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A review for advancements in standardization for additive manufacturing

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ABSTRACT

The need for standardization is important for all sectors starting from industrial manufacturers to delivering it to the consumers. The acceptance of AM in all aspects of manufacturing is always subjected to a lack of additive manufacturing standards. This issue is always being addressed by an eminent group of researchers, and scientists and organizations over the last three decades for developing the desired qualified standards in additive manufacturing. However, ASTM) and ISO along with different research groups have been working with high integrity to resolve this aspect to a greater extent across all sectors. The current research signifies the adoption of standards between ASTM and ISO for enforcing it globally by law with the inculcation of common AM standards. This work emphasizes recent development carried by such organizations and projects, depending on pathways laid by the conductance of several workshops with a focus on developing new standards in this field.

1. Introduction

There is no doubt that the need for having sustainable standards for every technology and working sector have to be globally worked on with every country being involved. This aspect in additive manufacturing needs to be addressed by researchers to scale up the utilization of this technology in wider sectors. Therefore, this paper concentrates on the recent advancements made with this trait. The custom parts are manufactured using direct automation which is based on the ideology of solid freeform manufacturing whereas the small parts are manufactured using molds and tools. As per ASTM clause 2792-12 which iterates AM to be the technology producing products from the 3D model by the addition of material in a layer by layer manner [1]. The work in Additive Manufacturing involves the collaboration of different fields of design, material, technology, commonly known as information and collaboration technologies [2]. Future holds personally customized and sustainably efficient manufacturing as per requirements. Additive Manufacturing involves processes from designing with any CAD software to manufacturing the final product. On general basis, additive manufacturing is the technology which uses layer by layer manufacturing in order to create a 3D object opposing the conventional manufacturing technique such as traditional machining [3]. The application of this technology is widespread and due to its ease of usage, large industrial applications make it a high potential manufacturing prospect. Major involvement of AM application involves in Aerospace, Medical, Aviation and Automation sectors [45]. Specifically, important factors such as infill density, temperature and etc. can be vital while designing components in these sectors as per suitable standards which have significant impact in determining the strength of the material for desired application [67]. Finally, recent works indicate the measure of importance that AM can play in minimizing the needs for machine tools in traditional casting processes as well highlighting the influence generated with application of additive manufacturing [8].

Classification of AM processes can be done via different parameters such as type of material used, solidification process of the material, and deposition ways [11]. As per directions in F42 ASTM committee has classified into seven primary processes namely [12]:

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a) Vat Polymerization (comprising of processes such as stereolithography and etc.)
b) Material Jetting (comprising of processes such as polyjet and etc.)
c) Binder Jetting (comprising of processes involving powder and binding materials)
d) Material Extrusion (comprising of processes such as FDM and etc.)
e) Powder Bed Fusion (comprising of processes such as SLS, EBM, DMLS, SLM and etc.)
f) Sheet Lamination (comprising of processes such as UAM, LOM and etc.)
g) Directed Energy Deposition (comprising of processes such as Laser Cladding and etc.)

The general technique for an AM process cycle is as shown in Fig. 1. The part to be manufactured is designed in a CAD software and is further converted and loaded into the printer's understandable format highlighting the triangular facets of the model (such as STL, AMF format). Thereafter printer is set up with requisite conditions, part is built with layer by layer deposition of material and removed. Post-processing of part is subjected to application and technology used [9]. The use of technology is widely accepted although some parameters have constricted the usage in broader prospects. These parameters include material types and their properties, the efficiency of processes, accuracy of parts, surface finishing for contoured surfaces, fabrication speed of the machines, size of the part to be build, quality and certified products, limitation of standards for AM due to corresponding data formats.

However, the present scenario still questions the feasibility of sustenance in AM standards with response to specific characteristics for the drive-in AM processes. This issue is currently not widely addressed as the systems are not widely accepted to qualify for certified applications wherein the part standards need to qualify certain standards especially in areas of aerospace, automotive, and medical industries.

However, there are limitations to the application of AM standards. To quote a few, layer deposition can cause the generation of anisotropic properties in a particular direction. Many research works have illustrated that mechanical properties along the X-Y direction can be different in the Z direction such as in the SLA process. Processes such as PBF (Powder Bed Fusion) and Sintering are dependent on laser power, layer thickness, tolerances and etc. defining the mechanical properties of the final part [1415]. Other works include hardness treatment processes affecting microstructure and mechanical properties depending upon processing parameters in SLM in 18Ni-300 steel making it look alike as conventionally manufactured part [16]. Moreover, other developments emphasize optimizing the parameters in the SLS process [17]. Furthermore, recycled powder usage for the manufacturing of new parts is also crucial in determining the dimensions and properties in the SLS process [1819]. More work is carried upon determining the accuracy and dimension governing the surface finish in SLS parts concluding that parameters governing the operations are more favoured than individual effects [20]. Although, it is also important to note that anisotropic shrinkage is a major cause for deformation due to thermal stress and thus the part produced is not adequate with dimensions [21]. Illustrating further, it is also found that for materials such as 316L stainless steel, surface finishing is heavily dependent on processing parameters, the orientation of formed walls, and laser beam [22]. Surface finishing is without a doubt a key issue with several AM methods, necessitating a post-process such as finishing FDM items after measuring and processing extrusion parameters through specific tests while there are other methods for surface finishing for parts manufactured by SLS where chemical vapor addition has been shown promising results [2324]. A prominent work on analysing different mechanical properties such as tensile strength, hardness, accuracy, surface finishing, etc. is compared by processes, machines while using different materials which quantifies usage of apparatus according to materials used in the processes [25]. For such quality of work, testing needs to be standardized with constraints. Another prominent work describes the usage of testing methods for analysing characterization behaviour. This testing work was further categorized depending on evaluation to be done for decision, processes, metal-based processes, and uses and is currently been evaluated with international committees for standardization [26]. It is still possible for multiple manufacturers trying to manufacture a similar product with the same design characteristics can still have different products based on different mechanical properties, surface finish, and dimensions and tolerances. Three decades earlier, when rapid prototyping was widely used to create prototypes, additive manufacturing was still tested for its standardization for manufactured parts. One of the promising breakthroughs came with a workshop in 1997 organized by National Institute of Standards and Technology which focused on identifying specific measurement and standard issues that needed to be implemented by the rapid prototyping community [27]. Few prominent points discussed include CAD to rapid prototyping data, evaluating rapid prototyping systems, and part dimension performance. It was a

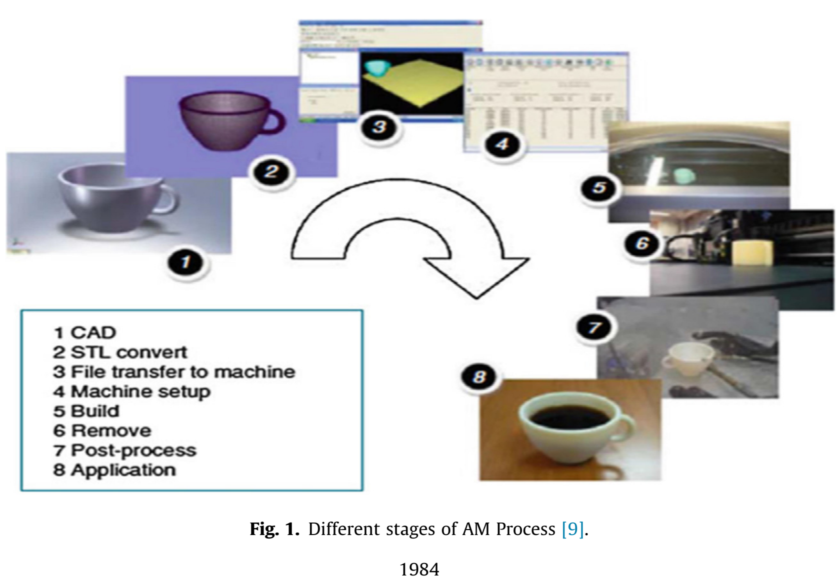

Fig. 1. Different stages of AM Process [9].

significant workshop during that time since the STL file formats didn't portray the different information such as colour, mixture, properties and etc. For instance, different data formats used and updated to date are analysed and studied for providing information relevant to the material and its properties [28]. The first reported standard development was carried out by E28.16 Rapid Prototyping Subcommittee of the ASTM E-28 Mechanical Testing Committee which develops tensile specimens for testing purposes which eventually led to the foundation of a new committee for additive manufacturing i.e. ASTM F42 which governs all activities with respect to additive manufacturing till date.

2. Understanding the requirement for standards

The application of conventional standards used in standard manufacturing for materials or technology may not be applicable in the case of additive manufacturing technology. The usage of material and unorthodox technologies dependent on operational parameters has an impact on the characteristics and quality of the manufactured part. Hence, many of the standards still used are conventionally adopted from conventional manufacturing. Around forty-six tests are carried across on material that compromises of following testing properties:

Over the years now, the need for new standards has been widely recognized as a necessity in academia, industries, and research organizations. However, there is a need for a new pathway for standardization which has recently evaluated the standards in the industry and arrived at conclusions such as recognizing the importance of standards on a national and international level, needs of the customer being a driving factor in upgrading AM standards, priorities in upgrading standards include materials, processes/methods, and test methods, improving machines and processes in standards development, increase in market opportunities, need for qualification of standards and etc. Another prominent survey work consists of 22 companies' suggestions on different standard aspects of AM out of which 11 responded with not adequate standards, 8 accepted the fact that the present standards apply to only certain aspects of the manufacturing sector while the remaining 3 suggested that current work in AM standards are acceptable. Hence the suggestions in this work were to develop standards relevant to mechanical testing, tolerances, and processing parameters [29]. Many believe that AM can be applied to a larger extent where controlling the quality of manufactured parts is critical in sectors of aerospace, medical and etc. [30]. Application of AM in this sector is easy given that the materials used in the application are used as per AM standards [31]. Many governing pathways created by researchers in the USA and EU suggest that there need to be standards implemented on AM materials. One such work is carried out in a report published by the University of Texas, Austin which stresses the development of processing standards and performance of manufactured parts tested for the aerospace sector which needs material processing standards signifying the development of high standards and its consequent development in AM [32]. Another report published by the science and technology policy institute also stressed the fact that the lack of standards is hampering the production in AM. Also, as evident in multiple research works, manufactured parts in AM need to efficiently perform on repeatable processes and reproducibility similar standards to conventionally manufactured parts. Also, proper systems need to be in place for tracking of entire product manufacturing chain [33]. Furthermore, NIST Intelligent Systems Division (ISD) also observed a lack of standards in materials, processes, equipment's, qualification and certifications, modelling, and simulations [34]. Another prominent work by NIST involves test artifacts that help in the characterization of machines and relevant processes. Artifacts stipulate the guidelines which help in designing processes and further developing design guidelines for manufacturing AM parts. Further works are also in process for powder characterization to make a significant contribution to material properties with developing proper methods and procedures for industrial manufacturing of AM.

Moreover, the Formation of Strategic Research Agenda also proposes process development with quality certification of AM, collaboration with different industries and organizations such as ASTM F42 and ISO for standard development is enhanced and defects in products are reduced with this initiation. Further work is carried by Support Action for Standardization in Additive Manufacturing (SASAM) takes care of implementing standards on deadline with priorities. The principles involve implementing a specific set of standards uniformly across the globe, proper organization of AM standards, use/upgrade/modify standards as per AM necessity, making synchronized collaboration between ISO TC261 and ASTM F42 committee to work on common goals. Standardization, Innovation and Research (STAIR) along with SASAM have started a pilot initiative that aims to standardize all of AM operations across Europe in a substantial manner. The above-mentioned organizations have been working continuously in developing standards of AM across the international community. Additionally, taking into consideration the above works present standardization process further in this paper. Tables 1 and 2.

3. Developmental activities carried out by different organizations

Many local and national organizations are working for standardization development but the primary emphasis is laid down by ASTM and ISO on a global level. Many of this work is supposed to be the foundation to global standards defined by ASTM/ISO few of which are listed below in Table 3.

ISO was founded back in 1947 and is a global leader in developing standards. Its area of operation involves specifications for practicing, services, products, etc. making them more suitable for industrial applications. The goal behind this development is to have a single line in international trading. On the other hand, ASTM International helps in delivering and developing these standards globally. The F42 committee has been founded back in 2009 with an aim to develop knowledge, research, and application of technology in AM. The F42 committee comprises of following subcommittees [36]:

ISO TC 261 on Additive Manufacturing Technologies was founded in 2011. The ISO TC 261 with 5 subcommittees namely [37]:

Table 1
Testing standards for material in AM for properties analysis.

S. No.	Properties	Properties Composition
1.	General properties in additive manufacturing products	Density, moisture absorption, ash content, etc. up to five tested parameters
2.	Mechanical properties in additive manufacturing products	Tensile strength, tensile modulus, flexural modulus, piezo impact, etc. up to 28 tested parameters
3.	Thermal properties in additive manufacturing products	Heat deflection temperature, coefficient of thermal expansion, specific heat capacity, etc. up to eight tested parameters
4.	Electrical properties in additive manufacturing products	Volume resistivity, surface resistivity, dissipation factor, etc. up to five tested parameters

Table 2
Testing barriers in standards as per NIST [34].

S. No.	Standards	Criticality	Identified Barriers
1.	Materials associated with additive manufacturing	Medium	Microstructural standards, powder chemistry, size distribution for measuring methods/specifications are limited.
2.	Process and Equipment associated with additive manufacturing	High	Machine Consistency/Testing Sensors are limited, Measurement of AM processes and artifacts with standards is also limited.
3.	Qualification and Certification associated with additive manufacturing	High	No standardized guidelines, no standards with respect to build process.
4.	AM Modelling and Simulation associated with additive manufacturing	High	Standards for modelling and simulation, dimensional accuracies, distortion, machine performance, etc. are limited. Also, validation and verification tools are also limited.

- ISO/TC 261/WG1 Guidelines for terms used in Additive Manufacturing
- ISO/TC 261/WG2 Guidelines for Processes, Systems, and Materials used in Additive Manufacturing
- ISO/TC 261/WG3 Guidelines for Testing Methods and Quality of Product specified using Additive Manufacturing
- ISO/TC 261/WG4 Guidelines for design part and processing data used in Additive Manufacturing
- ISO/TC 261/WG6 Guidelines for a manufactured part with regards to Environment, Safety and Health impact using Additive Manufacturing

Founded under 25 participating members and 8 participating countries, the primary goal of ISO TC 261 is to provide uniform standards in processes, test procedures, quality, process chains, and all basic parameters relevant in AM. The above-mentioned five subcommittees have been working to achieve two specific goals a) Developing current standards in AM and b) Studying, developing and adopting standards developed by other organizations in ISO standards. This engulf process is carried out in two ways either by adopting existing standards or negotiating between different parties for the standard [2]. Currently, 19 standards are published as per ISO TC261 standards listing.

Still, there are 35 standards under development as per ISO and ASTM standards which are listed in Table 4 below.

The expectations on current and developing established standards by both these organizations have been supposed to have a great impact on AM industry. Due to ASTM being established considerably earlier than ISO (also given that NIST was working cohesively with ASTM prior to its establishment), we always have greater standards published by ASTM than ISO. Table 5. Illustrates the standards approved and active by ASTM while Table 4. shows unpublished standards currently under development. Table. 4 also represents the standards that are currently under the developmental phase which are done by renowned researchers and are undergoing continuous changes with new refurbish, withdrawing few changes in original standards with the draft turning into the approved standard. However, the nomenclatures currently in use in AM industry has been an area of debate for some time now especially on two fronts i.e., a) Usage of Rapid Prototyping terms and technologies to associate with the concept of AM and b) All Rapid Manufacturing technologies are not categorized under AM technologies while all AM technologies are not considered 'quick' in their actions. Many platform nomenclatures have started to associate themselves getting acquainted with AM (such as in European Union). However, both sides of people are working to accept the terms and specifically RP community to change their long going practice. Hence, communities are actively addressing this issue beyond the scope of manufacturing a prototype Table 6 and Table 7.

Table 4
Sub Committee of F42 on AM Technologies.

Sub Committee	Scope of Work
F42.01	Testing Methods
F42.04	Design for Additive Manufacturing
F42.05	Materials and Processes for Additive Manufacturing
F42.06	Environment. Safety and Health concerning with additive manufacturing applications.
F42.07	Applications of Additive Manufacturing in Industrial Sectors
F42.08	Data used in Additive Manufacturing
F42.90	Execution in Additive Manufacturing
F42.91	The Terminology used in Additive Manufacturing
F42.95	US TAG collaboration with ISO TC 261

Classification of AM technologies is another aspect that needs proper attention. Consideration, Classification based on technologies or materials, Post-Processing and Finishing aspects, Indirect aspect where AM can start the initiation of the manufacturing process. To address this constraint, F42 has classified this into 7 technologies and hopes that future technologies can be added further into these categories. Another standard for developing is Specification for AMF Version 1.1. Majorly, STL files have been important to bridge the gaps between programs for design and printers. But as widely known, the STL file contains information only about surface mesh and nothing much more about other constraints such as colour, texture, etc. The AMF file format is widely a step ahead in

Table 3
Standards which are used in additive manufacturing based on work by some organizations [35].

S. No.	Organization	Country of Origin	Standard	Description
1.	AFNOR (Association Française de Normalisation)	France	AFNOR XP E67-010: 2014 AFNOR XP E67-030: 2013	Additive Manufacturing. Powders. Technical Specifications. Parts made by Manufacturing. Specifications and acceptance test
2.	AENOR (Asociación Española de Normalización y Certificación)	Spain	UNE 116005:2012	Additive Manufacturing. Preparation of test pieces.
3.	VDI (Verein Deutscher Ingenieure)	Germany	VDI 3405: 2015	Additive Manufacturing processes, rapid manufacturing. Basics, definitions, processes, materials, quality assurance and post-processing.
4.	DIN (Deutshe Industrie Normen)	Germany	DIN 35224: 2016	Welding for aerospace applications, Inspecting and Accepting LPBF (Powder based fusion) machines for additive manufacturing.

Table 5
Standards that are currently active as per ISO TC261 and ASTM listings [37].

Standard	Description
ISO 17296-2:2015	General guidelines in AM process categories and feedstock
ISO 17296-3:2014	General guidelines for AM characteristics for testing methods
ISO 27547-1:2010	General guidelines for laser sintering of testing specimens of thermoplastic materials using AM technology
ISO/ASTM 52900:2015	General theories in AM Terminologies
ISO/ASTM 52901:2017	General theories for buying AM parts
ISO/ASTM 52902:2019	Testing artifact guidelines for additive manufacturing systems
ISO/ASTM 52903-1:2020	Guidelines for feedstock plastic materials used in the extrusion process
ISO/ASTM 52903-2:2020	Guidelines for process equipment plastic materials used in the extrusion process
ISO/ASTM 52904:2019	General guidelines for process characteristics and performance including application for metal PBF process
ISO/ASTM 52907:2019	Guidelines to characterize metal powders
ISO/ASTM 52910:2018	Requirements and recommendations for AM design
ISO/ASTM 52911-1:2019	Design guidelines for Metal LPBF processes
ISO/ASTM 52911-2:2019	Design guidelines for Polymer LPBF processes
ISO/ASTM TR 52912:2020	Recommendations for grading AM
ISO/ASTM 52915:2020	Guidelines for AM file format Version 1.2 in AMF type
ISO/ASTM 52921:2013	Guidelines for determining coordinate systems and testing methodologies in AM processes
ISO/ASTM 52941:2020	Guidelines for AM system performance for testing LPBF machines for metal powders in the aerospace industry
ISO/ASTM 52942:2020	Guidelines for qualified machine operators of LPBF machines for metal powders and application of parts used in the aerospace industry
ISO/ASTM 52950:2021	Guidelines for data processing in AM

*LPBF: Laser Powder Bed Fusion.
*AM: Additive Manufacturing.

Table 6
Standards which are currently under development as per ISO TC261 listings [37].

Standard	Description
ISO/ASTM FDIS 52,900	Guidelines stating Fundamentals and vocabulary used in AM processes.
ISO/ASTM CD 52,902	Improving guidelines for testing artifact guidelines for additive manufacturing systems
ISO/ASTM CD 52903-2	Improving guidelines for process equipment plastic materials used in the extrusion process
ISO/ASTM CD 52,904	Improving general guidelines for process characteristics and performance including application for metal PBF process
ISO/ASTM AWI TR 52,905	Improving guidelines for detecting defects in AM parts using NDT techniques
ISO/ASTM DTR 52,906	Improving guidelines for seeding flaws in AM parts using NDT techniques
ISO/ASTM CD 52,908	Improving guidelines for post-processing, inspection, and testing of AM parts produced by PBF processes for metals
ISO/ASTM CD 52,909	Improving guidelines for orientation and location dependence of mechanical properties for PBF processes
ISO/ASTM CD 52,910	Improving guidelines for requirements and recommendations for AM design
ISO/ASTM AWI 52911-3	Improving guidelines for EPBF for designing AM metal parts
ISO/ASTM DTR 52913-1	Improving guidelines for characterizing powder flow properties in AM processes
ISO/ASTM DTR 52,916	Improving guidelines for optimizing data of generated medical images
ISO/ASTM DTR 52,917	Improving guidelines for Comparative Testing
ISO/ASTM CD TR 52,918	Improving guidelines for supporting different AM files along with ecosystem and evolutions
ISO/ASTM AWI 52919-1	Improving guidelines for mechanical properties of sand for the metal casting process
ISO/ASTM AWI 52919-2	Improving guidelines for physical properties of sand for the metal casting process
ISO/ASTM DIS 52,920	Improving guidelines for requirements at AM sites
ISO/ASTM DIS 52,921	Improving guidelines for AM position of part, build coordinates and part orientation
ISO/ASTM DIS 52,924	Improving guidelines for material specification for LPBF AM parts
ISO/ASTM DIS 52,925	Improving guidelines for properties in classified polymer part
ISO/ASTM CD 52926-1	Improving guidelines for machine operators in enhancing qualification standards
ISO/ASTM CD 52926-2	Improving guidelines for qualified machine operators of LPBF machines
ISO/ASTM CD 52926-3	Improving guidelines for qualified machine operators of EPBF machines
ISO/ASTM CD 52926-4	Improving guidelines for qualified machine operators of LDED machines
ISO/ASTM CD 52926-5	Improving guidelines for qualified machine operators of Arc-DED machines
ISO/ASTM CD 52,927	Improving general guidelines for process characteristics and performance including application for AM processes
ISO/ASTM CD 52,928	Improving general guidelines of life cycle management for powder
ISO/ASTM TS 52,930	Improving guidelines for LPBF machines in installing, and operating performance (IQ/OQ/PQ)
ISO/ASTM DIS 52,931	Improving guidelines for ensuring a sustainable and safe environment using metal powders
ISO/ASTM CD 52,932	Improving guidelines for ensuring a sustainable and safe environment for testing methods for determining polymer particle emission rates from desktop ME printers
ISO/ASTM WD 52,933	Improving guidelines for ensuring a sustainable and safe environment for reducing emissions of hazardous substances from non-industrial ME type printers at work sites.
ISO/ASTM CD 52,935	Improving guidelines for qualification of coordinators for AM metal part production.
ISO/ASTM DIS 52936-1	Improving guidelines for the preparation of test specimens for LPBF processes
ISO/ASTM AWI 52,937	Improving guidelines for qualified designers
ISO/ASTM AWI 52938-1	Improving guidelines for safety requirements for LPBF machines

*LPBF: Laser Powder BED Fusion.
*LDED: Laser-Based Directed Energy Deposition.
* EPBF: Electron-Based Powder BED Fusion.
*AM: Additive Manufacturing.

addressing this concern where the file type includes various prospects such as colour, complex structures, curved triangles, material and lattice specifications, and metadata. Since 2013, ASTM F42 and ISO TC261 are collaboratively working on developing AM standards on the following principles:

a) Common sets of AM standards across the globe.
b) Similar organizational structures and road maps for AM standards.
c) Using existing/modified standards for application whenever necessary.
d) Major stress should be given to working together and jointly developing standards in an efficient manner.

If materialized in the longer run, trade between technologies and products would be more common due to common standards enabling large AM industry globally. Accordingly, a structure has been laid for satisfying the requirements of both ASTM F42 and

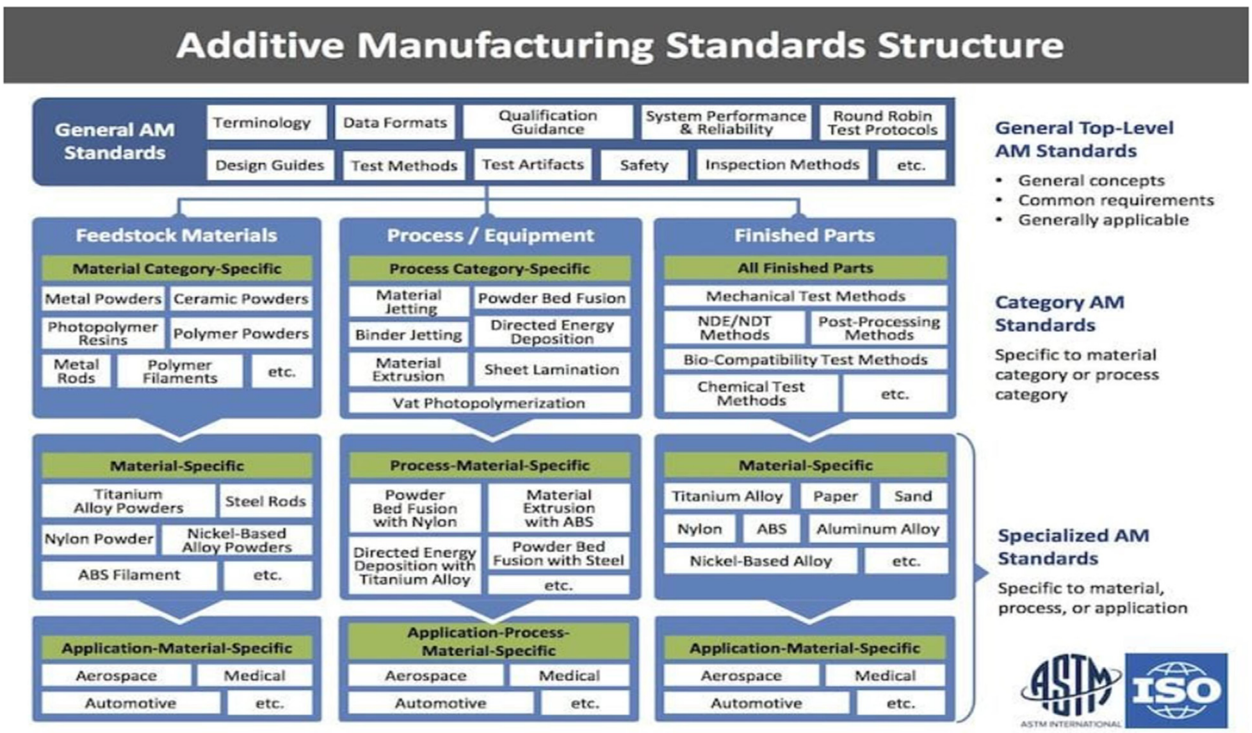

Fig. 2. Standardization Structure defined as per ASTM and ISO standards in Additive Manufacturing [10].

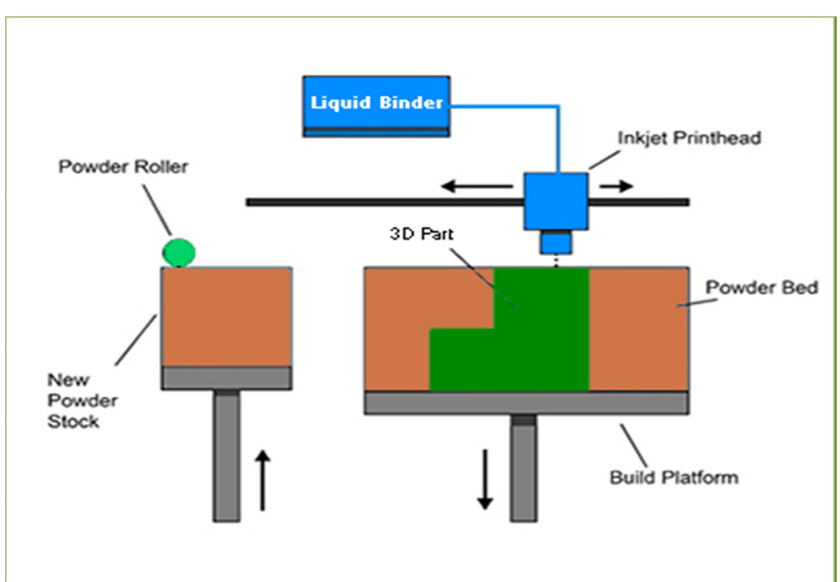

Fig. 3. A typical operational setup carried out in Binder Jetting Process [13].

Table 7
Approved Standards as per ASTM Listings and their respective scope of applications [36].

Standard Name	Standard Classification	Standard Scope
Test Methods	F2971-13	Classification of Testing Specimens in AM and reporting accumulated data
	F3122-14	Guidelines for Metal AM Manufactured Part Evaluation of Mechanical Properties
Design	F3413-19	Guidelines for DED Processes
Materials and Processes	F2924-14	Specifications for Ti-6Al-4V powder manufactured AM part with PBF process
	F3001-14	Specifications for Ti-6Al-4V ELI (Extra Low Interstitial) powder manufactured AM part with PBF process
	F3049-14	Guidelines for Characterizing Properties of Metal Powders Used for AM Processes
	F3055-14a	Guidelines for AM part Nickel Alloy (UNS N07718) manufactured with PBF processes
	F3056-14e1	Guidelines for AM part Nickel Alloy (UNS N06625) powder manufactured AM part with PBF processes
	F3091/ F3091M-14	Specification for PBF processes carried out with plastic materials
	F3184-16	Guidelines for AM part Stainless Steel Alloy (UNS S31603) powder manufactured AM part with PBF processes
	F3187-16	Guidelines for DED processes carried out with Metals
	F3213-17	Guidelines for AM part Cobalt-28 Chromium-6 Molybdenum via powder manufactured AM part with PBF processes
	F3301-18a	Guidelines for Thermal Treatment Post-Processing of AM Metal Parts manufactured with PBF processes using powders
	F3302-18	Specifications for Titanium Alloys for PBF processes post finishing
	F3318-18	Specifications for AlSi10Mg for LPBF processes post finishing
	F3434-20	Guidelines for Installation/Operation and Performance Qualification (IQ/OQ/PQ) of LPBF Machines for AM Production

*Ti-6Al-4V: Titanium-6 Aluminum-4 Vanadium.
*LPBF: Laser-Based Powder Bed Fusion.

ISO TC261 committees. The layout works on identifying standards in 3 levels as elucidated in Fig. 2 namely: Fig. 3.

I) Top priority standards: General Concepts, Common requirements and Largely Applicable
II) Categorized AM Standards: Highly conceptualized on developing material and process standards
III) Specialized AM Standards: Specific to materials, processes, and applications

The idea behind this structure largely involves developing standards, reducing the risk of duplicity and contradiction between standards. As stated below, the working committees of ASTM F42 and ISO TC261 collaboratively are composed to work for betterment on below stated fronts.

- Qualification and method improvements for certification
- Design guidelines
- Testing methods carried out for determining characteristics of raw materials
- Testing methods carried out for determining mechanical properties of finished AM parts
- Guidelines for Material recycling (re-usage)
- Standard guidelines for comparative testing methods
- Standards for test artifacts
- Requirements for purchasing AM parts
- Harmonization of existing ISO 17296-1 and ASTM 52,912 terminology standards

4. Conclusion

Right from initial workshops stipulating the initial layout to modern day collaboration between ISO and ASTM, the AM industry has evolved by setting up standards for the upcoming scientific community. These steps are helping in realizing the potential to extend AM industry which brings larger market billing worldwide ensuring quality and certified products in sectors where it is critical such as aerospace, medical and etc. Furthermore, with the help of various pathways and structures such as SASAM (as discussed in this paper), the development of standards is widely accelerated at a great pace. Also, as per demand by stakeholders, this structure provides a great foundation for providing practical standards in keeping with the remarkable development of AM technologies seen over the last decade—and predicted over the future decade—in accordance with the priorities sought by stakeholders. Prominently, the first objective of the community is to standardization process is to satisfy the industry's and AM community's real objectives and needs while avoiding needless standard rules that raise manufacturing costs. The second objective is coordinating standardization synchronously while working with a range of materials and processes. However, it is an important scenario to address since AM community is formed by researchers from various fields and industries (such as automotive, aerospace, medical, etc.) dealing with various ranges of materials (such as polymers, metals, and ceramics). The danger is that there will be some contradict with other scientific committees working in metals, plastics, aeronautics, and other fields, resulting in a conclusion that is much more general than the specific use of AM technology. In this regard, organizations such as ASTM and ISO have recognized the necessity for particular AM standards since it is important to fill this significant gap created by generic standards focusing on materials or any other process which cannot be bridged further. Finally, the prospect of shared ISO–ASTM standards offers up new avenues for the global expansion of AM among countries and businesses.

CRediT authorship contribution statement

Rajat Kawalkar: Conceptualization, Methodology, Writing – review & editing. **Harrsh Kumar Dubey:** Formal analysis, Investigation, Resources, Data curation, Supervision, Project administration. **Satish Lokhande:** Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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