AM Standards: An Update on Published Work and Development in Progress

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Where it all started, early applications:

"Rapid Prototyping": several systems launched through the late 1980s and the early 1990s

"Rapid Tooling" (1990's to early 2000's) ; producing tools based on "RP" technology ex. Keltool, Wibatool, early DMLS…

"Rapid Manufacturing" (late 1990's to mid 2000's): producing end-use parts based on "RP"- technology, -found some applications but did not really take off

-Well, perhaps it wasn't that "Rapid" after all…
From "Rapid Prototyping" to industrial manufacturing

Need for a different perspective:

• This is NOT a single process (-or technology for that matter…)
  • 7 different process categories identified….

• AM does not produce final products in a single process step
  • Prototyping processes v.s. Industrial manufacturing processes
    • A prototyping process includes everything from concept idea to the delivery of the physical prototype. Requirements are ad-hoc and settled by agreement between service provider and customer.
    • An industrial manufacturing process consists of a series of sub-processes, with defined interfaces and specified requirements. Consistency, predictability, traceability and quality control… Predetermined product requirements!

• AM as a part of a larger manufacturing system…
AM PROCESS CATEGORIES

Example process categories:
"powder bed fusion"
Example process categories: "material extrusion" and "directed energy deposition"
Example process categories:
"binder jetting" and "material jetting"
AM PROCESS CATEGORIES

Example process categories: "vat photopolymerization"
AM PROCESS CATEGORIES

Example process categories:
"sheet lamination"
Great expectations - Many challenges

Process and material are more coupled than conventional processes

- Multiple variables and parameters
  - Different machine systems, different set-ups, different calibrations, and different conditions produces different results…, stability and traceability!
- Quality management, traceability, inspection and verification
- Certification and qualification requires testing and evaluation under specified conditions
- Producers and customers: purchasing process, roles and responsibilities, communication…
The role of standards:
Standards are used for (among others):

• Specifying requirements
• Communicating guidance
  – "Why don't we have industrial manufacturing based on RP, RT, RM, FFF, LF, SFF, ALM, ALF, AF, DDF, DDM, 3DP, (-and others)?"
• Documenting best practices
• Defining test methods and protocols
  – Certifying bodies typically reference publicly available standards in their procedures
• Documenting technical data
• Accelerating the adoption of new technologies
STANDARDIZATION INITIATIVES

International market requires international standards:

ASTM International, Committee F42

• Established 2009, -coined & defined "Additive Manufacturing"

• **Scope:** "The promotion of knowledge, stimulation of research and implementation of technology through the development of standards for additive manufacturing technologies."

• Membership is based on representation of different stake holders: companies, universities, research organisations etc.
  • 1 vote/organisation

• Presently: 550+ individual members, more than 26 countries represented
ISO Technical Committee 261 (ISO/TC261)

• Established 2011, after an initiative from DIN, based on VDI Guidelines on "Rapid Technologies"

• **Scope:** "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."

• Membership is based on representation of different national standardization organization. Each member organization may nominate experts for different workgroups.
  - 1 vote/organization

• Presently: 22 participating countries +6 observers
ISO/TC261: INTERNATIONAL PARTICIPATION
COLLABORATION:
Standards are needed, but we don't necessarily need several competing standards...

ISO & ASTM have signed a Partnership Standards Development Organization (PSDO) agreement

- Fast tracking the adoption process of an ASTM International standard as an ISO final draft international standard
- Formal adoption of a published ISO standard by ASTM International
- Maintenance of published standards
- Publication, copyright and commercial arrangements
A JOINT PLAN FOR AM STANDARDS DEVELOPMENT

Guiding principles:
• One set of AM standards – to be used all over the world
• Common roadmap and organizational structure for AM standards
• Use and build upon existing standards, modified for AM when necessary
• For efficiency and effectiveness, ISO TC261 and ASTM F42 should begin the work together and in the same direction
• Emphasis on joint standards development
"ASTM F42 & ISO/TC261 Develops Additive Manufacturing Standards"
Additive Manufacturing Standards Structure

**General AM Standards**
- Terminology
- Data Formats
- Qualification Guidance
- System Performance & Reliability
- Round Robin Test Protocols
- Design Guides
- Test Methods
- Test Artifacts
- Safety
- Inspection Methods

**Feedstock Materials**
- Material Category-Specific
  - Metal Powders
  - Ceramic Powders
  - Photopolymer Resins
  - Polymer Powders
  - Metal Rods
  - Polymer Filaments
  - etc.

**Process / Equipment**
- Process Category-Specific
  - Material Jetting
  - Binder Jetting
  - Material Extrusion
  - Powder Bed Fusion
  - Directed Energy Deposition
  - Sheet Lamination
  - Vat Photopolymerization

**Finished Parts**
- All Finished Parts
  - Mechanical Test Methods
  - NDE/NDT Methods
  - Post-Processing Methods
  - Bio-Compatibility Test Methods
  - Chemical Test Methods
  - etc.

**Material-Specific**
- Titanium Alloy Powders
- Steel Rods
- Polyamid Powder
- Nickel-Based Alloy Powders
- ABS Filament
  - etc.

**Process-Material-Specific**
- Powder Bed Fusion with Polyamide
- Directed Energy Deposition with Titanium Alloy
- Powder Bed Fusion with ABS
  - etc.

**Application-Material-Specific**
- Aerospace
- Medical
- Automotive
  - etc.

**General Top-Level AM Standards**
- General concepts
- Common requirements
- Generally applicable

**Category AM Standards**
Specific to material category or process category

**Specialized AM Standards**
Specific to material, process, or application
EUNPEAN INITIATIVES

- **SASAM** - "Support Action for Standardisation of Additive Manufacturing" EU FP7 CSA-project
  - Scoping – stakeholder's requirements
  - Roadmap for standardization of AM
  - Project completed Apr 2014, roadmap updated 2015

- **STAIR-AM**: Cen-CENELEC working group (STAndardization, Innovation and Research)
  - Objective: "to be a meeting point of stakeholders from the AM research, innovation community and the global standardization community." (Ended 2015)
  - Activities continued by CEN/TC438 and AM-Platform

- **CEN/TC 438** (since July 2015)
  - Transform ISO/ASTM standards to EN ISO/ASTM standards
  - **CEN standards automatically replace any national standards in all member states**

- ASTM F42 start 2009
- ISO/TC261 start 2011
- ASTM-ISO joint standards development plan Jul. 2013
- Cen-CENELEC STAIR-AM, 2012-2015
- SASAM: FP7 Project, 2012-2014

CEN-TC 438
HOW STANDARDS ARE DEVELOPED

Very basic:

• All standards development is based on contribution from members
  – Members are stakeholders and base their contribution on an interest in developing the standards
  – No funding or compensation provided from the SDOs
  – SDO's have all the IPR

• Consensus based!

• ASTM: experts nominated directly by stakeholder (Company, University, Professional organization, etc.)
  – Type of membership depend on the nature of the stakeholder's interest

• ISO & CEN experts nominated national SDO committees, -which is based on stakeholder memberships
HOW STANDARDS ARE DEVELOPED:

New work item proposal

ASTM:
Submitted to Sub-committee
• Request for participation
• Sufficient commitment from members – work to develop standards documents begins
• A minimum of 60% committee participation in ballots is required for continuation of project

ISO:
Submitted to Secretariat
• Proposal circulated and submitted for ballot
• Call for experts from National mirror committees
• Work group secretariat normally appointed to the same SDO as submitted the proposal
• Draft circulated and submitted to repeated ballot processes

Joint ISO/ASTM: Each SDO may propose an item & invite the partner to join
3 - 5 experts from each SDO participate in the JG (Joint work Group)
ISO PRINCIPLES AND RECOMMENDATIONS FOR TERMS AND DEFINITIONS

• Terms should be as general as possible, -as long as they are clear, concise and short

• **NO Trade Marks!**

• Definitions for terms should:
  – Be possible to use as a replacement for the term in a text
  – Not include any restrictions, requirements or specifications
    • Should be defined as a part of the specific standards and not in the terminology
WHAT'S THE POINT WITH "NO TRADE MARKS"?

• For example: "Selective Laser Melting" – SLM
  – Originally developed and patented in collaboration between Fraunhofer ILT and Dr. Dieter Schwarze and Dr. Matthias Fockele from F&S Stereolithographietechnik GmbH
  
"SLM® is a registered trademark by SLM Solutions GmbH, Germany"

• SLM Solutions use "SLM" in their product names and marketing:
  – What if SLM Solutions decide to launch a product using:
    • An electron beam?
    • A laser, but no powder bed?
    • ...or any other product?
TRADE MARKS AND PROCESSES

For comparison in personal vehicles: the trade mark "Volvo" means "I roll". Is therefore all that rolls a "Volvo"?

- How about Volvo Construction Equipment, Volvo Penta, or Volvo Aero?

• Comparing "SLM" with "DMLS/DMLM" and "LaserCusing"? –Like comparing Mercedes Benz with BMW and Audi…
JOINT STANDARDS DEVELOPMENT AGREEMENT:

- Draft for review by both organizations
- Parallel ASTM and ISO ballots
  - ISO/TC 261: "Draft International Standard" (DIS) ballot; 3-month balloting cycle, an FDIS ballot may be needed...
  - ASTM F42: Final balloting; 30-days balloting cycle
- Editorial changes are allowed, comments resulting from the ASTM balloting can be submitted into the ISO balloting process
- Standards passed by TC261 can also be balloted by CEN/TC438 for publication as an EN-standard
  - "EN ISO/ASTM 529....."
PUBLISHED AM STANDARDS

Joint ISO-ASTM Standards

• EN ISO/ASTM52921-13 Standard Terminology for Additive Manufacturing-Coordinate Systems and Test Methodologies
• EN ISO/ASTM 52900-15 Additive Manufacturing - General principles – Terminology
• ISO/ASTM52910-17 Standard Guidelines for Design for Additive Manufacturing
ISO/ASTM52915-16

The AMF format: new standard file format for AM technology

• Developed on initiative by ASTM F42
• More dense format – smaller files
• Capable of representing, for example:
  • 3D Geometry
  • Material
  • Texture
  • Colour
  • Sub-structures
  • Metadata
ISO/ASTM52921-13

"Standard Terminology for Additive Manufacturing-Coordinate Systems and Test Methodologies"

Terms included cover:

• Definitions for machines/systems and their coordinate systems
• Location and orientation of parts
• Compliant with ISO 841, (where possible)
  • Clarify the specific adaptations for additive manufacturing
PUBLISHED AM STANDARDS

ISO Standards

• EN ISO 17296-2:2015 Additive manufacturing - General principles - Part 2: Overview of process categories and feedstock

• EN ISO 17296-3:2014 Additive manufacturing – General principles – Part 3: Main characteristics and corresponding test methods

PUBLISHED AM STANDARDS

ASTM Standards:

- F2971-13 Standard Practice for Reporting, Data for Test Specimens Prepared by Additive Manufacturing
- F3001-14 Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium ELI (Extra Low Interstitial) with Powder Bed Fusion
The standard includes, for example:

- Classification system
  - With specification of required post-processing operations (stress relieving, annealing, solution heat treated, etc.)
- Specification of requirements for ordering information
- Manufacturing plan, typically including:
  - Number of parts in the build cycle
  - Location & orientation on the build platform
  - Number, orientation & location of test specimen
  - Feedstock requirements

"Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium with Powder Bed Fusion"
PUBLISHED AM STANDARDS

More from ASTM...

• F3049-14 Standard Guide for Characterizing Properties of Metal Powders Used for Additive Manufacturing Processes
• F3055-14a Standard Specification for Additive Manufacturing Nickel Alloy (UNS N07718) with Powder Bed Fusion
• F3056-14e1 Standard Specification for Additive Manufacturing Nickel Alloy (UNS N06625) with Powder Bed Fusion
• F3091/F3091M-14 Standard Specification for Powder Bed Fusion of Plastic Materials
SOON TO BE PUBLISHED...

- ISO/ASTM 52901 Additive Manufacturing - General principles - Requirements for purchased AM parts
  - (Published electronically by ASTM, very soon by ISO)
- ISO/ASTM DIS 52903-1 Additive manufacturing - Standard specification for material extrusion based additive manufacturing of plastic materials - Part 1: Feedstock materials
ISO/ASTM 52901-16
ADDITIVE MANUFACTURING - GENERAL PRINCIPLES - REQUIREMENTS FOR PURCHASED AM PARTS

• Intended to enable efficient and unambiguous communication between part providers and customers of parts made by additive manufacturing to ensure that the resulting part meets the customer’s requirements. Specification includes:

  - Part ordering information

  - **Definition of the part to be manufactured:** part geometry, tolerances, surface texture, build orientation of the part, feedstock for the part to be manufactured, repair methods, Acceptable imperfection(s) or non-conformance, process control information

  - **Part characteristics:** test methods & inspection criteria, post processing (specification requirements...), etc.

  - **Procedure for acceptance:** qualification parts, first production part, final or reference part

  - Documentation of acceptance
SEVERAL WORKING GROUPS IN PROGRESS

- Standard test artefacts – New project approved
- Extrusion based additive manufacturing of plastic materials, Part 2 Process equipment – CD approved for DIS
- Standard practice for metal based powder bed fusion to meet rigid quality requirements
- Specific design guidelines on powder bed fusion
- Qualification, quality assurance, and post processing of powder bed fusion metallic parts
- NDT (Non-Destructive Testing) for AM parts
- Standard Practice/Guide for Intentionally Seeding Flaws in Additively Manufactured (AM) Parts
- New guide for anisotropy effects in mechanical properties of AM parts
- New guide for conducting Round Robin test for additive manufacturing
- New test methods for characterization of powder flow properties for AM applications
MORE WORKING GROUPS…

- Additive Manufacturing Cobalt-28 Chromium-6 Molybdenum Alloy (UNS R30075) with Powder Bed Fusion
- New Specification for AMF Support for Solid Modeling: Voxel Information, Constructive Solid Geometry Representations and Solid Texturing
- New Guide for Directed Energy Deposition of Metals
- New Specification for Additive Manufacturing Stainless Steel Alloy (UNS S31603) with Powder Bed Fusion
- New Specification for Additive Manufacturing Stainless Steel 17-4PH (UNS S17400) with Powder Bed Fusion
- New Specification for Additive Manufacturing Stainless Steel 15-5PH (UNS S15500) with Powder Bed Fusion
- Orientation and Location Dependence Mechanical Properties for Metal Additive Manufacturing
- Technical specification on metal powders
... EVEN MORE WORKING GROUPS...

- Technical report for the design of functionally graded additive manufactured parts
- Characterization of Powder Flow Properties for Additive Manufacturing Applications
- Principles of Design Rules in Additive Manufacturing
- Additive Manufacturing AlSi10Mg with Powder Bed Fusion
- Thermal Post Processing of Metal Powder Bed Fusion Parts

-And many more to come....
CLOUDS ON THE HORIZON…

- Since 2015 many new stakeholders (International and national SDOs, different TC's within the same SDO, various industrial and professional associations) have initiated their own AM standard development.

- In the US, for example:
  - ASTM E07 - Nondestructive Testing
  - ASTM E08 - Fatigue & Fracture
  - ASME Y14.46 - Geometric Dimensioning & Tolerancing
  - ASME B46 - Surface Texture
  - ASME BPVC - Welding, Brazing, Plastic Fusion
  - SAE AMS - AM Aerospace Material Specs
  - AWS D20 - AM Fabrication of Metal Components

- ISO/TC 44/SC 14 Welding and brazing in aerospace, have initiated their own group for AM standards for the aerospace industry…
The more, the merrier?
More activity – Faster over-all development?

Possibly, but lack of coordination also brings

• High risk of duplication of efforts and overlapping content
• High risk for inconsistencies (or even contradictions)
• Conflicting standards: -creates ambiguity and confusion in the market
  – In particular critical to AM!
• Expertise spread thin over several committees
Ongoing and initiated AM standard developments

VDI FA 105 ff.
Additive Manufacturing

ISO/TC 261 AM

ISO/TC 44/SC 14/WG 1

DIN NAS NA 092-00-17-01

DIN NWT NA 145-04-01AA

DIN NL NA 131-02-06

DIN NATG DIN 8580

ISO TC 261 AM

NEN NC 341107

SAC TC 562

ASTM F42 TAG

AMSC - Additive Manufacturing Standardization Collaborative (AmericaMakes - ANSI)

AWS D20, D22 u.a.

SAE AMSC-AM

ASME Y14 u.a.

ASTM E07.10 u.a.

ASTM F42 AM

DOD, IPC/JPCA, NIST, UL a.o.

VIENNA agreement (adaptation without change)

PSDO Agreement (co-development or adaption)

AMSC - Additive Manufacturing Standardization Collaborative (AmericaMakes – ANSI)
AMSC: Additive Manufacturing Standardization Collaborative

- US initiative, coordinated by ANSI and America Makes with the purpose:
  - "To coordinate and accelerate the development of (US) industry-wide AM standards and specifications, consistent with stakeholder needs, and thereby facilitate the growth of the AM industry"

- Principal objectives:
  - Coordinate and provide input to AM Standards Developing Organizations (SDOs)
  - Develop a (US) standardization roadmap for AM based on existing standards and specifications, as well as those in development, and identified gaps
  - As a general agreement all standards should use the same ISO/ASTM 52900 Terminology standard
ISO TC261/ASTM F42 & ISO TC44 WG1: Agreement to collaborate

Organization:

- Formally organized under the “umbrella” of TC261/ASTM F42 network
  - Decisions about convener and secretary will be decided in agreement between TC44/SC14 and TC261/ASTM F42
  - Experts to this joint working group will be nominated by each partner, as applicable
  - As a general understanding, it is agreed that the standards developed should use the same ISO/ASTM 52900 Terminology standard
- New work items and project leader can be proposed by each partner
  - Other partners respond by nomination of experts for the project as applicable
- Draft standards will be balloted within each of the organizations that has participated in the development of that draft standard.
  - Standards developed with participation of TC261 can also be balloted through CEN TC 438 for publication as an EN-standard (under the Vienna agreement).
AM-Platform Board: Standardization Group

Chair: Klas Boivie, SINTEF, Co-Chair: Martin Schäfer, Siemens

Task:

"To serve as the primary point of contact between the European AM community and the Standards Development Organizations (SDOs) currently engaged in development of standards concerning additive manufacturing technology"

- Manage liaisons between AM-Platform and SDOs, technical committees, and work groups
- Disseminate progress of ongoing standards development
  - New standards
  - New work items: Calls for experts
- Encourage European engagement in the development of new international standards
- Support the development of consistent coherent standards for AM technology under the vision: One set of standards, to be used all over the world"
Concluding remarks
International standards development

• Development of AM standards is a key element in establishing AM as a part of the industrial manufacturing system.
• International collaboration between ASTM, ISO and CEN is formally established and is growing
• One set of standards used all over the world!
• Common roadmap and organizational structure for AM standards
  – Use and build upon existing standards, modified for AM when necessary
• Joint working groups are in progress
• Several standards, both common and by the individual organizations, have been published and more are on the way
Final remarks

We are just in the beginning of exploring the many possibilities of AM technology

Knowledge is critical; This is a learning process for all of us

Misdirected expectations leads to disappointments

No one benefits from competing standards.

Please join and take part in the ongoing efforts, through ASTM, ISO and your national standardization organizations!

Let's work together and get this right!
It's not a tip of an iceberg we're seeing, we're entering a new universe in manufacturing...
Thank you for the attention!

Any Questions?
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