life Cycle Logistics Supportability) Committee plans to include AM in the upcoming revision of AS1390. Although the LCLS Committee has not opened a Work in Progress for AS1390, a team is working on revisions and has agreed to include AM. The SAE G-11M Committee is in the process of reorganizing but the chair has the AMSC requests on his radar. In addition, AMS2680C is currently under revision.	
Updates Since v2 was Published: **5/22/2019, LY:** Repair SC established.	
New Published Standards	**New In-Development Standards** **5/8/2019, LY:** SAE's Life Cycle Logistics Supportability Committee plans to include the acceptance of additive manufacturing in the upcoming revision to AS1390, *Level of Repair Analysis*.

Back to Top

Gap M4: Physical Inspection of Parts Repaired Using AM. A standard inspection process for component or tooling defects is needed to consider additive manufacturing technologies as potential solutions for preventative and corrective maintenance actions.	
R&D Needed: No	
Recommendation: Update SAE JA1011/1012 to include an inspection process for additive manufacturing repairs.	
Priority: Medium	
Organization: SAE, ISO/ASTM	
v2 Status of Progress: Not Started	
v2 Update: SAE G-11M, Maintainability, Supportability and Logistics Committee, will consider inclusion of an inspection process for AM repairs in the next update of JA1011_200908 and JA1012_201108.	
Updates Since v2 was Published:	
New Published Standards	**New In-Development Standards**

Back to Top

Gap M5: Model-Based Inspection. Standard practices for model-based inspection methods using AM are needed for repair assessments and scheduling.	
R&D Needed: No	
Recommendation: Develop standard practices for assessing level of damage for end-use parts.	
Priority: Medium	
Organization: ASME, ISO/ASTM, Dimensional Metrology Standards Consortium	
v2 Status of Progress: Not Started, or Unknown	
v2 Update: No update provided.	
Updates Since v2 was Published:	
New Published Standards	**New In-Development Standards**

Back to Top

Gap M6: Tracking Maintenance. A standard is needed for how preventative maintenance operations of AM machines are tracked (e.g., monitoring printer health, need for servicing, etc.).	
R&D Needed: No	
Recommendation: • Develop a standard for tracking maintenance operations to ensure a printer is ready when needed. See also Gap PC3 on machine health monitoring. • Develop a standard to address emergency repair/limited life parts for urgent cases in the field.	
Priority: Medium	
Organization: AWS, ASTM	
v2 Status of Progress: Unknown	
v2 Update: None provided	
Updates Since v2 was Published: **8/5/2020, MW**: ASTM AMCOE *Strategic Roadmap for Research & Development* (April 2020) notes that AMCOE Project 1901 (WK71395) addresses AMSC Gap M6.	
New Published Standards **11/20/2020, MW**: Bill Bihlman, SAE, Comment: • *SAE AMS7005, Wire Fed Plasma Arc Directed Energy Deposition Additive Manufacturing Process* (Jan 2019) • SAE AMS7007, *Electron Beam Powder Bed Fusion Process* (Jul 2020)	**New In-Development Standards** **3/31/2021, JM:** NRC presentation of 12/09/20 by Mohsen Seifi noted these ASTM work items: ASTM WK71395, *Additive manufacturing -- accelerated quality inspection of build health for laser beam powder bed fusion process* **11/20/2020, MW**: Bill Bihlman, SAE, Comment:

• SAE AMS7010, *Wire Fed Laser Directed Energy Deposition Additive Manufacturing Process (L-DED-wire)* (Jan 2020) • *SAE AMS7022, Binder Jetting Process* (Nov 2020) • *SAE AMS7027, Electron Beam Wire Fusion Process* (Nov 2020)	• *SAE AMS7002A, Process Requirements for Production of Metal Powder Feedstock for Use in Additive Manufacturing of Aerospace Parts* (Aug 2018) • *SAE AMS7003A, Laser Powder Bed Fusion Process* (Jun 2019) • *SAE AMS7010A, Wire Fed Laser Directed Energy Deposition Additive Manufacturing Process (L-DED-wire)* (Jan 2020) • *SAE AMS7029, Cold Metal Transfer Directed Energy Deposition (CMT-DED) Process* (Feb 2020) • *SAE AMS7031, Process Requirements for Recovery and Recycling of Metal Powder Feedstock for Use in Additive Manufacturing of Aerospace Parts* (Apr 2020) • *SAE AMS7034 - Hybrid Laser Arc Directed Energy Deposition (HLA-DED) (Aug 2020)*

Back to Top

Gap M7: Cybersecurity for Maintenance. In support of on-site repairs, guidance is needed that addresses cybersecurity considerations for maintenance and repair of parts that have 3D models ready to print. Secure storage in a database should ensure that only authorized personnel can download files and print parts.	
R&D Needed: Yes	
Recommendation: Guidance is needed to ensure the integrity and safe storage of AM files as maintenance and repair operations may take place in an uncontrolled environment. See also gap PC15 on configuration management: cybersecurity.	
Priority: Medium	
Organization: NIST, NEMA/MITA, NDIA JWG, ASTM, IEEE-ISTO PWG	
v2 Status of Progress: Not Started, or Unknown	
v2 Update: None provided	
Updates Since v2 was Published:	
New Published Standards	**New In-Development Standards**

Back to Top

Gap M8. Surface Preparation for Additive Repair. Standards are needed for chemical compatibility with additively manufactured materials for surface cleaning in preparation for an additive repair process. Additionally, standards are needed for removal of coatings, including paints and powder coating, and plating (chrome, zinc, etc.) for additively manufactured parts.	
R&D Needed: Yes	
Recommendation: Develop standards for approved chemical substances and mechanical processes used for the removal of coatings and plating on additively manufactured components, to include metals, polymers, ceramics, and other materials.	
Priority: Medium	
Organization: ASTM, SAE, ISO	
v2 Status of Progress: Not Started, or Unknown	
v2 Update: None provided	
Updates Since v2 was Published:	
New Published Standards	**New In-Development Standards**

Back to Top

Gap M9: Laser Based Additive Repair. Current standards do not specifically address the use of laser based systems (metal powder or wire feedstock) to additively repair parts or tools.	
R&D Needed: No	
Recommendation: Ensure that laser based additive repair processes are included in AWS D20.1.	
Priority: Low	
Organization: AWS, SAE AMS-AM	
v2 Status of Progress: New	
v2 Update: None provided	
Updates Since v2 was Published: **3/17/2020, MW**: Jessica Coughlin, AWS D20, comments: AWS D20.1 contains requirements for qualifying wire-fed and powder-fed laser DED procedures. In paragraph 5.2.3.2, AWS D20.1 requires that tension test specimens that include the material interface in the gage region be removed from procedure qualification builds used to qualify repairs. **5/22/2019, LY:** Repair SC established. **5/8/2019, LY:** SAE's AMS-AM Additive Manufacturing Committee established the Additive for Repair Working Group in September 2018. Currently developing a scenario to establish the specification framework utilizing a damaged airframe component requiring a directed energy deposition repair. Once finalized, the working group plans to develop material and process specifications for aerospace repair applications.	
New Published Standards **4/4/2019, LY:** The AWS recently published a new standard on AM, *AWS D20.1/D20.1M:2019 Specification for Fabrication of Metal Components using Additive Manufacturing*.	**New In-Development Standards** **11/20/2020, MW**: Bill Bihlman, SAE, Comment: WIP: SAE ARP Repair Guidance Document

Back to Top

Other Maintenance and Repair Activity - Relevance to Gaps Not Yet Determined

New Published Standards

New In-Development Standards

Back to Top