Standardization of Metal Additive Manufacturing – needs from Swedish industry

Annika Strondl (Swerim), Lars-Olov Nordberg (Swerim), Pelle Mellin (Swerim), Sven Karlsson (RISE IVF), Kristina Hellström (RISE IVF), Lars Nyborg (Chalmers University of Technology), Eduard Hryha (Chalmers University of Technology), Ann-Sofie Sjöblom (SIS)

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Picture courtesy of ASTM F42/ISO TC 261

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	Standardization of Metal Additive Manufacturing

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Abstract

Additive manufacturing (AM) of metal is a relatively new technology undergoing rapid development. The market metal AM is growing. However, to promote widespread use of AM technologies and to grow the market further, there is a prompt need for global standards. The goal of this project was to build a solid and well supported base for a Swedish standardization roadmap for metal AM.

A review of existing standards and ongoing standardization work within metal AM has been performed. Today, 25 standards are under development and approximately the same number of standards already exist. Input on needs for standardization from Swedish Industry has been gathered from stakeholders along the metal AM value chain. This has been done through a survey, interviews, and a workshop on February 5th, 2020, with around 30 participants.

Some of the highlighted needs might already be covered in the ongoing standardization work. Still, the analysis showed that the major gaps were identified in all areas along the value chain. A gap was defined as an area lacking standardization, neither any existing standards relating to the need nor any on-going standardization work. However, there are several important areas that needs more research and method development in order to build the necessary databases and the statistics to assess the standardization work properly. On the other hand, for some of the identified gaps the knowledge level of Swedish industry is high. Examples are powder related needs, where the powder producers use their own best practice. Other examples are the atmosphere in the print chamber and post treatment by HIP, where joint research involving technology supplier is on-going.

The needs identified in the RAMP-UP roadmap for industrialization of metal AM are to a large extent overlapping with the needs for standardization identified in this project, where knowledge is still lacking. Development of methods and systems for qualification of AM products for different end user branches, and for quality assurance, are still high priority. The use of standardized working routines and traceability could reduce scattering of final properties. Further research projects within those areas could be used as a base for subsequent standardization.

The results have been summarized in this report, which will be discussed within SIS technical committee for AM, SIS/TK 563 Additiv tillverkning. The results can be the basis for future global standardization work being suggested by Sweden through SIS/TK 563, within ISO/TC 261 Additive Manufacturing. The results will also be used to identify research needs to support standardization. The Swedish Arena for AM of Metals and CAM2 will actively contribute by pushing for Swedish research activities to support the standardization, in dialog with Swedish funding agencies.

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1 Introduction

Additive manufacturing (AM) of metal is a relatively new technology undergoing rapid development. The market metal AM is growing. However, to promote widespread use of AM technologies and to grow the market further, there is a prompt need for global standards. The goal of this project was to build a solid and well supported base for a Swedish standardization roadmap for metal AM. Today, international standardization roadmaps exist as well as a roadmap for industrialisation of metal AM in Sweden, RAMP-UP[1]. It was now time to connect them and prioritize standardization based on input from Swedish industry to open the market. In fact, lack of appropriate standards has been identified as one of the important obstacles to realise increased industrialization and reach the market. A priority for Sweden is therefore to set a strategic scope on national level to identify the most important standardization issues and to guide the effort of contributing and influencing international standardization work. This work was funded by a Vinnova project with Swerim, Chalmers, RISE IVF and SIS as partners and is performed in collaboration with the Swedish Arena for AM of Metals, CAM2 and SIS. AMEXCI has also given their active support to the project, as well as the reference group consisting of Håkan Brodin, Siemens Industrial Turbomachinery, and Sigurd Berg, Höganäs.

A review of existing standards and ongoing standardization work within metal AM has been performed. Input on needs for standardization from Swedish Industry has been gathered from stakeholders along the metal AM value chain. This has been done through a survey, interviews, and a workshop on February 5th, 2020, with around 30 participants. The results have been summarized in this report, which will be discussed within SIS technical committee for AM, SIS/TK 563 Additiv tillverkning. The results can be the basis for future global standardization work being suggested by Sweden through SIS/TK 563, within ISO/TC 261 Additive Manufacturing. The results will also be used to identify research needs to support standardization. The Swedish Arena for AM of Metals and CAM2 will actively contribute by pushing for Swedish research activities to support the standardization, in dialog with Swedish funding agencies.

2 State of the art of standards within metal additive manufacturing and the ongoing work

2.1 International standardization

“Standardization can transform the future of additive manufacturing. We need to be sure that whatever is going to be produced is going to be consistent, safe, and of high quality. We need to be able to formalize the rules and the ways that we can make things with additive manufacturing and that’s why standards are so critical”, said by Ralph Resnick, Founding

[1] RAMP-UP project group, Research Needs and Challenges for Swedish Industrial Use of Additive Manufacturing, 2017-10-06, Available at www.AM.Arena.se (2020-04-15)

Director of America Makes, and President and CEO, National Center for Defense Manufacturing and Machining.

2.1.1 International Organization for Standardization (ISO) in strategic partnership with World Trade Organization (WTO)

The World Trade Organization (WTO) deals with the rules governing trade among its 162 member states. WTO agreements cover goods, services and intellectual property. A key WTO agreement is the Technical Barriers to Trade (TBT) agreement which aims to ensure that technical regulations, ***standards*** and conformity assessment procedures, which governments might use to describe the characteristics of products being traded, do not create unnecessary technical barriers to trade.

International Organization for Standardization (ISO), International Electrotechnical Commission (IEC) and International Telecommunication Union (ITU) have strategic partnerships with WTO. Standards developed by IEC, ISO and ITU are consistent with the decision of the WTO's TBT committee on principles for the development of International Standards. Standards developed by these three organizations respect the principles of ***openness, transparency, impartiality and consensus, effectiveness and relevance, coherence, and the development dimension,*** agreed by the WTO's TBT committee. Policy makers can have confidence when using IEC, ISO or ITU International Standards that they are fulfilling their WTO obligations, and not creating any unnecessary obstacles to international trade.

ISO, IEC and ITU have national member bodies from all over the world and fulfil the WTO TBT definition of International Standards development organizations as their membership is open to the relevant bodies of at least all Members of the WTO TBT. In Sweden the member of ISO is Swedish Institute for Standards (SIS).

Standardization within AM is being conducted within ISO with a SIS national committee of AM, see details below.

2.1.2 Standardization organizations in Sweden, Europe and globally

Global standards within the area of AM are being developed within ISO and the Swedish member of ISO is SIS. See information below on Standardization in Sweden and how Swedish stakeholders can influence global standardization.

Global standards are developed within ISO, IEC (electrotechnical area),and in addition, ITU covers the telecommunication area. ISO is currently having 164 members of which SIS is one of them.

The corresponding structure for European standardization is CEN, CENELEC (electrotechnical area) and ETSI (telecommunication area). The Members of CEN are the National Standardization Bodies of 34 European countries – including all the member states of the European Union (EU) and other countries that are part of the European Single Market.

European Standardization is a key instrument for consolidating the Single Market and facilitating cross-border trade, within Europe and also with the rest of the world. It is a valuable tool for strengthening the competitiveness of European companies, thereby creating the conditions for economic growth.

Each National Standardization Body that is part of the CEN system is obliged to adopt each European Standard as a national standard and make it available to customers in their country. They also have to withdraw any existing national standard that conflicts with the new European Standard. Therefore, one European Standard (EN) becomes the national standard in all 34 countries covered by CEN Members.

In Sweden, SIS is the national member of ISO and CEN, SEK is the national member of IEC and CENELEC and ITS is the national member of ITU and ETSI. The relationship is shown in Figure 1.

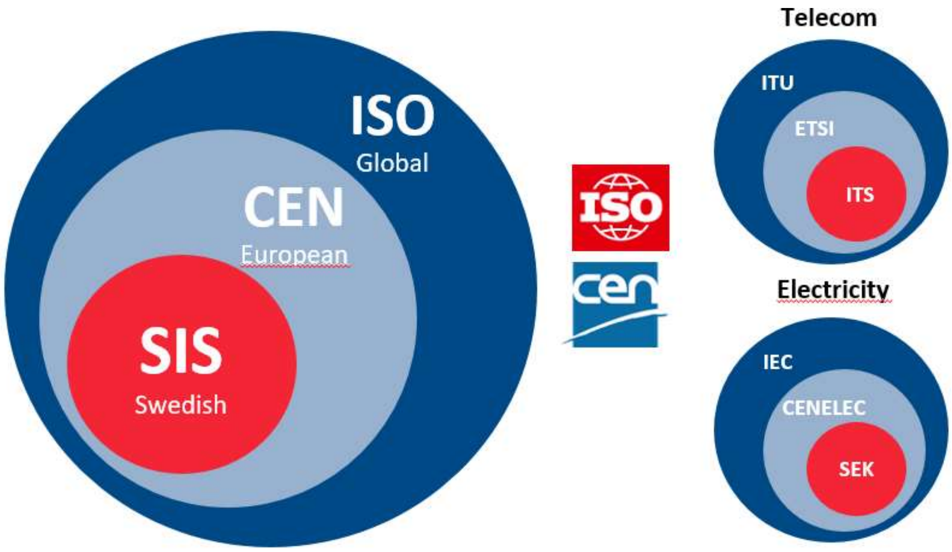

Figure 1 Global and European standardization organizations, and their respective Swedish members

2.1.3 International standardization within additive manufacturing

International standardization within AM is aiming at one set of AM standards, used worldwide. Therefore, global standardization is being conducted within ISO Technical Committee number 261 Additive Manufacturing[2], which since 2011 is working in close cooperation with ASTM F42 Additive Manufacturing. The cooperation means ongoing collaborative efforts between the two organizations to adopt and jointly develop International Standards that serve the global marketplace in the field of AM. The purpose of this agreement is to eliminate duplication of effort while maximizing resource allocation within the AM industry. Read more on the homepage of ISO/TC 261 Additive manufacturing[3].

[2] https://www.iso.org/committee/629086.html
[3] https://committee.iso.org/home/tc261

Practically, the standardization development is being conducted in approximately 30 joint ISO/TC 261 and ASTM F42 Additive Manufacturing groups consisting of experts from both ISO and ASTM. All groups are listed here[4]. Experts meet physically twice a year in the US and Europe/Asia respectively and in between in digital meetings. In the physical meetings approximately 100 experts participate.

The scope of ISO/TC 261 is: Standardization in the field of AM concerning their processes, terms and definitions, process chains (Hard- and Software), test procedures, quality parameters, supply agreements and all kind of fundamentals.

ISO/TC 261 Additive manufacturing has 26 participating members, of which Sweden is one. Seven members are non-active participants. 13 standards have been published and 31 standards are being produced currently.

The main objectives of ISO/TC 261 are to standardize the processes of AM, their process chains (Data, Materials, Processes, Hard- and Software, Applications), test procedures, quality parameters, supply agreements, fundamentals and vocabularies. It is agreed by all member bodies that those objectives always have to follow the market needs and enable flexible reaction on changes. In Figure 2 an overview of the different areas for AM standardization made by ASTM F42/ISO TC 261.

Figure 2 An overview of different areas for AM standardization from ASTM F42/ISO TC 261[5]

[4] https://www.iso.org/committee/629086.html
[5] https://www.astm.org/COMMIT/F42_AMStandardsStructureAndPrimer.pdf

The Figure 3 below illustrates the type of standards that are being produced within the collaboration between ISO/TC 261 and ASTM F42. They are structured into general top-level standards, category standards and specialized standards.

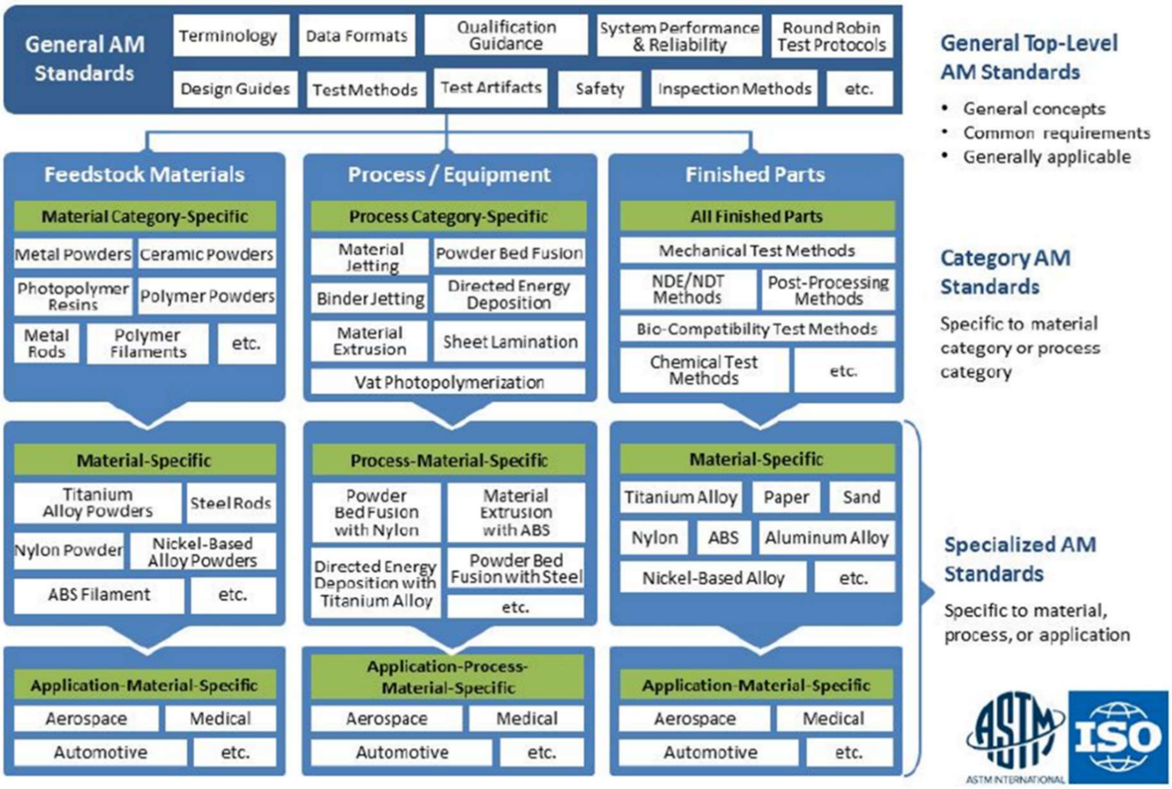

Figure 3 AM standardization framework, developed and approved by ASTM F42/ISO TC261[6]

2.1.4 European standardization within additive manufacturing

ISO and CEN have within the area of AM agreed upon developing standards globally within ISO in cooperation with ASTM. There is a CEN-committee within AM: CEN/TC 438 Additive Manufacturing. This CEN-committee is adopting the global ISO/ASTM-standards being published within ISO as European standards, having the prefix EN of the standard. When an EN standard has been adopted, it is mandatory to implement it as national standard in the European countries, and no "alternative" standard is allowed to co-exist. This also includes the "original" ISO version of the standard. Because of the lead time in implementing the European standard, a more recent version of a standard may exist within ISO for some time, until it has become processed and implemented as an EN standard.

2.1.5 Other standardization organizations (SDO)

Besides ASTM and ISO, who since October 2011 has an agreement and since July 2013 a plan of joint standards development as viewed in Figure 2, several other standard development organisations are active in the AM space. Listed below are of America Makes & ANSI Additive

[6] https://www.astm.org/COMMIT/F42_AMStandardsStructureAndPrimer.pdf

Manufacturing Standardization Collaborative (AMSC) identified SDOs and each SDOs work is shortly described in the AMSC roadmap[7].

Association for the Advancement of Medical Instrumentation (AAMI)

American Society for Mechanical Engineers (ASME)

American Welding Society (AWS)

Institute for Electrical and Electronics Engineers (IEEE)

IPC – Association Connecting Electronics Industries (IPC)

Medical Imaging & Technology Alliance (MITA) and Digital Imaging and Communications in Medicine (DICOM) of the National Electrical Manufacturers Organisation (NEMA)

Metal Powder Industries Federation (MPIF)

MT Connect Institute (MTConnect)

SAE International (SAE)

2.1.6 Roadmaps

Several roadmaps for standardization have been presented and among those the following can be given as examples to reflect the metal AM industry.

<u>NIST: Measurement Science Roadmap for Metal-Based Additive Manufacturing, 2013[8]</u>

The report summarises a workshop held on 4-5 December 2012. Several challenges were identified and for some of them it was noted that they cut across all aspects of AM, from materials and modelling to design and manufacturing processes, for example:

- ✓ **Standards and protocols** for all aspects of AM, from materials design and use to part build and inspection.
- ✓ **Measurement and monitoring techniques and data**, from material feedstock through final part inspection, including effective process controls and feedback.
- ✓ **Fully characterized materials properties**, which are key to materials development, processing effectiveness and repeatability, qualification of parts, and modelling at many levels.
- ✓ **Modelling systems that couple design and manufacturing**, which impacts the development of materials as well as new processing technologies.
- ✓ **Closed loop control systems for AM**, which are vital for processing and equipment performance, assurance of part adherence to specifications, and the ability to qualify and certify parts and processes.

<u>AM Platform: SASAM Standardization Roadmap, 2015[9]</u>

The document describes the roadmap for standardization activities for Additive

Manufacturing as drafted from the SASAM project. It is based on the on-going developments within this sector, it contains the needs and visions from the industry and other principal

[7] https://www.americamakes.us/america-makes-ansi-publish-version-2-0-standardization-roadmap-additive-manufacturing/

[8] https://www.nist.gov/system/files/documents/el/isd/NISTAdd_Mfg_Report_FINAL-2.pdf

[9] http://www.rm-platform.com/component/jdownloads/send/50-strategic-research-agenda/608-sasam-standardisation-roadmap-open-june-2015?Itemid=0.

stakeholders and reflects development trends within the manufacturing industry and society in general.

FoFAM: Additive manufacturing roadmap: gaps and actions on market driven value chains, 2016[10]

This document aims at presenting the AM implementation map on market driven value chains and constitutes an open working document, developed in the framework of FoFAM project "Industrial and regional valorisation of FoF Additive Manufacturing projects" (Grant agreement no. 636882). This roadmap was designed with the aim to offer a strategy for building the fundamental knowledge and actions necessary to accelerate the design, application and implementation in the market of AM. The sectors in focus were Medical and dental, Aerospace, Automotive, Consumer goods (including electronics), and Industrial equipment.

America Makes & ANSI Additive Manufacturing Standardization Collaborative (AMSC): Standardization Roadmap for Additive Manufacturing, Version 1.0, 2017 & Version 2.0, 2018[11]

The 2nd edition of the America Makes & ANSI roadmap describes the current AM standardization and identifies 93 gaps – 18 of them with high priority – and a gap is defined as where no published standard or specification currently exists that cover the issue in question. In 65 of those gaps, additional pre-standardization research & development needs are identified. The report also analyses the status of the 89 gaps that were identified and described in the 1st edition. The focus for the roadmap is the industrial AM market, especially for aerospace, defence, and medical applications and is not limited to metals. The roadmap covers the life cycle of an AM part, from initial design, to materials and process selection, production, post-processing to finished material properties, qualification and certification, NDT, and maintenance. The hope is that the roadmap will be broadly adopted by the standards community and that it will facilitate a more coherent and coordinated approach to the future development of standards and specifications for AM.

Various organizations have hosted workshops with the aim of identifying areas where existing standards, for example used in the powder metallurgy field, need to be customized to AM or where new standards need to be developed. The paper by Seifi *et al.*[12] can serve as an example.

The ASTM International Additive Manufacturing Center of Excellence (AM CoE)[13] is a collaborative partnership among ASTM and its 30 000 members and representatives from government, academia, and industry that bridges and conducts strategic R&D to advance standards across all aspects of AM which will accelerate the development and adoption of robust, game-changing technologies. In a white paper[14] describing the benefits of early collaborative engagements to bridge the gap between innovation and market the AM CoE initiative is used as an example.

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[10] http://www.rm-platform.com/downloads2/send/52-associated-projects/605-am-roadmap-2016.

[11] https://www.americamakes.us/america-makes-ansi-publish-version-2-0-standardization-roadmap-additive-manufacturing/

[12] Seifi, M. *et al*: "Progress Towards Metal Additive Manufacturing Standardization to Support Qualification and Certification", JOM, Vol. 69, No. 3, p. 439-455, 2017; DOI: 10.1007/s11837-017-2265-2

[13] https://amcoe.org/

[14] ASTM white paper: Standards Development: Enabling Manufacturing Innovation and Accelerating Commercialization

2.2 Standardization in Sweden

SIS main task is to organize and coordinate the national expertise into the global standardization work. This is usually done two ways – by having experts participating directly in the ISO work in developing standards, and by having national mirror committees as reference for the work – to obtain a national consensus in the voting on standard proposals subjected to nation-wise ballot.

SIS has a a technical committee within AM: SIS/TK 563 Additiv tillverkning (SIS/TK 563)[15]. SIS/TK 563 is mirroring ISO/TC 261 Additive manufacturing meaning it, through SIS ensurance, is voting and commenting on every ongoing standardization-project within ISO/TC 261 Additive manufacturing. SIS/TK 563 currently consists of 18 members from companies/organizations/academia. The members meet regularly discussing matters relating to Swedish stakeholders as input into the international standardization within ISO/TC 261. Some of the members of SIS/TK 563 participate directly in the workings groups within ISO/TC 261 as experts in addition to being members in SIS/TK 563.

A new work item could be proposed to ISO/TC 261 through SIS/TK 563. The work item then has to be approved by the members of ISO/TC 261 through a ballot.

2.3 Existing standards within metal AM

Standards currently published under ISO/TC 261 are listed in 2.3.1 and can be found here[16]. For 12 of the standards there is a prefix of SS meaning they have been adopted as Swedish standards. The prefix EN means they have been adopted as European standards. In 2.3.2 there is a list of other standards, e.g. ASTM, DIN, SAE.

Currently within AM there are a substantial number of individual processes which vary in their method of layer manufacturing. Individual processes will differ depending on the material and machine technology used. As per ISO/ASTM standards (SS-EN ISO 17296-2) AM can be divided into seven process categories according to the techniques used to create those layers:

1. Binder jetting – metals, polymers, ceramics
2. Directed energy deposition – only metal
3. Material extrusion – today polymers, but development with metal (similar to MIM)
4. Material jetting – basically polymer/wax, but development metal and ceramic
5. Powder bed fusion – metal, polymer, ceramic
6. Sheet lamination – metal, hybride, ceramic, paper
7. Vat photopolymerization – polymer, ceramic

[15] https://www.sis.se/standardutveckling/tksidor/tk500599/sistk563/
[16] https://www.iso.org/committee/629086/x/catalogue/p/1/u/0/w/0/d/0

For metal, binder jetting, directed energy deposition, and powder bed fusion are main technologies, being commercial today. For material extrusion, material jetting, and sheet lamination there is development and partial commercialization for specific applications.

2.3.1 Standards under direct responsibility of the ISO/TC 261 secretariat

The Swedish standards, SS-EN are listed with an English title below, due to that the current report is written in English. However, there is still a Swedish name to be found when looking into the SS-EN database at SIS[17].

SS-EN ISO/ASTM 52907:2020 Additive manufacturing - Feedstock materials - Methods to characterize metal powders (ISO/ASTM 52907:2019);

SS-EN ISO/ASTM 52910:2019 Additive manufacturing - Design - Requirements, guidelines and recommendations (ISO/ASTM 52910:2018);

SS-EN ISO/ASTM 52911-1:2019 Additive manufacturing - Design - Part 1: Laser-based powder bed fusion of metals (ISO/ASTM 52911-1:2019);

SS-EN ISO/ASTM 52902:2019 Additive manufacturing - Test artefacts - Geometric capability assessment of additive manufacturing systems (ISO/ASTM 52902:2019);

SS-EN ISO/ASTM 52901:2018 Additive manufacturing - General principles - Requirements for purchased AM parts (ISO/ASTM 52901:2017);

SS-EN ISO/ASTM 52915:2017 Specification for additive manufacturing file format (AMF) Version 1.2 (ISO/ASTM 52915:2016);

SS-EN ISO/ASTM 52900:2017 Additive manufacturing - General principles - Terminology (ISO/ASTM 52900:2015);

SS-EN ISO 52921:2016 Standard terminology for additive manufacturing - Coordinate systems and test methodologies (ISO/ASTM 52921:2013);

SS-EN ISO 17296-2:2016 Additive manufacturing - General principles - Part 2: Overview of process categories and feedstock (ISO 17296-2:2015);

SS-EN ISO 17296-3:2016 Additive manufacturing - General principles - Part 3: Main characteristics and corresponding test methods (ISO 17296-3:2014);

SS-EN ISO 17296-4:2016 Additive manufacturing - General principles - Part 4: Overview of data processing (ISO 17296-4:2014);

ISO/ASTM 52904:2019 Additive manufacturing — Process characteristics and performance — Practice for metal powder bed fusion process to meet critical applications; and

SS-ISO 14649-17:2020 Industrial automation systems and integration - Physical device control - Data model for computerized numerical controllers - Part 17: Process data for additive manufacturing (ISO 14649-17:2020, IDT).

[17] https://www.sis.se/

2.3.2 Other published standards

DIN EN ISO/ASTM 52942 Additive manufacturing - Qualification principles - Qualifying machine operators of metal powder bed fusion machines and equipment used in aerospace applications (ISO/ASTM DIS 52942:2019);

DIN 65122 Aerospace series - Powder for AM with powder bed process - Technical delivery specification;

ASTM Committee F42 standards that contain specific HIP process parameters for specific metals include: ASTM B998-17, Standard Guide for Hot Isostatic Pressing (HIP) of Aluminum Alloy Castings (previously WK47205), ASTM F2924-14, Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium with Powder Bed Fusion, and ASTM F3001-14, Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium ELI (Extra Low Interstitial) with Powder Bed Fusion;

ASTM F3049-14, Standard Guide for Characterizing Properties of Metal Powders Used for Additive Manufacturing Processes;

ASTM F3055-14a, Standard Specification for Additive Manufacturing Nickel Alloy (UNS N07718) with Powder Bed Fusion;

ASTM F3056-14e1, Standard Specification for Additive Manufacturing Nickel Alloy (UNS N06625) with Powder Bed Fusion;

ASTM F3122-14 Standard Guide for Evaluating Mechanical Properties of Metal Materials Made via Additive Manufacturing Processes. The following standards are not referred to directly in the guide but also have information that may be useful in the testing of metal test specimens made via additive manufacturing: A370, A1058, B211, B348, B557, B565, B724, B769, E3, E6, E7, E290, E467, E468, E837, E915, E1049,E182;

ASTM F3301-18 Standard for Additive Manufacturing – Post Processing Methods – Standard Specification for Thermal Post-Processing Metal Parts Made Via Powder Bed Fusion; and

SAE AMS-AM standards that contain specific HIP process parameters for specific metals include: SAE AMS4999A, Titanium Alloy Laser Deposited Products~6Al - 4V~Annealed, SAE AMS7000, Laser-Powder Bed Fusion (L-PBF) Produced Parts, Nickel Alloy, Corrosion and Heat-Resistant, 62Ni – 21.5Cr – 9.0Mo – 3.65 Nb Stress Relieved, Hot Isostatic Pressed and Solution Annealed.

2.4 Standards under development for metal AM

Present status of 31 standards, and/or projects, under development under the responsibility of ISO/TC 261 are found at here[18]. The list covers all items under development.

ISO/ASTM DIS 52900 Additive manufacturing — General principles — Fundamentals and vocabulary*

ISO/ASTM AWI 52902 Additive manufacturing — Test artefacts — Geometric capability assessment of additive manufacturing systems

ISO/ASTM DTR 52905 Additive manufacturing — General principles — Non-destructive testing of additive manufactured products

[18] https://www.iso.org/committee/629086/x/catalogue/p/0/u/1/w/0/d/0

ISO/ASTM CD TR 52906 Additive manufacturing — Non-destructive testing and evaluation — Standard guideline for intentionally seeding flaws in parts

ISO/ASTM AWI 52908 Additive manufacturing — Post-processing methods — Standard specification for quality assurance and post processing of powder bed fusion metallic parts

ISO/ASTM AWI 52909 Additive manufacturing — Finished part properties — Orientation and location dependence of mechanical properties for metal powder bed fusion

ISO/ASTM CD TR 52912 Additive manufacturing - Design - Functionally graded additive manufacturing

ISO/ASTM 52915 Specification for additive manufacturing file format (AMF) Version 1.2

ISO/ASTM WD 52916 Additive manufacturing — Data formats — Standard specification for optimized medical image data

ISO/ASTM WD 52917 Additive manufacturing — Round Robin Testing — Guidance for conducting Round Robin studies

ISO/ASTM CD TR 52918 Additive manufacturing — Data formats — File format support, ecosystem and evolutions

ISO/ASTM WD 52919-1 Additive manufacturing — Test method of sand mould for metal casting — Part 1: Mechanical properties

ISO/ASTM WD 52919-2 Additive manufacturing — Test method of sand meld for metal casting — Part 2: Physical properties

ISO/ASTM WD 52920-2 Additive manufacturing — Qualification principles — Part 2: Requirements for industrial additive manufacturing sites

ISO/ASTM DIS 52921 Additive manufacturing — General principles — Standard practice for part positioning, coordinates and orientation

ISO/ASTM WD 52926-1 Additive manufacturing — Qualification principles — Part 1: Qualification of machine operators for metallic parts production

ISO/ASTM WD 52926-2 Additive manufacturing — Qualification principles — Part 2: Qualification of machine operators for metallic parts production for PBF-LB

ISO/ASTM WD 52926-3 Additive manufacturing — Qualification principles — Part 3: Qualification of machine operators for metallic parts production for PBF-EB

ISO/ASTM WD 52926-4 Additive manufacturing — Qualification principles — Part 4: Qualification of machine operators for metallic parts production for DED-LB

ISO/ASTM WD 52926-5 Additive manufacturing — Qualification principles — Part 5: Qualification of machine operators for metallic parts production for DED-Arc

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

ISO/ASTM DIS 52941 Additive manufacturing — System performance and reliability — Standard test method for acceptance of powder-bed fusion machines for metallic materials for aerospace application

ISO/ASTM DIS 52942 Additive manufacturing — Qualification principles — Qualifying machine operators of laser metal powder bed fusion machines and equipment used in aerospace applications

ISO/ASTM DIS 52950 Additive manufacturing — General principles — Overview of data processing

ASTM WK47031 New Guide for Non-destructive Testing of Metal Additively Manufactured Metal Aerospace Parts After Build

Notes: AWI = Approved work item, WD = Working draft, CD = Committee draft, DIS = draft international standard, FDIS = Final draft international standard, TR = technical report

* ISO/TC261/WG1 is the mirror group for JG51 which is responsible for the maintenance and continuous revision of the International Standard ISO/ASTM 52900 Additive manufacturing — General principles — Terminology, including the development of definitions for new terms as well as necessary amendments, emerging from the ongoing work within ISO/TC 261 and the American Society for Testing and Materials (ASTM) group "ASTM F42 – Additive Manufacturing". The scope of the working group is: Standardization of terms and definitions as well as fundamental concepts in the field of AM. SIS is holding the secretariat for the working group and the current version of ISO/ASTM 52900 is currently being revised with publication planned for 2020.

3 State of the art of certification and the use of standards in Swedish industry

A survey was sent to 50 stakeholders along the metal AM value chain and 17 companies responded. The survey asked questions both about the current situation and future needs. In this chapter the current situation is described for powder manufacturers (4), technology suppliers (3) and end users (10).

The powder manufacturers are assuring quality by characterization of the metal powder according to existing powder standards and complying to the customer specification. The powder is packed and stored in controlled environments.

The technology suppliers are dealing with AM-machines and everything around them, but also suppliers of media and post treatment are considered in this group. The machines and processes are developed to fulfil quality demands according to customer specific standards e.g. for aerospace and medical applications. The suppliers contribute to the quality assurance by offering solutions and procedures for process control, storage of powder and measurement of process atmosphere, robust post process for densification etc..

End users from industries like aerospace, automotive, energy, and process answered the survey. The metal AM manufacturing is performed in-house and/or subcontracted to service bureaus. The service bureaus are small enterprises and are also considered in this group. The group follow general standards for e.g. material testing, AM specific standards and application specific standards for their different industrial segments. One way to assure quality is to buy powder from AM-machine supplier and user corresponding process parameters for the material. Suitable storage of powder and measurement of oxygen level in the build chamber are also mentioned. Visual inspection and control of the powder bed during printing can be followed by non-destructive testing, like CT-scanning, or destructive testing and metallography of test pieces built at the same time.

When ordering powder for AM, the specification include chemical composition, flowability, particle size distribution, and particle morphology. As a customer of AM-components, ordered internally or externally, the quality can be assured by setting the tolerances of the component, clearly state the demand on properties and good descriptions of the final state of the component, and specification of the post treatment method (if known). If the appearance is important, a picture could be added to the order, or a similar type of component provided as comparison.

4 Standardization needs from Swedish industry to grow the market

A summary of the needs is presented below, as identified by the survey and discussed by five different groups at the workshop. The needs have been divided into standards associated to the areas: general issues, feedstock material, AM process and equipment, application specific, and finished AM part. Those areas are the same areas as ASTM F42/ISO TC 261 uses to structure standardization of AM in Figure 2. Environment health and safety needs can be found in all areas and are discussed in correlation to on-going work in chapter 5.6. An important general conclusion was that standards should make life easier, outcome more transparent and more predictable, but not act against technical development.

4.1 General standards

Terminology: The need for harmonisation regarding terminology within AM is pivotal to the success of the standards being produced in the area. A common language and an agreement upon terminology within the area eliminates the risk of confusion and increases effectiveness in the work being conducted within standardization.

Traceability: A standardised way on how to store data along the whole value chain, from raw material, process, post treatment to microstructure and final properties would help. Need of traceability is discussed more for the different areas below.

Purchase: The AM-manufacturer needs more guidance on how to ensure the quality of the end-product to the end-user. On the other hand, the end user needs more guidance on how to set the requirements of purchased AM parts.

Environment, health, and safety: Safety guarantees needed regarding toxicity and combustion etc. Guidelines for the producer on how to handle the powder, dimension of filters etc. are needed.

Development of material databases: A lot of material data is being generated and to collect and share material data could be efficient use of resources and a good base for standardization.

Material standards with requirements: Standard specifications for different materials

Handling of drawing requirements in 3D-CAD-files: Today, all information about a component needs to be defined on 2D-drawings, which are archived on paper. How can this be handled for 3D-CAD-files of complex geometries?

4.2 Feedstock Material standards

Identified needs regarding feedstock material are described below. Most of the input are related to powder, but some needs are valid also for wire.

Traceability of powder and marking of containers: Standardized sort of information on labels on powder containers from all powder suppliers. Regarding mixing of batches it is hard to retain traceability as user, systematic approach to handle this.

Safety data sheets: Important to have safety data sheets for all feedstock materials.

Flowability and spreadability: Many different powder testing methods exist but no relevant standardized method for flowability and spreadability of AM-powder. The correlation between flowability and spreadability is also not fully understood. A spreadability method is needed that reflects the AM-machines and should be developed. To make a test print for each shipment of powder is not realistic. The fine cut in some AM processes are at the verge of not flowing.

Particle size distribution (PSD): No flexibility if only requiring one PSD for each type of AM process and we are still not certain what PSD works best in different AM-processes. To specify the PSD is not at a guarantee for good spreadability. Recycling of the powder also effects the PSD. It is possible to measure both morphology and PSD, but more knowledge is needed on what works in the AM processes and how to evaluate it. Some guidelines are needed.

Standard specification of powder material: The specification should contain powder characterization data like PSD and flowability, chemical analysis, and material properties. Additionally, recommendation of parameters for heat treatment and printing could be included. Similar specification could be applicable for wire feedstock material.

Recycling: When recycling the powder it is hard to retain quality and traceability and know how recycling effects the powder properties.

Cleaning support and lattice structures from powder: If powder is not completely cleaned out from support and lattice structures, it can be an EHS and post-process problem. Already in the build preparation, the problem should be possible to avoid be adapting the structures for easier powder removal.

Transportation: Guidelines and best practice for transportation of powder to avoid segregation, oxidation and assure safety.

4.3 AM Process and Equipment standards

Identified input on process needs are summarized below. The technologies addressed mainly include powder bed fusion (PBF-LB, PBF-EB), but also energy deposition (DED) and binder jetting (BJ) were mentioned.

Process and hardware calibration: This was considered to be most important, i.e. Priority 1. It was found to be of interest to depict machine conditions and to be able to differentiate between performance and capabilities as these are different things. It was also considered to be important to be able to ascertain between individuals within a family or between different types and also to be able to cover other techniques directed like energy deposition (DED) and binder jetting (BJ).

Standard that addresses the actual AM-process: This was considered as second priority (Priority 2). The question was raised whether this relates to 52904. If so, does this standard cover all important aspects? How do you consider key variables and statistics? It was noted that this issue considers more than the actual printing process itself and hence it will be misleading to think that you can separate out the AM-process in a processing chain.

The atmosphere in print chamber: This includes methods to assess oxygen and moisture content and was put as Priority 3. In some way it was found that it is important to have a correlation in some way, i.e. to have some way to make sure that input (material) to output (product) is traced. Considering oxygen content of material, there are different ways to measure it and also that measuring oxygen does not necessarily capture moisture. Question of need for some kind of standardization was hence raised.

Traceability: Consistently producing parts of high quality and ensuring a repeatable process each time remains one of the current challenges within AM. The digital thread, traceability within the AM-process, is non existing today. Also, a lot of post-processing is being conducted within AM today. Standardization can help to define the parameters for each step of AM production, helping to create a consistent process in every step. This way, a company can compare the quality and performance of its AM-processes against a set of criteria. This ensures that the desired quality outcome is achieved.

Support structure: It can finally be concluded that support structures is not an issue for standardization, but more of aspect of guidelines and so in connection to powder handling.

Process stability and process monitoring: Considered to be important, but at the same it was found to be too early to consider this as a field for standardization. The topic has significant connection to the concept of Industry 4.0.

4.4 Application specific standards

Aerospace Fatigue - it has been shown that the atmosphere during storage of powders influences on the fatigue performance, necessary to have control of the atmosphere during storage as well as printing. NDT-methods and other properties – specific to each application.

Medicine Requires stable materials.

Pressure vessels Harmonizing standards for all materials, Parts Manufacturers Approval - PMA – how to use standards to be able to meet the demands in the pressure vessel directive – PED EUs directive 2014/68/EU, AFS 2016:1, does it need to be per process, for each charge/batch of powder, or?, review of existing standards is needed to be able to meet the PED. Is it possible to use existing standards for AM parts? Demand for stricter requirements, use existing standards until specific AM standards are available, closer tolerances. SIS has a separate technical committee for pressure vessels[19].

Requirements Specify requirements for surface roughness, geometry, corrosion etc. Separate requirements connected to application, right level. Specific test program is under development for high speed testing of AM manufactured rotating parts. Custom specific standards are developed, when is it good enough? Dependence of printing direction.

Automotive Sufficient general standards in order to be able to cover several applications and manufacturing methods. Modify existing standards to be applicable also for AM produced parts and their suppliers. Is it possible to have different sets of standards connected to the application of the component and its function, that is, if it is a critical part or not? Guidelines for design of AM-parts required, rather than standards.

4.5 Finished AM Part standards

A summary of the needs of finished AM parts standards is presented below, as identified by the survey and discussed by five different groups at the workshop.

Standards for specification of tolerances: No important surfaces are used as printed. Should be similar as standard products. How are they measured? What are the limitations in the AM process. Can a standard build job be defined that handles this? CAD to CAM using a drawing that is transferred to a STL-file. How is this coupled to tolerances. How is surface roughness defined? How is surface roughness defined to the AM-process?

Standards for test specimens: An approach like MPIF Standard No 35 could be used. The effect of build time and thermal history needs to be considered. How is the microstructure normalized to conventional materials? The test direction is very important because of the thermal history on grain growth and orientation.

Standards for material testing coupled to the specific AM-process: The test method for bulk properties should capture the surface noise. Shall every part be CT-scanned?

Could an alternative design of test specimens be used (size and shape). It may be possible to screen powder properties by using standard test specimens. What type of type of material testing procedure should be used, cast-bulk or welding surfaces? Bulk testing can be done by standard test specimens. Acceptance criteria for a specific AM process should be documented on the drawing. Guidelines for safety limits and acceptance should be coupled to product.

[19] https://www.sis.se/standardutveckling/tksidor/tk200299/sistk298/

Standard for fatigue testing. Guidelines for material and product testing is necessary. The standard should be similar as for standard products. There is a strong effect of the surface properties. Current scatter in properties using the AM process is still very high.

Standards for HIP treatment: Show on the effect on densification and heat treatment on microstructure.

Test methods: Materials testing in metal AM involves evaluation of finished parts. New & Renewable Energy Development Corporation (NREDCAP) has conducted a gathering of requirements from stakeholders within welding and there is a belief that the same will be done within AM. This would result in a clearer view on which characteristics of the finished products that are important. Test methods has also to include orientation and size dependent properties.

Traceability: Define how the printing data is used to store information with respect to how the melt pool and slag formation is affecting the microstructural dependent properties?

Testing of complicated geometries: How are test methods to be designed for sandwich structures and other.

5 Gap analysis - Comparison between needs and ongoing standardization work

For all the needs identified in chapter 4, a deeper investigation has been performed to search for existing standards related to the need, on-going standardization work, and if the need has been identified in existing roadmaps for AM. Based on this, a gap analysis has been made. The detailed mapping of needs identified by the project is listed in appendix 1. The identified gaps found in the mapping survey has been divided in a similar manner as in the summary of needs in the standardization framework presented in chapter 4, above; general issues, feedstock material, AM process and equipment, application specific, and finished AM part. For each category of standardization needs, the results are summarized according to the following definitions:

A gap is defined as an area lacking standardization, neither any existing standards relating to the need nor any on-going standardization work.

A minor gap is defined as an area where standardization work is on-going. A contribution to fulfil the need may be available in on-going standardization work. Furthermore, for all those areas, standards already exist relating to the need.

Deeper analysis: For the areas where no standardization work is ongoing, but at least one standard exists relating to the need, a deeper analysis must be made. How much of the need is covered by the standard? Do we have enough knowledge to start additional standardization work? Who are prepared to contribute in the standardization work?

An additional chapter for environment, health and safety (5.6) was included to further highlight and discuss this area in more detail.

5.1 General standards

The gap identified regarding general standards in the current mapping is:

- Traceability

Minor gaps, i.e. on-going standardization work, have been identified in:

- Terminology
- EHS

Deeper analyses needed:

- Purchase
- Development of material databases
- Material standards with requirements
- Handling of drawing requirements in 3D-CAD-files

5.2 Feedstock material standards

The gaps in the feedstock material category of AM standards are:

- Traceability of powder and marking of containers
- Recycling – a high priority in the 2018 AMSC Roadmap, GAP PC7
- Cleaning support and lattice structures from powder
- Transportation of powder – a medium priority in the 2018 AMSC Roadmap, GAP PC8

Minor gaps, i.e. on-going standardization work, have been identified in:

- Safety data sheet

Deeper analyses needed of:

- Flowability and spreadability
- Particle size distribution
- Standard specification of powder material

5.3 AM process and equipment standards

The gaps in the AM process and equipment standards category are:

- The atmosphere in print chamber
- Traceability

Minor gaps, i.e. on-going standardization work, are identified in:

- Process and hardware calibration
- Standard that addresses the actual AM-process
- Support structures
- Process stability and process monitoring

5.4 Application specific standards

The gap in the application specific standards category is:

- Pressure vessels (*one related existing standard, but still considered a gap*)

Minor gaps, i.e. on-going standardization work, are identified in:

- Needs within aerospace and automotive applications
- Requirements

Deeper analysis needed of:

- Needs within medicine applications

5.5 Finished AM part standards

The gaps in the Finished AM part standards category are:

- Fatigue testing – on going work in E08:05 and E08:6
- Traceability
- Testing of complicated geometries

Minor gaps, i.e. on-going standardization work, are identified in:

- Standards for material testing coupled to the specific AM-process
- Standards for HIP treatment

Deeper analyses needed of:

- Standards for specification of tolerances
- Standards for test specimens

5.6 Environment health and safety

It was highlighted in the 2018 AMSC Roadmap, that established practices and knowledge regarding environmental health and safety (EHS) were missing. This area was listed as gap PC14: Protection of Machine Operators with high priority.

To the project group, this gap in knowledge and standardization was known since before. However, the survey did not show that this to be as high priority as before. The reason is probably that several research projects and coming standard already address this area. As such, this area cannot be considered as a roadblock that prevents growth of the market. Below is a short summary of projects and standards.

A few projects that are ongoing or finished:

- Hälso- och miljöpåverkan av additiv tillverkning och dess utmaningar för en hållbar produktion (HÄMAT). Swedish project which started 2017. Finished
- Hälso- och miljöpåverkan orsakad av additiv tillverkning och utmaningar för en hållbar produktion 2 (HÄMAT2). Swedish project which started 2018. Ongoing.
- Nanosafety[20]. Swedish project which started 2020. Ongoing.
- Plate-forme nano sécurité. French project which started 2017. Ongoing.
- UL Chemical Safety in collaboration with Georgia Institute of Technology (Georgia Tech) and Emory University[21]. North American project which started 2015. Finished.

Standards that are existing or upcoming:

- ISO 11553-1:2005, Safety of machinery - Laser processing machines - Part 1: General safety requirements. Existing.
- ISO 45001:2018, Occupational health and safety management systems - Requirements with guidance for use. Existing.
- ISO ASTM 52931 - Additive manufacturing — Environmental health and safety — Standard guideline for use of metallic materials. Upcoming.
    - This draft standard is not publicly available. It will likely become a standard in the near future. The current draft has been studied, and commented on, in the framework of the project with access provided by SIS.
    - It covers AM techniques based on metal wire and metal powder, and covers all the usual steps in AM.
- VDI VDI 3405 Blatt 6.1 - Additive manufacturing processes - User safety on operating the manufacturing facilities - Laser beam melting of metallic parts. Existing. Current version is 2019-11.
    - This is not a standard. It is a guideline document published by VDI (the Association of German Engineers).
    - Similarly to ISO ASTM 52931 it covers all the usual steps of AM, but only for metal powder based techniques.

Additionally, in Sweden, existing hygienic limit values and the legislative work is applicable to the AM production chain. The defined limits are found in the Work Environment Authority's regulations (AFS 2018:1) and is updated regularly. Outside Sweden, similar hygienic limit values are applied in the AM production chain.

Identified needs (by the participating researchers in this project) that were not specifically called for by any company includes:

- More harmonized safety datasheets. Datasheets for the same product, from different suppliers, can differ in terms of recommended personal protection equipment.
- An additional need that could be addressed is introduction of limit on number of particles in air. This reflects manufactured nanoparticles, that can form as a result of various production processes. This type of limit has been introduced in Finland based on a study from the Netherlands[22].

6 Suggested workplan for future work

[20] http://alfrednobelsp.se/nytt-projekt-utforskar-halsorisker-med-3d-printing/
[21] https://chemicalinsights.org/initiatives/3d-printing/
[22] https://doi.org/10.1093/annhyg/mes043

The results summarized in this report will be discussed within SIS technical committee for AM, SIS/TK 563 Additiv tillverkning. The results can be the basis for future global standardization work being suggested by Sweden through SIS/TK 563, within ISO/TC 261 Additive Manufacturing. The results will also be used to identify research needs to support standardization. The Swedish Arena for AM of Metals and CAM2 will actively contribute by pushing for Swedish research activities to support the standardization, in dialog with Swedish funding agencies. SIS/TK563, The Swedish Arena for AM of Metals, and CAM2 will continue the collaboration after the project to jointly work for progress within the identified needs for Swedish industry.

In column F in Appendix 1, an assessment has been made whether the knowledge level at the moment is enough for standardization or not. This is very hard to judge and needs to be further discussed in SIS/TK563.

In some cases, stakeholders along the value chain would indirectly benefit from standards in other parts of the value chain. Standardised AM-machines would make life easier for the powder producers and, on the other hand, standardised powder quality would always behave the same way in different AM-machines. As all stakeholder would like to have unique products, it is important to find an appropriate level of standardization, to get a win-win situation.

6.1 Standardization needs that could be proposed as standards with limited further research

For some of the identified needs the knowledge to write, or contribute to, a standard is high. Where standardization work is on-going, the knowledge level should be high, but the new standard might not still fully cover the need from Swedish industry. Here it will be important to contribute as early as possible to influence the content of the standard and to identify need for additional standards.

For some of the identified gaps, where no related standards exist and no standardization work is on-going, the knowledge level of Swedish industry, on the other hand, is high. Examples are powder related needs, like traceability, marking of containers, handling and transportation of powder, where the powder producers use their own best practice. Another example is the atmosphere in the print chamber, where joint research involving technology supplier is on-going. Likewise, with technology supplier for HIP'ing. Standardization could be one way to open the market, which could be of interest for the suppliers of powder and technology.

6.2 Research needs and correlation to the roadmap for industrialisation of metal AM in Sweden, RAMP-UP

The RAMP-UP roadmap for industrialisation of metal AM in Sweden was made in 2017[23]. The needs identified in the roadmap are to a large extent overlapping with the needs for

[23] RAMP-UP project group, Research Needs and Challenges for Swedish Industrial Use of Additive Manufacturing, 2017-10-06, Available at www.AM.Arena.se (2020-04-15)

standardization identified in this project, where knowledge is still lacking. Column G in Appendix 1 shows how the standardization needs overlaps with the RAMP-UP roadmap.

In many areas, the knowledge level is still not mature for standardization. This can clearly be seen in column F in Appendix 1, even if the assessment of the knowledge level is difficult and might not be fully correct. Research associating to many of the needs are ongoing, but more general knowledge and statistics are in many cases lacking.

Linked to the need of material databases, NIST has developed a material database system in the US called Materials Data Curation System, with open access. The AM-Arena is developing a Swedish material database for metal AM using the system. NIST also initiated an AM benchmark test series (AM-Bench), with the primary goal of enabling modelers to test their simulations against rigorous, highly controlled AM benchmark test data for public use. A lot of material data is being generated and to collect and share material data could be efficient use of resources and a good base for standardization.

Suggestions of new research project that could be used as a base for subsequent standardization could involve development of methods and systems for qualification of AM products for different end user branches, and for quality assurance. National funding of joint projects like those would be essential to make them happen. No individual company could bear the cost, but in-kind contribution of many companies is easier to accomplish.

7 Conclusions

A review of existing standards and ongoing standardization work within metal AM has been performed. Today, 25 standards are under development and approximately the same number of standards already exist. Input on needs for standardization from Swedish Industry has been gathered from stakeholders along the metal AM value chain. Some of the highlighted needs might already be covered in the ongoing standardization work. Still, the analysis showed that the major gaps were identified in all areas along the value chain. A gap was defined as an area lacking standardization, neither any existing standards relating to the need nor any on-going standardization work.

However, there are several important areas that needs more research and method development in order to build the necessary databases and the statistics to assess the standardization work properly. On the other hand, for some of the identified gaps the knowledge level of Swedish industry is high. Examples are powder related needs, where the powder producers use their own best practice. Other examples are the atmosphere in the print chamber and post treatment by HIP, where joint research involving technology supplier is on-going. Standardization could be one way to open the market, which could be of interest for both suppliers and end users.

The needs identified in the RAMP-UP roadmap for industrialization of metal AM are to a large extent overlapping with the needs for standardization identified in this project, where knowledge is still lacking. Development of methods and systems for qualification of AM products for different end user branches, and for quality assurance, are still high priority. The use of standardized working routines and traceability could reduce scattering of final properties. Further research projects within those areas could be used as a base for subsequent standardization.

The results summarized in this report will be discussed within SIS technical committee for AM, SIS/TK 563 Additiv tillverkning. The results can be the basis for future global standardization work being suggested by Sweden through SIS/TK 563, within ISO/TC 261 Additive Manufacturing. The results will also be used to identify research needs to support standardization. The Swedish Arena for AM of Metals and CAM2 will actively contribute by pushing for Swedish research activities to support the standardization, in dialog with Swedish funding agencies. SIS/TK563, The Swedish Arena for AM of Metals, and CAM2 will continue the collaboration after the project to jointly work for progress within the identified needs for Swedish industry.

8 Acknowledgments

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Appendix

Appendix 1 includes tables with identified needs for each of the areas: general issues, feedstock material, AM process and equipment, application specific, and finished AM part. For each need an attempt has been made to find existing standards, on-going standardisation work, correlation to international roadmap, and investigate knowledge level and overlap with RAMP-UP. The tables can be find in appendix as pdf, but also exist as an Excel-file, for closer examination and further work.

Appendix 1.1 General standards

Need	Existing standards related to the need	On-going standardisation work	Need indentified in international roadmap	Comment	Is the knowledge level enough for standardisation? (Yes/No/Do not know)	Is the need overlapping with RAMP-UP or not? (Yes/No/No research question)
Terminology: The need for harmonisation regarding terminology within additive manufacturing is pivotal to the success of the standards being produced in the area. A common language and an agreement upon terminology within the area eliminates the risk of confusion and increases effectiveness in the work being conducted within standardisation.	SS-EN ISO/ASTM 52915:2017 Specifikation för additiv tillverkning filformat (AMF) Version 1.2 (ISO/ASTM 52915:2016) SS-EN ISO/ASTM 52900:2017 Additiv tillverkning - Allmänna principer - Terminologi (ISO/ASTM 52900:2015) SS-EN ISO 52921:2016 Standardiserad terminologi för additiv tillverkning - Koordinatsystem och provningsmetodik (ISO/ASTM 52921:2013)	ISO/ASTM DIS 52900 Additive manufacturing — General principles — Fundamentals and vocabulary; revision of ISO/ASTM 52900:2015			Yes	No research question
Traceability: A standardised way on how to store data along the whole value chain, from raw material, process, post treatment to microstructure and final properties would help. Need of traceability is discussed more for the different areas.					Do not know	Yes, "Digitalisation", "Bigdata", "Digital Twin"
Purchase: The AM-manufacturer needs more guidance on how to ensure the quality of the end-product to the end-user. On the other hand, the end user needs more guidance on how to set the requirements of purchased AM parts.	ISO/ASTM 52901 AM -- General principles -- Requirements for purchased AM parts				Yes	Yes, "Methods for product verification"
Environment, health, and safety: Safety guarantees needed regarding toxicity and combustion etc. Guidelines for the producer on how to handle the powder, dimension of filters etc. are needed.	ISO 11553-1:2005, Safety of machinery - Laser processing machines - Part 1: General safety requirements ISO 45001:2018, Occupational health and safety management systems - Requirements with guidance for use,	ISO/ASTM 5CD 2931, AM EHS - Standard guideline for use of metallic materials	1) Below		Yes	Yes, "EHS"
Development of material databases: A lot of material data is being generated and to collect and share material data could be efficient use of resources and a good base for standardisation.	ASTM F2971-13 Standard Practice for Reporting Data for Test Specimens Prepared by AM				Yes	
Material standards with requirements: Standard specifications for different materials	ASTM F2924-14 Standard Specification for AM Titanium-6 Aluminum-4 Vanadium with Powder Bed Fusion, ASTM F3001-14 Standard Specification for AM Titanium-6 Aluminum-4 Vanadium ELI (Extra Low Interstitial) with Powder Bed Fusion, ASTM F3055-14A Standard Specification for AM Nickel Alloy (UNS N07718) with Powder Bed (i.e. IN718), ASTM F3056-14 Standard Specification for AM Nickel Alloy (UNS N06625) with Powder Bed Fusion (i.e. IN625), ASTM F3184-16 Standard Specification for AM Stainless Steel Alloy (UNS S31603) with Powder Bed Fusion; ASTM F3318-18 Standard for AM – Finished Part Properties – Specification for AlSi10Mg with Powder Bed Fusion – Laser Beam				Do we have enough testing for any new material in a specific AM-process?	Yes, "Increase material portfolio"
Handling of drawing requirements in 3D-CAD-files: Today, all information about a component needs to be defined on 2D-drawings, which are archived on paper. How can this be handled for 3D-CAD-files of complex geometries?	ASTM F2915-16 Standard Specification for AM File Format (AMF) Version 1.2, SS-EN ISO/ASTM 52915:2017 Specifikation för additiv tillverkning filformat (AMF) Version 1.2 (ISO/ASTM 52915:2016)				Do not know	Not explicity, but could be part of "Part and system design" and "System for quality assurance during production"

1) AMSC Roadmap 2018 Gap PC14: Environmental Health and Safety: Protection of Machine Operators, High priority. 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). 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. Research is underway.

Appendix 1.2 Feedstock Material Standards

Need	Existing standards related to the need	On-going standardisation work	Need indentified in international roadmap	Comment	Is the knowledge level enough for standardisation? (Yes/No/Do not know)	Is the need overlapping with RAMP-UP or not? (Yes/No/No research question)
Traceability of powder and marking of containers: Standardized sort of information on labels on powder containers from all powder suppliers. Regarding mixing of batches it is hard to retain traceability as user, systematic approach to handle this.	DIN 65122 Aerospace series - Powder for AM with powder bed process - Technical delivery specification			1) Below	Yes	Correlates to "System for quality assurance during production"
Safety data sheets: Important to have safety data sheets for all feedstock materials .	ISO 11014 Safety data sheet for chemical products, ISO/TR 13329 Nanomaterials -- Preparation of material safety data sheet (MSDS),	ISO/ASTM AWI 52931 AM - Environmental health and safety - Standard guideline for use of metallic materials		2) Below	Possibly after the HÄMAT 2 project.	Input from "EHS"
Flowability and spreadability: Many different powder testing methods exist but no relevant standardized method for flowability and spreadability of AM-powder. The correlation between flowability and spreadability is also not fully understood. A spreadability method is needed that reflects the AM-machines and should be developed. To make a test print for each shipment of powder is not realistic. The fine cut in some AM processes are at the verge of not flowing.	ISO/ASTM 52907 AM — Feedstock materials — Methods to characterize metal powders with references to standards about flow; ISO 4490, ASTM B417		AMSC Roadmap 2018 Gap PM2: Demand for development of standards covering powders spreadability		No	Yes, "Method for evaluation of spreadability"
Particle size distribution (PSD): No flexibility if only requiring one PSD for each type of AM process and we are still not certain what PSD works best in different AM-processes. To specify the PSD is not at a guarantee for good spreadability. Recycling of the powder also effects the PSD. It is possible to measure both morphology and PSD, but more knowledge is needed on what works in the AM processes and how to evaluate it. Some guidelines are needed.	ISO/ASTM 52907 AM — Feedstock materials — Methods to characterize metal powders with references to standards about particle size: ISO 4497, 13320, 13322-1, 13322-2				No	Yes, "How should powder be tuned with respect to characteristic properties?", "How should powder be characterized?"
Standard specification of powder material: The specification should contain powder characterization data like PSD and flowability, chemical analysis, and material properties. Additionally, recommendation of parameters for heat treatment and printing could be included. Similar specification could be applicable for wire feedstock material.	ISO/ASTM 52907 AM — Feedstock materials — Methods to characterize metal powders, ISO/ASTM 52904 AM -- Process characteristics and performance -- Practice for metal powder bed fusion process to meet critical applications, ASTM F3301-18A Standard for AM – Post Processing Methods – Standard Specification for Thermal Post-Processing Metal Parts Made Via Powder Bed Fusion, ASTM F3122-14 Standard Guide for Evaluating Mechanical Properties of Metal Materials Made via AM Processes, DIN 65122 Aerospace series - Powder for AM with powder bed process - Technical delivery specification				No	Yes, could be a part of "Process stability and product quality"
Recycling: When recycling the powder it is hard to retain quality and traceability and know how recycling effects the powder properties.			AMSC Roadmap 2018 Gap PC7, high priotity: : Recycle & Re-use of materials - 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.		No	Yes, "Controlled recycling of powder material"
Cleaning support and lattice structures from powder: If powder is not completely cleaned out from support and lattice structures, it can be an EHS and post-process problem. Already in the build preparation, the problem should be possible to avoid be adapting the structures for easier powder removal.					Do not know	Yes, "How to design for optimal post processing"
Transportation: Guidelines and best practice for transportation of powder to avoid segregation, oxidation and assure safety .			AMSC Roadmap 2018 Gap PC8 Stratification, Medium priority - 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. 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.		Yes, some powder producers have the knowledge	Yes, "Powder handling-knowledge transfer"

1) SAE's Aerospace Materials Specifications support the certification of aircraft and spacecraft critical parts by protecting the integrity of material property data and providing traceability within the supply chain. Industry consensus standards for additive manufacturing of aerospace parts are an enabler for the migration from part qualification to material qualification. An integral part of specification development is deriving specification minimum values for lot acceptance of the final AM processed material.

2) Applicable standards for the preparation of those MSDS may be found in ANSI Z400.1/Z129.1-2010, Hazardous Workplace Chemicals - Hazard Evaluation and Safety Data Sheet and Precautionary Labeling Preparation.

Appendix 1.3 AM Process and Equipment standards

Need	Existing standards related to the need	On-going standardisation work	Need indentified in international roadmap	Comment	Is the knowledge level enough for standardisation? (Yes/No/Do not know)	Is the need overlapping with RAMP-UP or not? (Yes/No/No research question)
Process and hardware calibration: This was considered to be most important, i.e. Priority 1. It was found to be of interest to depict machine conditions and to be able to differentiate between performance and capabilities as these are different things. It	SS-EN ISO 17296-2:2016 Additive manufacturing - General principles - Part 2: Overview of process categories and feedstock (ISO 17296-2:2015)	ISO/ASTM AWI 52908 Additive manufacturing — Post-processing methods — Standard specification for quality assurance and post processing of powder bed fusion metallic parts			No	Yes, "System for quality assurance during production"
Standard that addresses the actual AM-process: This was considered as second priority (Priority 2). The question was raised whether this relates to 52904. If so, does this standard cover all important aspects. How do you consider key variables and statist	SS-EN ISO/ASTM 52911-1:2019 Additive manufacturing - Design - Part 1: Laser-based powder bed fusion of metals (ISO/ASTM 52911-1:2019)	ISO/ASTM AWI 52909 Additive manufacturing — Finished part properties — Orientation and location dependence of mechanical properties for metal powder bed fusion			No	Yes, "Process stability and product quality"
The atmosphere in print chamber: This includes methods to assess oxygen and moisture content and was put as Priority 3. In some way it was found that it is important to have a correlation in some way, i.e. to have some way to make sure that input (materi					No (some knowledge but more needed)	Yes, "In process control"
Traceability: Consistently producing parts of high quality and ensuring a repeatable process each time remains one of the current challenges within additive manufacturing. The digital thread, traceability within the AM-process, is non existing today. Also	SS-EN ISO/ASTM 52901:2018 Additive manufacturing - General principles - Requirements for purchased AM parts (ISO/ASTM 52901:2017)				No	Yes, "Reproducability and robustness"
Support structure: It can finally be concluded that support structures is not an issue for standardization, but more of aspect of guidelines and so in connection to powder handling.	SS-EN ISO/ASTM 52911-1:2019 Additive manufacturing - Design - Part 1: Laser-based powder bed fusion of metals (ISO/ASTM 52911-1:2019)	ISO/ASTM AWI 52909 Additive manufacturing — Finished part properties — Orientation and location dependence of mechanical properties for metal powder bed fusion			Yes, for guideline?	Yes, "Develop design guidelines for AM production and components"
Process stability and process monitoring: Considered to be important, but at the same it was found to be too early to consider this as a field for standardization. The topic has significant connection to the concept of Industry 4.0.	SS-EN ISO 17296-4:2016 Additive manufacturing - General principles - Part 4: Overview of data processing (ISO 17296-4:2014)	ISO/ASTM AWI 52902 Additive manufacturing — Test artefacts — Geometric capability assessment of additive manufacturing systems			No	Yes, "Process stability and product quality", "In process control"

Appendix 1.4 Application specific standards

Need	Existing standards related to the need	On-going standardisation work	Need indentified in international roadmap	Comment	Is the knowledge level enough for standardisation? (Yes/No/Do not know)	Is the need overlapping with RAMP-UP or not? (Yes/No/No research question)
Aerospace Fatigue - it has been shown that the atmosphere during storage of powders influences on the fatigue performance, necessary to have control of the atmosphere during storage as well as printing. NDT-methods and other properties – specific to each application.	ISO/ASTM 52904:2019 Additive manufacturing — Process characteristics and performance — Practice for metal powder bed fusion process to meet critical applications	ISO/ASTM DTR 52905 AM - General principles - Non-destructive testing of additive manufactured products, ISO/ASTM CD TR 52906 AM - Non-destructive testing and evaluation - Standard guideline for intentionally seeding flaws in parts, ISO/ASTM DIS 52941 AM - System performance and reliability - Standard test method for acceptance of powder-bed fusion machines for metallic materials for aerospace application, ISO/ASTM 52942 AM - Qualification principles - Qualifying machine operators of laser metal powder bed fusion machines and equipment used in aerospace applications", ASTM WK47031 New Guide for Nondestructive Testing of Metal Additively Manufactured Metal Aerospace Parts After Build	AMSC Roadmap 2018 Gap D4, High priority: Design Guide s for Specifc Applications	1) Below	No	Yes, "Non destructive testing", "Less sensitive material handling in AM-machine and storage", "In process control"
Medicine Requires stable materials.	ASTM F3127-16 Standard Guide for Validating Cleaning Processes Used During the Manufacture of Medical Devices; ISO/ASTM 52904:2019 Additive manufacturing — Process characteristics and performance — Practice for metal		AMSC Roadmap 2018 Gap FMP3, High priority: Cleanliness of Medical AM Parts; Gap D4, High priority: Design Guides for Specific Applications	2) Below	?	
Automotive Sufficient general standards in order to be able to cover several applications and manufacturing methods. Modify existing standards to be applicable also for AM produced parts and their suppliers. Is it possible to have different sets of standards connected to the application of the component and its function, that is, if it is a critical part or not? Guidelines for design of AM-parts required, rather than standards.	ISO/ASTM 52901:2017 Additive manufacturing -- General principles -- Requirements for purchased AM parts	ISO/ASTM AWI 52908 AM - Post-processing methods - Standard specification for quality assurance and post processing of powder bed fusion metallic parts, ISO/ASTM AWI 52909 AM - Finished part properties - Orientation and location dependence of mechanical properties for metal powder bed fusion	AMSC Roadmap 2018 Gap D4, High priority: Design Guide s for Specifc Applications		Don´t know	
Pressure vessels Harmonizing standards for all materials, Parts Manufacturers Approval - PMA – how to use standards to be able to meet the demands in the pressure vessel directive – PED EUs directive 2014/68/EU, AFS 2016:1, does it need to be per process, for each charge/batch of powder, or?, review of existing standards is needed to be able to meet the PED. Is it possible to use existing standards for AM parts? Demand for stricter requirements, use existing standards until specific AM standards are available, closer tolerances. SIS has a separate technical committee for pressure vessels,	ISO/ASTM 52904:2019 Additive manufacturing — Process characteristics and performance — Practice for metal powder bed fusion process to meet critical applications		AMSC Roadmap 2018 Gap FMP4: Addition of AM materials into the stress and physical properties tables in ASME II Part D, ASME Boiler & Pressure Vessel Code; Gap D4 High priority: Design Guides for Specific Applications; ASME is working on design guides for pressure retaining equipments, that is, pressure vessels.		No	
Requirements Specify requirements for surface roughness, geometry, corrosion etc. Separate requirements connected to application, right level. Specific test program is under development for high speed testing of AM manufactured rotating parts. Custom specific standards are developed, when is it good enough? Dependence of printing direction.	ISO 17296:3 Additive manufacturing -- General principles - Part 3: Main characteristics and corresponding test methods (2014)		AMSC Roadmap 2018 Gap P4 Medium priority: Surface finish		Yes	

1) Additive Part Qualification: Aerospace Perspective. Once form and fit have been established, the end user of an AM component must validate the systematic functionality of the AM component. In addition to basic, foundantial knowledeg about fundamental material properties and processing effects, reasonable component level destructive test and nondestructive testing methods performed by ISO/IEC 17025 accredited testing laboratories should be used to qualify the AM component function. Examples of component-level destructive tests could include: part cut-ups to validate dimensional and critical material morphology, static or fatigue/damage tolerance strength evaluations from a configured part, lug or crippling strength/stability evaluations, etc. Non-destructive examples could include Xray/computed tomography, pressure, eddy current, etc. Note that these non-destructive functionality tests may evolve into a statistically-based plan for ongoing validation of AM part quality in production.

2) Additive Part Qualification: Medical Device Perspective. Mechanical properties testing for components and coupons is integral to the qualification and approval process. For any given part, different aspects may be critical to its function. In the medical field, AM devices can be used to match a patient's anatomy or create an implant that would otherwise be impossible to manufacture. Some applications require long fatigue life and strength as the primary mechanical properties (e.g., a hip implant). Others require flexibility, and the ability to degrade over time in a way that maintains geometric stability (e.g., a tracheal splint). In medicine, the diversity of applications and complexity of geometric shapes means there are many different aspects that may be tested for any given part. It is often difficult to determine what can be tested with coupons and what must be tested on the part. In addition, the quality of the part can be strongly influenced by the other parts in the build volume or positioning of parts in the space, meaning that careful coupon planning is imperative. Clear guidelines are not yet available for these aspects of coupon use in AM for the medical field; however, some general guidelines do exist.

Appendix 1.5 Finished AM Part Standards

Need	Existing standards related to the need	On-going standardisation work	Need indentified in international roadmap	Comment	Is the knowledge level enough for standardisation? (Yes/No/Do not know)	Is the need overlapping with RAMP-UP or not? (Yes/No/No research question)
Standards for specification of tolerances: No important surfaces are used as printed. Should be similar as standard products. How are they measured? What are the limitations in the AM process. Can a standard build job be defined that handles this? CAD to CAM using a drawing that is transferred to a STL-file. How is this coupled to tolerances. How is surface roughness defined? How is surface roughness defined to the AM-process?	**ISO/ASTM 52902:2019** Additive manufacturing -- Test artifacts -- Geometric capability assessment of additive manufacturing systems. This document does not discuss a specific procedure or machine settings for manufacturing a test piece, which are covered by ASTM F 2971 and other relevant process specific specifications. **ASTM F2971-13** Standard Practice for Reporting Data for Test Specimens Prepared by Additive Manufacturing			1) Below	No	Yes partly by "Methods for geometrical assurance", "Better surface finish", "How should a new CAD software format that is true to the native CAD model look like?"
Standards for test specimens: An approach like MPIF Standard No 35 could be used. The effect of build time and thermal history needs to be considered. How is the microstructure normalized to conventional materials? The test direction is very important because of the thermal history on grain growth and orientation.	ASTM F3302-18 Standard for Additive Manufacturing – Finished Part Properties – Standard Specification for Titanium Alloys via Powder Bed Fusion		Metallic Materials Property Development & Standardization (MMPDS) Handbook, Composite Materials Handbook -17, CMH-17; AM data to be included in future revisions		Yes	Yes, "Methods for material characterisation"
Standards for material testing coupled to the specific AM-process: The test method for bulk properties should capture the surface noise. Shall every part be CT-scanned? Could an alternative design of test specimens be used (size and shape). It may be possible to screen powder properties by using standard test specimens. What type of type of material testing procedure should be used, cast-bulk or welding surfaces? Bulk testing can be done by standard test specimens. Acceptance criteria for a specific AM process should be documented on the drawing. Guidelines for safety limits and acceptance should be coupled to product.	**ASTM F3122-14** Standard Guide for Evaluating Mechanical Properties of Metal Materials Made via Additive Manufacturing Processes. The following standards are not referred to directly in the guide but also have information that may be useful in the testing of metal test specimens made via additive manufacturing: A370, A1058, B211, B348, B557, B565, B724, B769, E3, E6, E7, E290, E467, E468, E837, E915, E1049,E182 **ISO 17296-3:2014** Additive manufacturing -- General principles -- Part 3: Main characteristics and corresponding test methods. The standard covers the principal requirements applied to testing of parts manufactured by additive manufacturing processes. It specifies main quality characteristics of parts, specifies appropriate test procedures, and recommends the scope and content of test and supply agreements. **ISO/ASTM 52921:2013** Standard terminology for additive manufacturing -- Coordinate systems and test methodologies	ISO/ASTM AWI 52909 AM - Finished part properties - Orientation and location dependence of mechanical properties for metal powder bed fusion			Yes	Yes, "Methods for material characterisation"
Standard for fatigue testing. Guidelines for material and product testing is necessary. The standard should be similar as for standard products. There is a strong effect of the surface properties. Current scatter in properties using the AM process is still very high.			ASTM Committee E08 Fatigue and Fracture	2) Below	Yes	Yes, "Methods for material characterisation"
Standards for HIP treatment: Show on the effect on densification and heat treatment on microstructure.	ASTM Committee F42 standards that contain specific HIP process parameters for specific metals include: o ASTM B998-17, Standard Guide for Hot Isostatic Pressing (HIP) of Aluminum Alloy Castings (previously WK47205) o ASTM F2924-14, Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium with Powder Bed Fusion o ASTM F3001-14, Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium ELI (Extra Low Interstitial) with Powder Bed Fusion o ASTM F3049-14, Standard Guide for Characterizing Properties of Metal Powders Used for Additive Manufacturing Processes o ASTM F3055-14a, Standard Specification for Additive Manufacturing Nickel Alloy (UNS N07718) with Powder Bed Fusion o ASTM F3056-14e1, Standard Specification for Additive Manufacturing Nickel Alloy (UNS N06625) with Powder Bed Fusion ASTM A1080-15, Standard Practice for Hot Isostatic Pressing of Steel, Stainless Steel, and Related Alloy Castings ASTM A988/A988M-17, Standard Specification for Hot Isostatically-Pressed Stainless Steel Flanges, Fittings, Valves, and Parts for High Temperature Service ASTM F3301-18, Standard for Additive Manufacturing – Post Processing Methods – Standard Specification for Thermal Post-Processing Metal Parts Made Via Powder Bed Fusion SAE AMS-AM standards that contain specific HIP process parameters for specific metals include: o SAE AMS4999A, Titanium Alloy Laser Deposited Products~6Al - 4V~Annealed o SAE AMS7000, Laser-Powder Bed Fusion (L-PBF) Produced Parts, Nickel Alloy, Corrosion and Heat-Resistant, 62Ni – 21.5Cr – 9.0Mo – 3.65 Nb Stress Relieved, Hot Isostatic Pressed and Solution Annealed	ASTM work items that contain, or will contain, specific HIP process parameters for specific metals. ASTM WK51329, New Specification for Additive Manufacturing Cobalt-28 Chromium-6 Molybdenum Alloy (UNS R30075) with Powder Bed Fusion. ASTM WK53423, New Specification for Additive Manufacturing-Finished Part Properties-Standard Specification for AlSi10Mg via Powder Bed Fusion. SAE AMS AMEC, Hot Isostatic Pressing	AMSC Roadmap 2018 Gap P3: Existing HIP standards does not fully address AM material-related issues such as slow cooling rate and its effect on formation in grain boundaries as well as the effect of thermal exposure on excessive grain growth and the effect of removing parts from the building plate before HIP. Develop material specific standards based on R&D defined HIP parameters for AM with acceptance criteria for internal discontinuities.		Yes	Yes, "Smart post-processes developed for AM"
Traceability: How is printing data used to store information with respect to the melt pool and slag formation?					Do not know	
Testing of complicated geometries: How are test methods to be designed for sandwich structures and other.					No	Yes, "Gain understanding of lattice structures"

1) 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.”

2) E08: Fatigue and Fracture develops standards that focus on the fatigue and fracture of materials and structures that are manufactured from conventional manufacturing technologies. The emergence of additive manufacturing has the committee looking at its current fatigue testing standards to determine if they need to be modified if test specimens are built using AM. There are many details involved in making an AM build that will affect fatigue resistance, and these details need to be brought into the current standards. Standardization is a key and vital element to establish trust in components fabricated using AM, and many industries are rapidly moving forward with the use of AM. Subcommittees E08.05 on Cyclic Deformation and Fatigue Crack Formation and E08.06 on Crack Growth Behavior are leading the effort in Committee E08 as they pursue standards activities in AM.