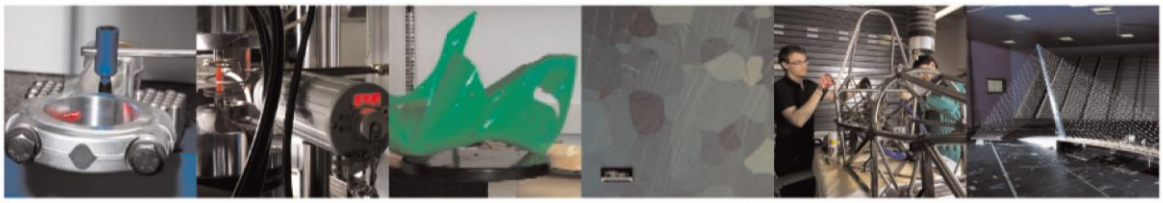

On standardization efforts for additive manufacturing

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On standardization efforts for additive manufacturing

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Abstract. Additive manufacturing is a set of technologies potentially covering the needs of many industrial sectors, some of which require the certification of the final product. This is the main motivation explaining why the International Organization for Standardization (ISO) and the American Society for Testing and Materials (ASTM) are putting significant efforts into defining standards covering different topics in this area. Efforts that very soon have become joint efforts to rapidly realize common standards under the name of ISO/ASTM standards. In this paper, the state of the art of these efforts is presented and discussed.

Keywords: Additive Manufacturing, Standard, ISO/TC261, ASTM F42.

1 Introduction

Additive manufacturing is blooming and spreading with a variety of technologies and applications. Each of the seven process categories additive manufacturing technologies are classified in is a quite complex collection of methods, machines, and materials, potentially covering the needs of many industrial sectors, from medical to aerospace. Some of this industrial fields require for the certification of the final product, through the certification of the product design stage, of each manufacturing steps, and of the workers involved in.

This is the main motivation explaining why the International Organization for Standardization (ISO) and the American Society for Testing and Materials (ASTM) are putting significant efforts into defining standards covering different topics in this area. Those efforts were initially separated efforts, therefore bringing to separate ISO and ASTM standards, but very soon the two standardization bodies realized that they were doubling the efforts with no reasons and publishing slightly different standards, just creating confusion among the potential users. Therefore, the relevant decision to join the efforts to rapidly realize common standards under the name of ISO/ASTM standards.

In the following the additive manufacturing standards structure is presented and discussed.

2 Additive Manufacturing Standards Structure

2.1 ISO AM Standards Structure

The ISO Technical Committee ISO/TC 261 Additive manufacturing is active since 2011, with the following scope [1]: "*Standardization in the field of Additive Manufacturing (AM) concerning their processes, terms and definitions, process chains (Hard- and Software), test procedures, quality parameters, supply agreements and all kind of fundamentals*." The ISO/TC 261 has 25 participating and 8 observing members, from all over the world.

The expected benefits achievable through AM standardization effort are:

1) systematic development, modification and use of AM processes resulting in innovative products;
2) guidelines to select the appropriate technology for the specified product demands;
3) specification of appropriate quality parameters and relative test procedures to assess the quality of products and processes;
4) standardization of AM process chains securing functionality and compatibility and of data formats and structures for AM models;
5) standardization of vocabulary required to define products and processes.

In order to achieve the considered benefits, ISO/TC 261 is organized in the following Working Group (WG) and Joint Working Group with other ISO/TCs (JWG):

- ISO/TC 261/WG 1 Terminology
- ISO/TC 261/WG 2 Processes, systems and materials
- ISO/TC 261/WG 3 Test methods and quality specifications
- ISO/TC 261/WG 4 Data and Design
- ISO/TC 261/WG 6 Environment, health and safety
- ISO/TC 261/JWG 10 Additive manufacturing in aerospace applications (Joint ISO/TC 261 - ISO/TC 44/SC 14)
- ISO/TC 261/JWG 11 Additive manufacturing for plastics (Joint ISO/TC 261 - ISO/TC 61/SC 9)

Table 1 shows the published standards by ISO, while in Table 2 the results of the joint cooperation of ISO and ASTM are presented.

2.2 ASTM AM Standards Structure

ASTM Committee F42 on Additive Manufacturing Technologies is active since 2009, with the following scope [2]: "*The promotion of knowledge, stimulation of research and implementation of technology through the development of standards for additive manufacturing technologies.*" These standards are expected to play a preeminent role in all aspects of additive manufacturing technologies.

ASTM Committee F42 is composed of subcommittees addressing the following specific segments:

- F42.01 Test Methods
- F42.04 Design

- F42.05 Materials and Processes
- F42.06 Environment, Health, and Safety
- F42.07 Applications
  - F42.07.01 Aviation
  - F42.07.02 Spaceflight
  - F42.07.03 Medical/Biological
  - F42.07.04 Transportation/Heavy Machinery
  - F42.07.05 Maritime
  - F42.07.06 Electronics
  - F42.07.07 Construction
  - F42.07.08 Oil/Gas
  - F42.07.09 Consumer
- F42.91 Terminology
- F42.95 US TAG to ISO TC 261

Table 1 shows the published standards by ASTM, while in Table 2 the results of the joint cooperation of ISO and ASTM are presented.

2.3 ISO/ASTM AM Standards Structure

In order to eliminate duplication of efforts, in September 2011 ISO and ASTM have signed a cooperative agreement to govern the ongoing collaborative efforts between the two Organisations to adopt and jointly develop International Standards that serve the global marketplace in the field of additive manufacturing.

The active Joint Group are the following:

- ISO/ASTM JG51 - Terminology
- ISO/ASTM JG52 - Standard test artifacts
- ISO/ASTM JG53 - Requirements for purchased AM parts
- ISO/ASTM JG54 - Fundamentals of design
- ISO/ASTM JG55 - Standards specification for Extrusion Based AM of Plastic Materials
- ISO/ASTM JG56 - Standard practice for Metal Powder Bed Fusion to meet rigid quality requirements
- ISO/ASTM JG57 - Process-specific design guidelines and standards
- ISO/ASTM JG58 - Qualification, quality assurance and post processing of powder bed fusion metallic parts
- ISO/ASTM JG59 - Non-destructive testing for AM parts
- ISO/ASTM JG60 - Guide for intended seeding flaws in AM parts
- ISO/ASTM JG61 - Guide for anisotropy effects in mechanical properties of AM parts
- ISO/ASTM JG62 - Guide for conducting round robin studies for AM
- ISO/ASTM JG63 - Test methods for characterization of powder flow properties for AM applications
- ISO/ASTM JG64 - Additive Manufacturing File Format (AMF)
- ISO/ASTM JG66 - Technical specification on metal powders
- ISO/ASTM JG67 - Technical specification for the design of functionally graded AM parts

- ISO/ASTM JG68 - EH&S for 3D printers
- ISO/ASTM JG69 - EH&S for use of metallic materials
- ISO/ASTM JG70 - Optimized medical image data
- ISO/ASTM JG71 - Powder quality assurance
- ISO/ASTM JG72 - Machine – Production process qualification
- ISO/ASTM JG73 - Digital product definition and data management
- ISO/ASTM JG74 - Personnel qualifications
- ISO/ASTM JG75 - Industrial conformity assessment at AM centres
- ISO/ASTM JG76 - Revision of ISO 17296-3& ASTM F3122-14
- ISO/ASTM JG77 - Test method of sand mold for metalcasting
- ISO/ASTM JG78 - Safety regarding AM-machines

The main structure of the joint efforts in standardization is shown in Figure 1.

The first level is the general top-level AM standards concerning topics like: Terminology, Design guides, Data formats, Qualification guidance, Inspection Method, Test methods, Test artifacts, System performance and reliability, Round robin test protocols, Safety.

The second level is related to specific category, and is divided with respect to materials, process and equipment, and finished parts. Then, the following levels refer to specific materials or processes, and to applications, at present mainly related to aerospace, medical, and automotive sectors.

The results of the ISO/ASTM joint efforts are shown in Table 2 as published standards, in Table 3 as standards under development, and in Table 4 as preliminary work items.

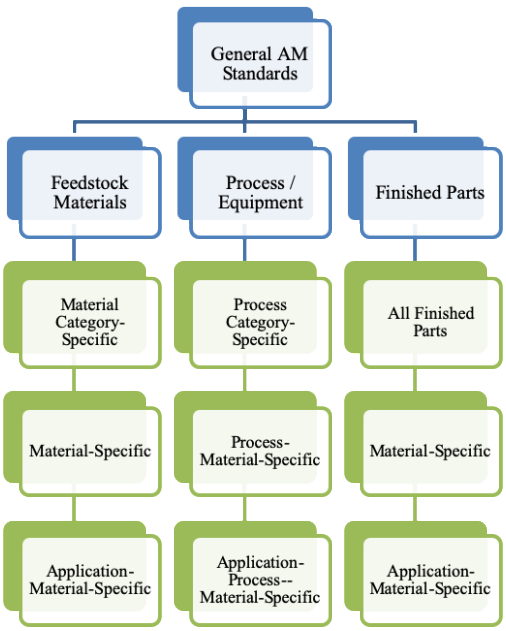

Fig. 1. ISO/ASTM Additive Manufacturing Standards Structure

Table 1. ISO and ASTM published standards.

Number	Title
ISO 17296-2:2015	Additive manufacturing - General principles - Part 2: Overview of process categories and feedstock
ISO 17296-3:2014	Additive manufacturing - General principles - Part 3: Main characteristics and corresponding test methods
ISO 17296-4:2014	Additive manufacturing - General principles - Part 4: Overview of data processing
ISO 27547-1:2010 (confirmed in 2015)	Plastics - Preparation of test specimens of thermoplastic materials using mouldless technologies - Part 1: General principles, and laser sintering of test specimens
ASTM F2924-14	Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium with Powder Bed Fusion
ASTM F2971-13	Standard Practice for Reporting Data for Test Specimens Prepared by Additive Manufacturing
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 F3091/F3091M-14	Standard Specification for Powder Bed Fusion of Plastic Materials
ASTM F3122-14	Standard Guide for Evaluating Mechanical Properties of Metal Materials Made via Additive Manufacturing Processes
ASTM F3184-16	Standard Specification for Additive Manufacturing Stainless Steel Alloy (UNS S31603) with Powder Bed Fusion
ASTM F3187-16	Standard Guide for Directed Energy Deposition of Metals
ASTM F3213-17	Standard for Additive Manufacturing - Finished Part Properties - Standard Specification for Cobalt-28 Chromium-6 Molybdenum via Powder Bed Fusion
ASTM F3301-18a	Standard for Additive Manufacturing - Post Processing Methods - Standard Specification for Thermal Post-Processing Metal Parts Made Via Powder Bed Fusion1, 2
ASTM F3302-18	Standard for Additive Manufacturing - Finished Part Properties - Standard Specification for Titanium Alloys via Powder Bed Fusion
ASTM F3318-18	Standard for Additive Manufacturing - Finished Part Properties - Specification for AlSi10Mg with Powder Bed Fusion - Laser Beam

Table 2. ISO/ASTM published standards.

Number	Title	Note
ISO/ASTM 52900:2015	Additive manufacturing - General principles - Terminology	Will be replaced by ISO/ASTM DIS 52900
ISO/ASTM 52901:2017 (JG 53)	Additive manufacturing - General principles - Requirements for purchased AM parts	
ISO/ASTM 52902:2019	Additive manufacturing - Test artifacts - Geometric capability assessment of additive manufacturing systems	Will be replaced by ISO/ASTM AWI 52902
ISO/ASTM 52904:2019 (JG 56)	Additive manufacturing - Process characteristics and performance - Practice for metal powder bed fusion process to meet critical applications	
ISO/ASTM 52907:2019 (JG 66)	Additive manufacturing - Feedstock materials - Methods to characterize metal powders	
ISO/ASTM 52910:2018 (JG 54)	Additive manufacturing - Design - Requirements, guidelines and recommendations	
ISO/ASTM 52911-1:2019 (JG 57)	Additive manufacturing - Design - Part 1: Laser-based powder bed fusion of metals	
ISO/ASTM 52911-2:2019 (JG 57)	Additive manufacturing - Design - Part 2: Laser-based powder bed fusion of polymers	
ISO/ASTM 52915:2016	Specification for additive manufacturing file format (AMF) Version 1.2	Will be replaced by ISO/ASTM FDIS 52915
ISO/ASTM 52921:2013	Standard terminology for additive manufacturing - Coordinate systems and test methodologies	Will be replaced by ISO/ASTM DIS 52921

Table 3. ISO/ASTM standards under development.

Number	Title	Note
ISO/ASTM DIS 52900 (JG 51)	Additive manufacturing - General principles - Fundamentals and vocabulary	Approved as FDIS
ISO/ASTM AWI 52902 (JG 52)	Additive manufacturing - Test artifacts - Geometric capability assessment of additive manufacturing systems	New project approved
ISO/ASTM FDIS 52903-1 (JG 55)	Additive manufacturing - Material extrusion-based additive manufacturing of plastic materials - Part 1: Feedstock materials	Close Voting
ISO/ASTM DIS 52903-2 (JG 55)	Additive manufacturing - Standard specification for material extrusion based additive manufacturing of plastic materials - Part 2: Process - Equipment	Ballot
ISO/ASTM CD 52903-3 (JG 55)	Additive manufacturing - Standard specification for material extrusion based additive manufacturing of plastic materials - Part 3: Final parts	Project Deleted
ISO/ASTM DTR 52905 (JG 59)	Additive manufacturing - General principles - Non-destructive testing of additive manufactured products	Approved as DIS
ISO/ASTM CD TR 52906 (JG 60)	Additive manufacturing - Non-destructive testing and evaluation - Standard guideline for intentionally seeding flaws in parts	Committee Draft
ISO/ASTM AWI 52908 (JG 58)	Additive manufacturing - Post-processing methods - Standard specification for quality assurance and post processing of powder bed fusion metallic parts	Project Started
ISO/ASTM AWI 52909 (JG 61)	Additive manufacturing - Finished part properties - Orientation and location dependence of mechanical properties for metal powder bed fusion	Project Started
ISO/ASTM CD TR 52912 (JG 67)	Additive manufacturing - Design - Functionally graded additive manufacturing	Approved as DIS
ISO/ASTM 52915:2013	Standard specification for additive manufacturing file format (AMF) Version 1.1	Withdrawn
ISO/ASTM FDIS 52915 (JG 64)	Specification for additive manufacturing file format (AMF) Version 1.2	Close Voting
ISO/ASTM WD 52916 (JG 70)	Additive manufacturing - Data formats - Standard specification for optimized medical image data	Working Draft
ISO/ASTM WD 52917 (JG 62)	Additive manufacturing - Round Robin Testing - Guidance for conducting Round Robin studies	Approved as CD
ISO/ASTM CD TR 52918 (JG 64)	Additive manufacturing - Data formats - File format support, ecosystem and evolutions	Committee Draft
ISO/ASTM WD 52919-1 (JG 77)	Additive manufacturing - Test method of sand mold for metal-casting - Part 1: Mechanical properties	Approved as CD
ISO/ASTM WD 52919-2 (JG 77)	Additive manufacturing - Test method of sand mold for metal-casting - Part 2: Physical properties	Approved as CD
ISO/ASTM DIS 52921 (JG 51)	Additive manufacturing - General principles - Standard practice for part positioning, coordinates and orientation	Approved as FDIS
ISO/ASTM DIS 52924 (JWG 11)	Additive manufacturing - Qualification principles - Classification of part properties for additive manufacturing of polymer parts	Close Voting
ISO/ASTM DIS 52925 (JWG 11)	Additive manufacturing - Qualification principles - Qualification of polymer materials for powder bed fusion using a laser	Close Voting
ISO/ASTM AWI 52931 (JG 69)	Additive manufacturing - Environmental health and safety - Standard guideline for use of metallic materials	New project approved
ISO/ASTM WD 52932 (JG 68)	Additive manufacturing - Environmental health and safety - Standard test method for determination of particle emission rates from desktop 3D printers using material extrusion	Working Draft
ISO/ASTM WG 52938-1 (JG 78)	Additive manufacturing - Environmental health and safety - Part 1: Safety requirements for laser beam powder bed fusion machine using metallic feedstock.	Working Draft
ISO/ASTM FDIS 52941 (JWG 10)	Additive manufacturing - System performance and reliability - Standard test method for acceptance of powder-bed fusion machines for metallic materials for aerospace application	Approved as FDIS
ISO/ASTM FDIS 52942 (JWG 10)	Additive manufacturing - Qualification principles - Qualifying machine operators of laser metal powder bed fusion machines and equipment used in aerospace applications	Approved as FDIS
ISO/ASTM DIS 52950 (JG 67)	Additive manufacturing - General principles - Overview of data processing	Approved as FDIS

Table 4. ISO/ASTM Preliminary Work Items (PWI).

Number	Title
ISO/ASTM PWI 52911-3 (JG 57)	Additive manufacturing - Technical design guideline for powder bed fusion - Part 3: Standard guideline for electron-based powder bed fusion of metals
ISO/ASTM PWI 52913 (JG 63)	Additive manufacturing - Process characteristics and performance - Standard test methods for characterization of powder flow properties
ISO/ASTM PWI 52914 (JG 54)	Additive manufacturing - Design - Standard guide for material extrusion processes
ISO/ASTM PWI 52920-1 (JG 75)	Additive manufacturing - Qualification principles - Part 1: Conformity assessment for AM System in industrial use
ISO/ASTM PWI 52920-2 (JG 75)	Additive manufacturing - Qualification principles - Part 2: Conformity assessment at Industrial additive manufacturing centers
ISO/ASTM PWI 52922 (JG 54)	Additive manufacturing - Design - Directed energy deposition
ISO/ASTM PWI 52923 (JG 54)	Additive manufacturing - Design decision support
ISO/ASTM PWI 52926-1 (JG 74)	Additive manufacturing - Qualification principles - Part 1: Qualification of machine operators for metallic parts production
ISO/ASTM PWI 52926-2 (JG 74)	Additive manufacturing - Qualification principles - Part 2: Qualification of machine operators for metallic parts production for PBF-LB
ISO/ASTM PWI 52926-3 (JG 74)	Additive manufacturing - Qualification principles - Part 3: Qualification of machine operators for metallic parts production for PBF-EB
ISO/ASTM PWI 52926-4 (JG 74)	Additive manufacturing - Qualification principles - Part 4: Qualification of machine operators for metallic parts production for DED-LB
ISO/ASTM PWI 52926-5 (JG 74)	Additive manufacturing - Qualification principles - Part 5: Qualification of machine operators for metallic parts production for DED-Arc
ISO/ASTM PWI 52927 (JG 76)	Additive manufacturing - Process characteristics and performance - Test methods
ISO/ASTM PWI 52928 (JG 71)	Powder life cycle management
ISO/ASTM PWI 52930 (JG 72)	Guideline for Installation - Operation - Performance Qualification (IQ/OQ/PQ) of laser-beam powder bed fusion equipment for production manufacturing
ISO/ASTM PWI 52933 (JG 68)	Additive manufacturing - Environment, health and safety - Consideration for the reduction of hazardous substances emitted during the operation of the non-industrial ME type 3D printer in workplaces, and corresponding test method
ISO/ASTM PWI 52934 (JG 69)	Additive manufacturing - Environmental health and safety - Standard guideline for hazard risk ranking and safety defence.
ISO/ASTM PWI 52935 (JG 74)	Additive manufacturing - Qualification principles - Qualification of coordinators for metallic parts production
ISO/ASTM PWI 52936-1 (JWG 11)	Additive manufacturing - Qualification principles - Laser-based powder bed fusion of polymers - Part 1: General principles, preparation of test specimens
ISO/ASTM PWI 52937 (JG 74)	Additive manufacturing - Qualification principles - Qualification of designers for metallic parts production
ISO/ASTM PWI 52938-1 (JG 78)	Additive manufacturing - Environmental health and safety - Part 1: Safety requirements for laser beam powder bed fusion machine using metallic feedstock.
ISO/ASTM PWI 52943-1 (JWG 10)	Additive manufacturing - Process characteristics and performance - Part 1: Standard specification for directed energy deposition using wire and beam in aerospace applications
ISO/ASTM PWI 52943-2 (JWG 10)	Additive manufacturing - Process characteristics and performance - Part 2: Standard specification for directed energy deposition using wire and arc in aerospace applications
ISO/ASTM PWI 52943-3 (JWG 10)	Additive manufacturing - Process characteristics and performance - Part 3: Standard specification for directed energy deposition using laser blown powder in aerospace applications
ISO/ASTM PWI 52944 (JWG 10)	Additive manufacturing - Process characteristics and performance - Standard specification for powder bed processes in aerospace applications
ISO/ASTM PWI 52951 (JG 73)	Additive manufacturing - Data packages for AM parts

3 AM Published Standards Overview

In the following a short overview of the published standards is presented, according to structure presented in Figure 1.

3.1 General AM Standards

ISO 17296 Series of Standards [3-5]

This series of standards is devoted to general principles related to additive manufacturing. In particular, ISO 17296-2:2015 gives an overview of existing process categories and describes the process fundamentals. It also explains how different process categories make use of different types of materials to shape a product's geometry. ISO 17296-3:2014 specifies the main quality characteristics of parts and appropriate test procedures. It is aimed at machine manufacturers, feedstock suppliers, machine users, part providers, and customers to facilitate the communication on main quality characteristics, whatever the process category is. ISO 17296-4:2014 specifies terms and definitions which enable exchanging information on geometries or parts. It is aimed at users and producers of additive manufacturing processes and associated software systems.

ASTM F2971 [6]

It describes a method for reporting results by testing or evaluation of specimens produced by AM. This practice provides a common format for presenting data for two purposes: to establish further data reporting requirements, and to provide information for the design of material property databases.

ISO/ASTM 52900 [7]

It establishes and defines terms used in AM technology. The terms have been classified into specific fields of application. New terms emerging from the future work within ISO/TC 261 and ASTM F42 will be included in upcoming amendments and overviews of this International Standard.

ISO/ASTM 52901 [8]

It defines and specifies requirements for purchased parts made by additive manufacturing. It gives guidelines for the elements to be exchanged between customers and the part providers at the time of the order, including the customer order information, part definition data, feedstock requirements, final part characteristics and properties, inspection requirements and part acceptance methods.

ISO/ASTM 52902 [9]

This standard covers the general description of benchmarking test piece geometries along with quantitative and qualitative measurements to be taken on the benchmarking test piece to assess the performance of AM systems. This performance assessment may serve to evaluate capability and to calibrate AM systems. The benchmarking test piece

is primarily used to quantitatively assess the geometric performance of an AM system. It describes a set of geometries, each designed to investigate one or more specific performance metrics and several example configurations of these geometries into test piece. It prescribes quantities and qualities of the test geometries to be measured but does not dictate specific measurement methods. This document does not discuss a specific procedure or machine settings for manufacturing a test piece, which are covered by other standards.

ISO/ASTM 52910 [10]

It gives requirements, guidelines and recommendations for using additive manufacturing (AM) in product design. It is applicable during the design of all types of products, devices, systems, components or parts that are fabricated by any type of AM system.

ISO/ASTM 52915 [11]

It provides the specification for the Additive Manufacturing File Format (AMF), an interchange format to address the current and future needs of additive manufacturing technology. It does not specify any explicit mechanisms for ensuring data integrity, electronic signatures and encryptions.

ISO/ASTM 52921 [12]

It includes terms, definitions of terms, descriptions of terms, nomenclature, and acronyms associated with coordinate systems and testing methodologies for additive manufacturing (AM) technologies.

3.2 Materials Category-Specific

ASTM F3049 [13]

This guide introduces the techniques for metal powder characterization useful for powder-based AM processes including binder jetting, directed energy deposition, and powder bed fusion. It refers to other existing standards that may be applicable for the characterization of new and used metal powders processed in AM systems.

ASTM F3122 [14]

This standard serves as a guide to original or variations of existing standards that may be applicable to determine specific mechanical properties of metal materials made with an AM process.

ISO/ASTM 52907 [15]

It provides technical specifications for metallic powders intended to be used in additive manufacturing and covers the following aspects: documentation and traceability, sampling, particle size distribution, chemical composition, characteristic densities, morphology, flowability, contamination, packaging and storage. It also gives specific

requirements for used metallic powders in additive manufacturing. It does not deal with safety aspects.

3.3 Process Category-Specific

ASTM F3187 [16]

This standard is intended to serve as a guide for defining the direct energy deposition applicability, system set-up considerations, machine operation, process documentation, work practices, and available system and process monitoring technologies.

ISO/ASTM 52904 [17]

It describes the operation and production control of metal powder bed fusion machines and processes to meet critical applications such as aerospace components and medical implants. The requirements contained herein are applicable for production components and mechanical test specimens using powder bed fusion with both laser and electron beams.

ISO/ASTM 52911 [18-19]

This series of standards specifies the features of laser-based powder bed fusion of metals (PBF-LB/M) and provides detailed design recommendations. It also provides a state-of-the-art review of design guidelines associated with the use of powder bed fusion. In particular, ISO/ASTM 52911-1:2019 refers to metals and ISO/ASTM 52911-2:2019 refers to polymers

3.4 Process Material-Specific

ISO 27547 Series of Standards [20]

This series of standards is devoted to general principles related on testing specimen. In particular, the ISO 27547-1:2010 specifies the general principles to be followed when test specimens of thermoplastic materials are prepared by laser sintering. It provides a basis for establishing reproducible sintering conditions. Its purpose is to promote uniformity in describing the main parameters of the sintering process and also to establish uniform practice in reporting sintering conditions.

ASTM F2924 [21]

It covers additively manufactured Titanium-6Aluminum-4Vanadium (Ti-6Al-4V) parts using powder bed fusion such as electron beam melting and laser melting. The parts produced by these processes are used in applications that typically require mechanical properties similar to machined forgings and wrought products. Parts manufactured to this specification are often, but not necessarily, post processed via machining, grinding, electrical discharge machining, to meet necessary surface finish and dimensional and geometrical requirements.

ASTM F3001 [22]

It covers additively manufactured Titanium-6Aluminum-4Vanadium with extra low interstitials (Ti-6Al-4V ELI) parts using powder bed fusion. The parts produced by these processes are used in applications that typically require mechanical properties similar to machined forgings and wrought products. Parts manufactured to this specification are often, but not necessarily, post processed via machining, grinding, electrical discharge machining, polishing, and other finishing processes, to meet necessary surface finish and dimensional and geometrical requirements.

ASTM F3055 [23]

It covers additively manufactured UNS N07718 alloy parts using powder bed fusion. The parts produced by these processes are used in applications that typically require mechanical properties similar to machined forgings and wrought products. Parts manufactured to this specification are often, but not necessarily, post processed via machining, grinding, electrical discharge machining, polishing, and other finishing processes, to meet necessary surface finish and dimensional and geometrical requirements.

ASTM F3056 [24]

It covers additively manufactured UNS N06625 alloy parts using full-melt powder bed fusion such as electron beam melting and laser melting. The parts produced by these processes are used in applications that typically require mechanical properties similar to machined forgings and wrought products. Parts manufactured to this specification are often, but not necessarily, post processed via machining, grinding, electrical discharge machining, polishing, and other finishing processes, to meet necessary surface finish and dimensional and geometrical requirements.

ASTM F3091/F3091M [25]

This specification describes a method for defining requirements and ensuring integrity for plastic parts created using powder bed fusion processes. Materials include unfilled formulations and formulations containing fillers, functional additives, and reinforcements or combinations thereof.

ASTM F3184 [26]

It covers additive manufacturing of UNS S31603 alloy parts by means of powder bed fusion processes. The parts produced by these processes are used in applications that typically require mechanical properties similar to machined forgings and wrought products. Parts manufactured to this specification are often, but not necessarily, post processed via machining, grinding, electrical discharge machining, polishing, and other finishing processes, to meet necessary surface finish and dimensional and geometrical requirements.

3.5 Finished Parts Material-Specific

ASTM F3213 [27]

It covers additively manufactured cobalt-28 chromium-6 molybdenum alloy parts with similar chemical composition to UNS R30075 by means of powder bed fusion processes. The parts produced by these processes are used typically in applications that require mechanical properties similar to cast or wrought products. Parts manufactured to this specification are often, but not necessarily, post processed via machining, grinding, electrical discharge machining, polishing, and other finishing processes, to meet necessary surface finish and dimensional and geometrical requirements.

ASTM F3301 [28]

It specifies the requirements for thermal post-processing of parts produced via metal powder bed fusion to achieve the material properties and microstructure required to meet engineering requirements.

ASTM F3302 [29]

It covers additive manufacturing of parts by means of powder bed fusion processing of titanium alloys. The parts produced by these processes are used typically in applications that require mechanical properties similar to wrought products. Parts manufactured to this specification are often, but not necessarily, post processed via machining, grinding, electrical discharge machining, polishing, and other finishing processes, to meet necessary surface finish and dimensional and geometrical requirements.

ASTM F3318 [30]

It covers additively manufactured AlSi10Mg (similar to DIN EN 1706:2013-12 EN AC-43000) parts using powder bed fusion. The parts produced by these processes are used in applications that typically require mechanical properties similar to or exceeding those of cast aluminum products of equivalent alloys. Parts manufactured to this specification are often, but not necessarily, post processed via machining, grinding, electrical discharge machining, polishing, and other finishing processes, to meet necessary surface finish and dimensional and geometrical requirements.

4 Conclusions

Standardization is essential for the use of AM in critical applications such as energy saving applications in aerospace or implants fabrication for medical applications. Standards will enable the certification and approval for medical and aerospace applications. Without standards such certifications and approvals are very complicated if not impossible. For Jörg Lenz, Former Chair of ISO/TC 261 on Additive Manufacturing, "*the industry really needs International Standards to provide clarity and dispel concerns, to provide reliability, acceptance and safety, and to further push the technology in the market*" [1].

The International Organization for Standardization (ISO) and the American Society for Testing and Materials (ASTM) are putting significant joint efforts into defining standards covering different topics in this area: from terminology and data formats, to design guidelines, parts and processes qualification assessment and health and safety issues, considering both general and specific aspects and applications.

Nevertheless, all these efforts are missing a relevant point as suggested by [31, 32, 33]: the geometric dimensioning and tolerancing of additively manufactured parts. As a matter of fact, the AM processes enabled “complexity for free” requires new design approaches and the appropriate methods to define the geometrical product specifications, so that the uncertainty may be properly managed along the lifecycle of the AM products.

Acknowledgements

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