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INDUSTRIALISATION OF ADDITIVE MANUFACTURING: STANDARDS DEVELOPMENT AND KEY CHALLENGES

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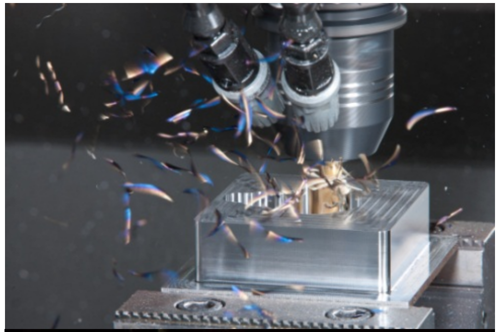
IN PERSPECTIVE:

Principal methods of shaping materials:

- Subtractive shaping: Shaping a raw material by successive subtraction of pieces of the original block of material; i.e. machining, grinding drilling
- Formative shaping: Shaping a raw material by the application of pressure to the material; i.e. forging, pressing, bending, casting, etc.
- Additive shaping: Shaping by the successive addition of material(s); i.e. Additive Manufacturing technologies



Introduction: Let's take a step back…

Additive Manufacturing; shaping objects by successive addition of material…
-New Technology?

A scallop

First modern system: *Stereo Lithography*, patent 1986, first machine sold in 1987
-The technology may be fairly new, but the principle is just natural and ancient!

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The origins of modern AM technology

- 1970-s and 80-s: Developments in 3D CAD
- 1980-s; challenges, among others, in the US automotive industry identified the need for augmented prototyping processes
- Several "Rapid Prototyping" (RP) processes developed during the 1980-s and early 90-s, for example:
  - Stereolithography (SLA, Hull, 1986)
  - Selective sintering (SLS, Deckard, 1989)
  - "Apparatus and Method for Creating Three-Dimensional Objects" -Fused deposition modelling (FDM, Crump, 1992)
  - Techniques for Three Dimensional printing (3DP, Emanuel M. Sachs et al. 1993)
  - Laminated Object Manufacturing (LOM, Feygin, Sung 1996)
  - Casting shapes (Arcella, Lessman 1989)
  - ....

The origins of AM: 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 on an industrial scale

Industrialization:
From "Rapid Prototyping“ to industrial manufacturing

Need for a different perspective:

- This is NOT a single process (-or technology for that matter…)
  - Multiple different "RP" processes (i.e. 'products') with unique trademarked names…
- Prototyping processes vs. 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!
- Producers and customers: purchasing process, roles and responsibilities, communication…

Industrialization:

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…,
- Fulfilling product requirements
  - Need for predictability, stability and traceability!
- Quality management, traceability, inspection and verification
- Documentation
- Certification and qualification requires testing and evaluation under specified conditions

Industrialization:

The role of standards:

Standards are used for (among others):

- Specifying requirements
- Communicating guidance
  - "What do you mean by 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

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Standardization: Getting structured…

- What are we actually working on?
  - Name? The least common denominator…
  - Definition: what is the actual *AM-process*, and what is a the AM enabled *production chain*?
  - Single-step and multi-step processes
- Many different processes, with trademarked names: categorization..!
- Identification of process categories:
  - Identification of common denominators based on <u>process architecture</u>
  - Naming of process categories

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Name? -The least common denominator:

Understanding AM - Definition by ISO/ASTM 52900:

2.1.2
additive manufacturing, noun
AM
process of joining materials to make *parts* (2.6.1) from 3D model data, usually *layer* (2.3.10) upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies

Note 1 to entry: Historical terms: additive fabrication, additive processes, additive techniques, additive layer manufacturing, layer manufacturing, solid freeform fabrication and freeform fabrication.

Note 2 to entry: The meaning of "additive-", "subtractive-" and "formative-" manufacturing methodologies are further discussed in Annex A.

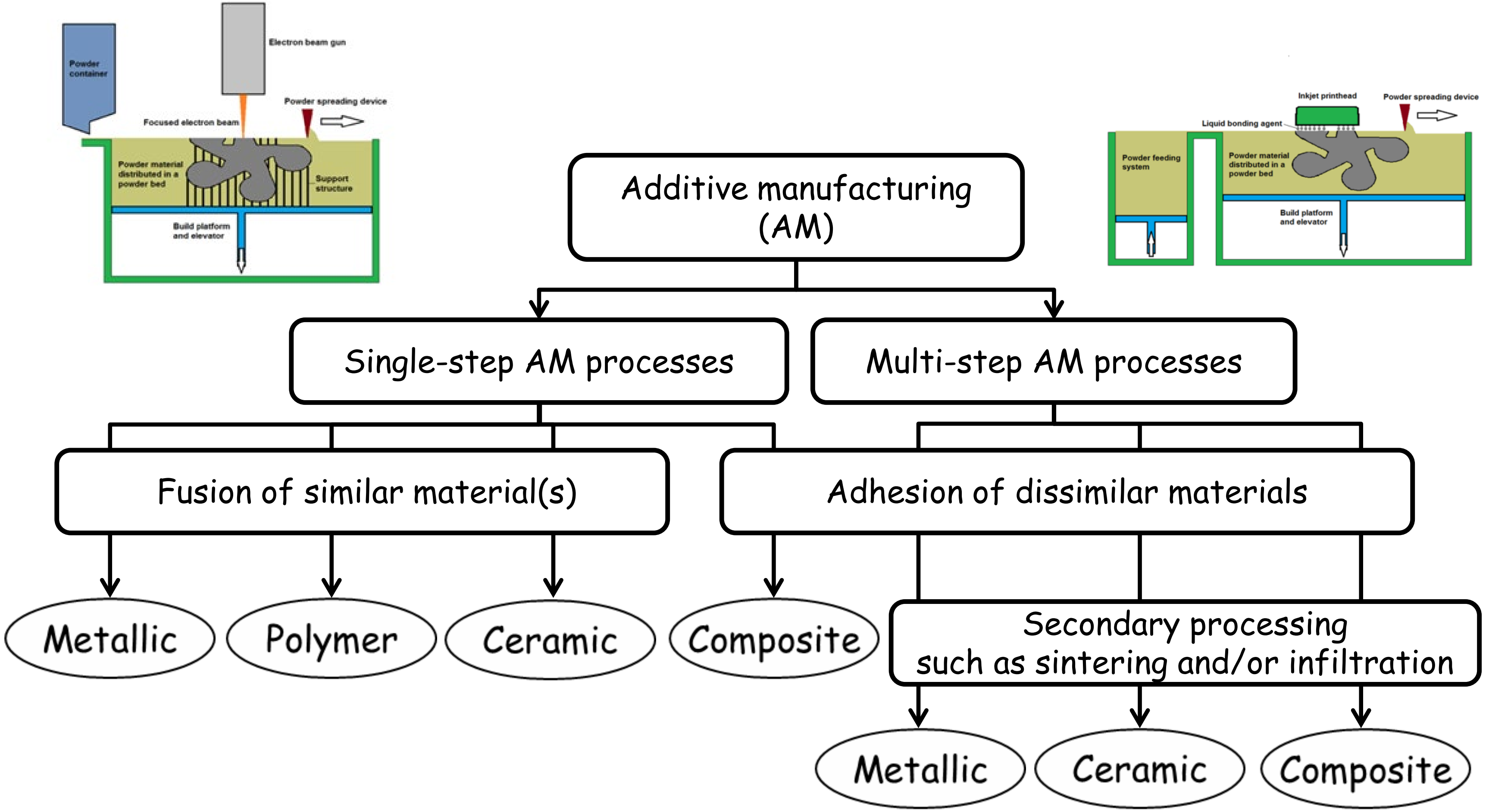
- *AM is enabled by the creation and communication of a 3D model data file*
  - *The 3D model is, in practice, a specification for the parts made by an AM process*
- *An AM process is characterized by how the material is added:*
  - *Mechanism for delivering the feedstock material*
  - *Mechanism for joining the feedstock – Subject to the laws of physics and chemistry!*

The AM-process, beginning and end

By definition: "process of joining materials to make parts from 3D model data…"

- The beginning, defined by: "….from 3D model data…."
- The end, defined by: "….to make parts…"
  - Definition of part: "joined material forming a functional element that can constitute all or a section of an intended product"
- The AM process starts by the 3D model file and ends when all the material needed to fulfil the specification of this model has been joined such that the bonding of the intended product material has been formed.
  - Metallic material: metallic bonding
  - Ceramic material: ceramic bonding (ionic, covalent, etc…)
  - Polymer material: covalent bonds with entangled and/or cross-linked polymer chains…

Single-, and multi-step AM process principles



Categorization!

- Many different processes, with common traits, but different trademarked names
- Categorization based on common process architecture
- 7 Process categories identified (so far):
  - Binder jetting (BJT)
  - Directed energy deposition (DED)
  - Material extrusion (MEX)
  - Material jetting (MJT)
  - Powder bed fusion (PBF)
  - Sheet lamination (SHL)
  - Vat photopolymerization (VPP)

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Introduction of new process categories?

Sure, they are welcome! However….

- To be new, they have to have a process architecture that is fundamentally different from the presently identified process categories
- Needs to be available on the market, with proven "staying power"
- Needs to have a developed a market: i.e. a number of providers (of equipment or services), a number of customers and/or users

STANDARDIZATION INITIATIVES

International market requires international standards:

ASTM International, Committee F42

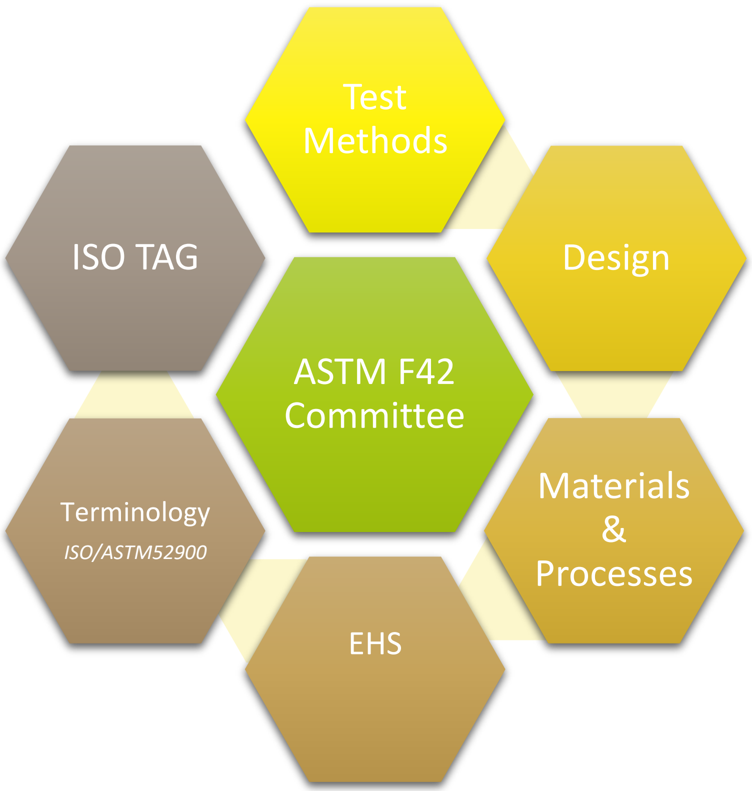
- Established 2009, -coined & defined "Additive Manufacturing"
- **Scope:** "The promotion of knowledge, stimulation of research and implementation of technology through the development of standards for additive manufacturing technologies."
- Membership is based on representation of different stake holders: companies, universities, research organisations etc.
    - 1 vote/organisation

ASTM F42 at a glance

Quick facts

Formed: 2009
Current Membership: 725+ members (150+ outside US)
Standards: 24 approved, 40+ in development

Subcommittees and Focus



Global Representation: 27 Countries

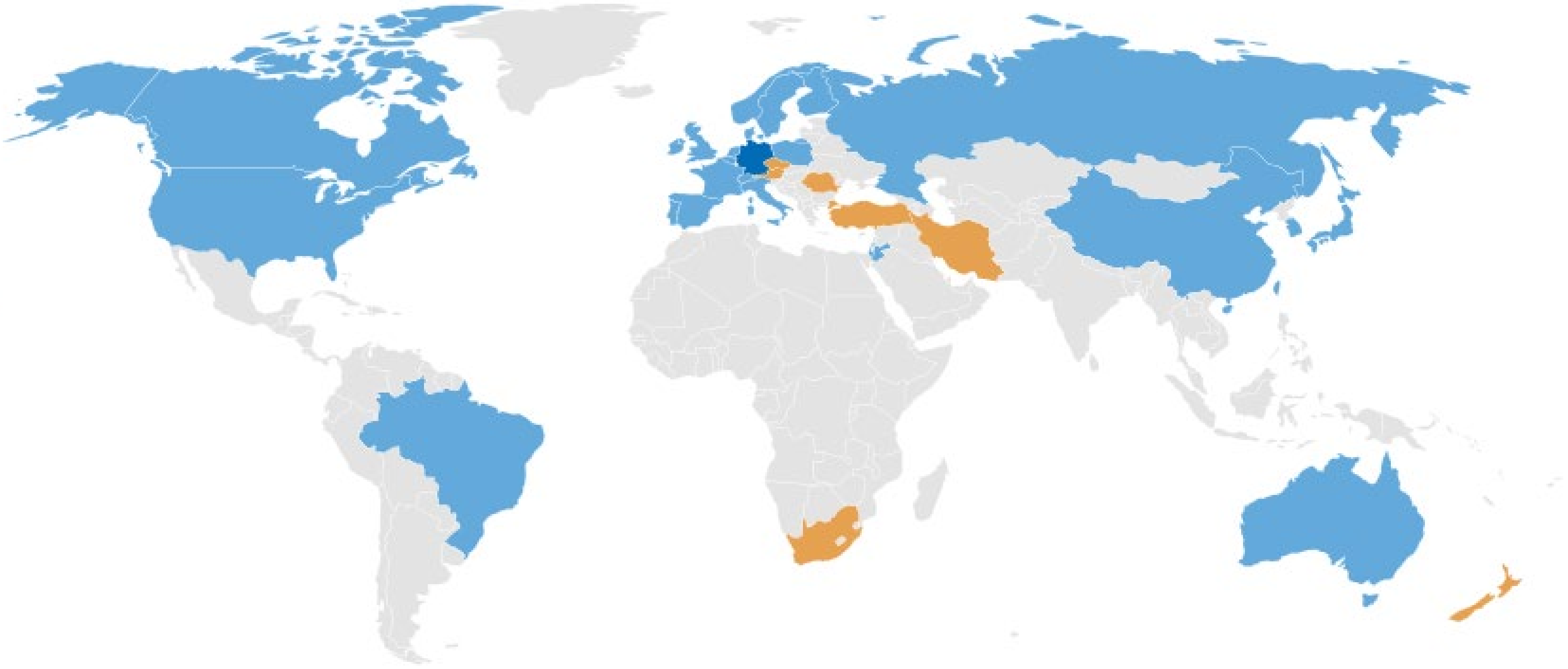
Argentina
Australia
Austria
Belgium
Canada
China
Czech Republic
France
Germany
India
Italy
Japan
Korea
Mexico
Netherlands
Nigeria
Norway
Puerto Rico
Russian Federation
Singapore
South Africa
Spain
Sweden
Switzerland
Taiwan
United Kingdom
United States

-EVEN MORE INTERNATIONAL…

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: 26 participating countries +7 observers

ISO/TC 261: International participation



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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 FDIS (Final Draft International Standard
- Formal adoption of a published ISO standard by ASTM International
- Maintenance of published standards
- Publication, copyright and commercial arrangements


James Thomas, ASTM President, and Rob Steele, ISO Secretary-General

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
- Emphasis on joint standards development

ISO

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Additive Manufacturing Standards Structure

Additive Manufacturing Standards Structure

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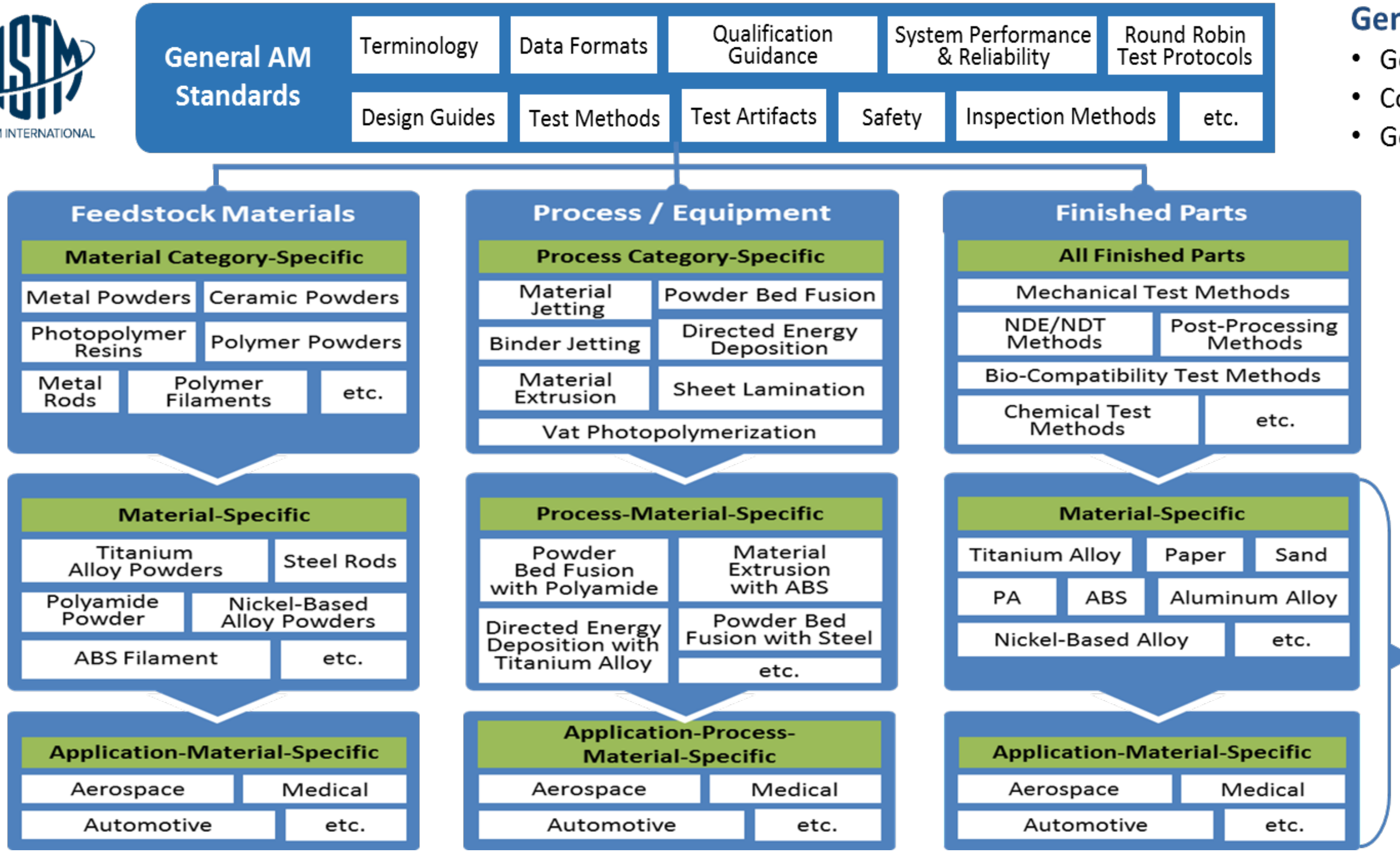

General Top-Level AM Standards

- 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

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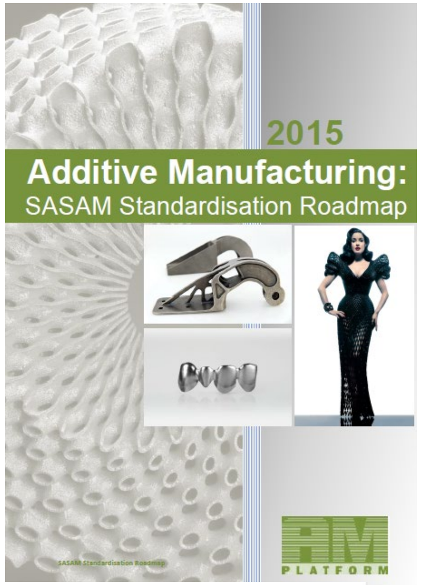
EUPOPEAN INITIATIVES

- 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*



HOW STANDARDS ARE DEVELOPED

<u>Very basic:</u>

- 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)

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ASTM F42 and ISO/TC261:

Sub-Committees

- F42.01 Test Methods
- F42.04 Design
- F42.05 Materials and Processes
  - F42.05.01 Metals
  - F42.05.02 Polymers
  - F42.05.05 Ceramics
- F42.06 Environment, Health, and Safety
- F42.07 Applications*
- F42.08 Data
- F42.91 Terminology

Workgroups

- ISO/TC 261/WG 01 "Terminology"
- ISO/TC 261/WG 02 "Processes, systems and materials"
- ISO/TC 261/WG 03 "Test methods and quality specifications"
- ISO/TC 261/WG 04 "Data and Design"
- ISO/TC 261/WG 06 "Environment, health and safety"
- JWG 10 "Joint ISO/TC 261 - ISO/TC 44/SC 14 WG; Additive manufacturing in aerospace applications
- JWG 11 "Joint ISO/TC 261 - ISO/TC 61/SC 9 WG; Additive manufacturing for plastics"
- ISO/TC 150/JWG 1: Joint ISO/TC 150 - ISO/TC 261 WG: Additive manufacturing in surgical implant applications

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"New subcommittee": F42.07 Applications

"Bridging the gap between AM standards and existing product specifications"

- 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

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

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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 –Non-destructive 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
- In ISO, for example
  - ISO/IEC JTC1/WG12 3D Printing and scanning
  - ISO/TC184/SC1 Physical device control
  - ISO/TC184/SC4 Industrial data

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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

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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

Concluding remarks

International standards development

- Development of AM standards is a key element in establishing AM as a part of the industrial manufacturing system and provide an intellectual infrastructure to the market.
- 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

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Even if we have not seen the tip of the iceberg yet,

-but we have surely entered a new universe in manufacturing!

Thank you for the attention!

Any Questions?

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