America Makes and ASMC Design for Additive Manufacturing Workshop

DFAM in ASTM F42 and ISO/TC 261

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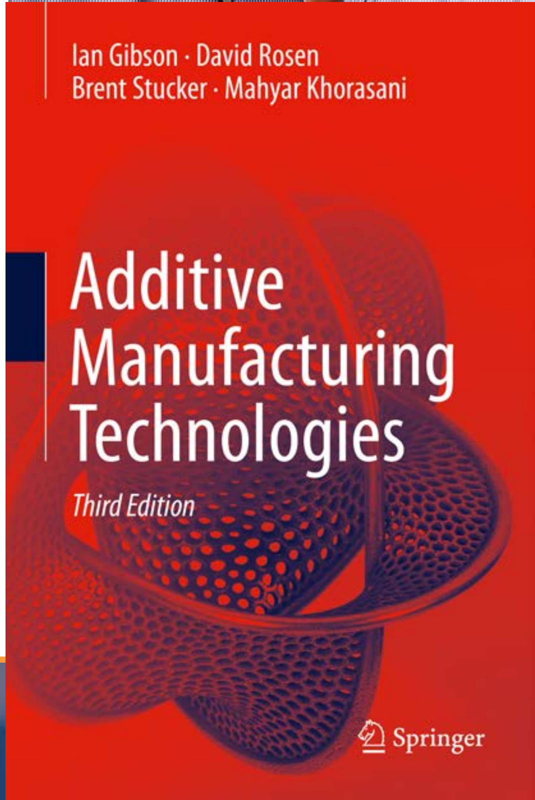
2 year leave-of-absence in Singapore:
Research Director, Digital Manufacturing and Design (DManD) Centre
Singapore University of Technology and Design

25 years of AM experience



Overview

- Design activities: F42.04 Design Subcommittee
- AMF - file format
- Design for AM
- General design requirements and guidelines ISO/ASTM 52910
- Process-specific design guides (e.g., PBF for both metals and polymers, DED, binder jetting, material extrusion)
- ASTM Center of Excellence
- Design for post-processing
- Process simulation

Design for AM

ASTM F42.04 Design

Mirror: ISO TC261, WG4
Chair: Eujin Pei, Brunel Univ.

- Data/information exchange
  - AMF – additive manufacturing format. ISO/ASTM 52915
  - Solid modeling technology representations. JG64
  - Digital product definition and data management. JG73 (Paul W.)

- Design guidelines and decision support
  - ISO/ASTM 52910 Standard Guidelines for Design for AM
  - Process-specific design guides
  - Design decision guide
  - Design for post-processing guide

Design Guides & Decision Guide

General Guides

Standard Guide for Design for AM
ISO/ASTM 52910 Standard Guidelines for Design for AM (general context)

- **Standard Guide for Principles of Design Rules for AM** WK54586
  (common language and terms for design rules. used in process-specific guides)
- **Report on Design of Functionally Graded Materials** ISO/ASTM 52912 (TR)
- **Standard Guide for Design Decision Support** JG54, ISO/ASTM 52923

Process-Specific Design Guides

- **Guide for Design for Powder Bed Fusion, Polymers**
  ISO/ASTM 52911-2
- **Guide for Design for Powder Bed Fusion, Laser-based Metals**
  ISO/ASTM 52911-1
- **Guide for Design for Powder Bed Fusion, Electron-beam-based Metals.** JG57 ISO/ASTM 52911-3
- **Guide for Design for Directed Energy Deposition**
  ASTM F3413, ISO/ASTM 52922
- **Guide for Design for Material Extrusion**
  To be balloted in 2021. JG55
- **Guide for Design for Post-Processing**
  Balloted late 2020.
- **Guide for Design for Binder Jetting**
  Began in 2020.

Application-Specific Design Guides

Application-specific design guides not defined yet
Medical devices?

Design for Additive Manufacturing

Aid designers in leveraging the unique capabilities of AM

Opportunistic Design

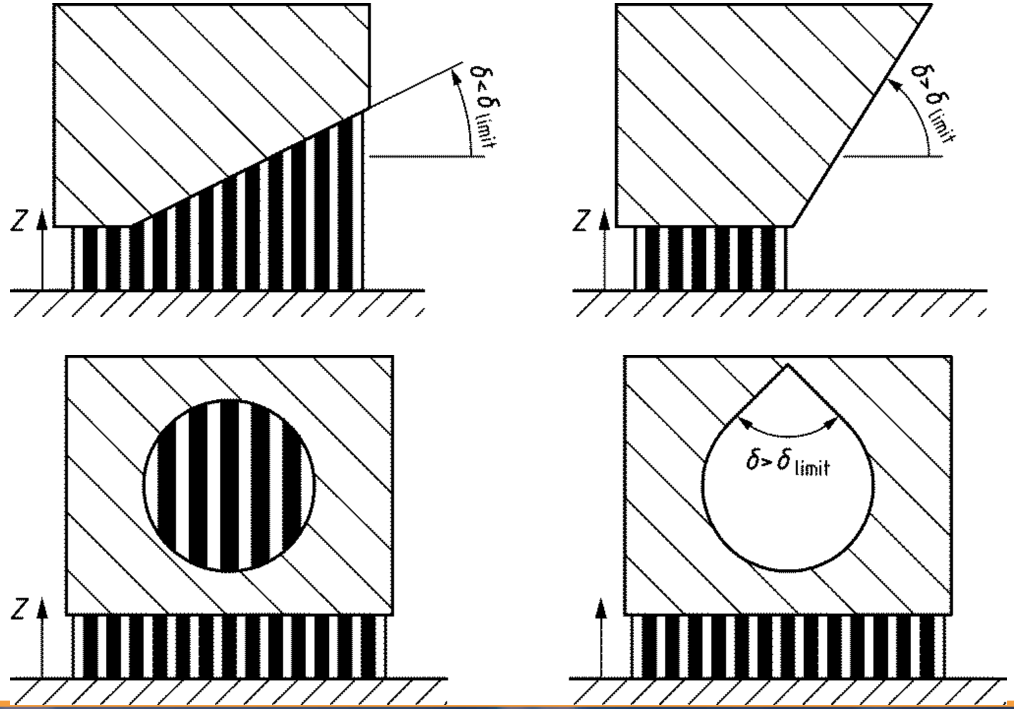
Maximize product performance through the synthesis of shapes, sizes, hierarchical structures, and material compositions.

Achieve multi-functional parts by consolidating many parts into one.

Custom/personalized parts

Restrictive Design (DFM)

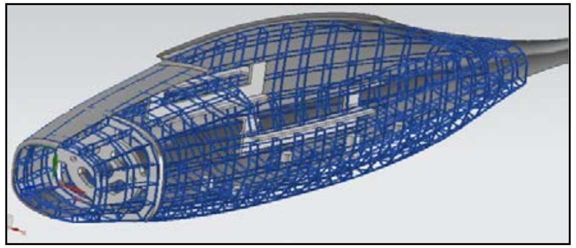
Understand manufacturing process constraints and figure out how to design around them.

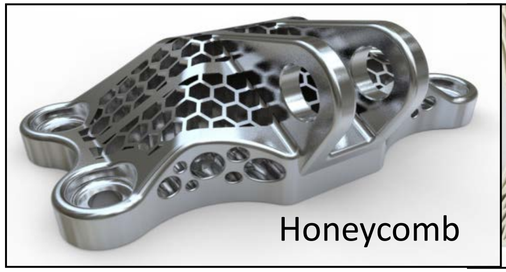


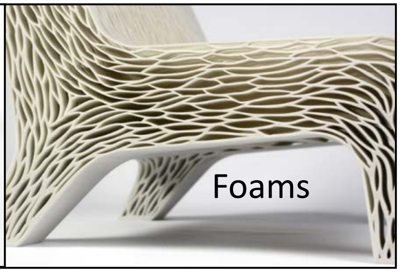
Design Innovation Methods

Complex Geometry

Lattices



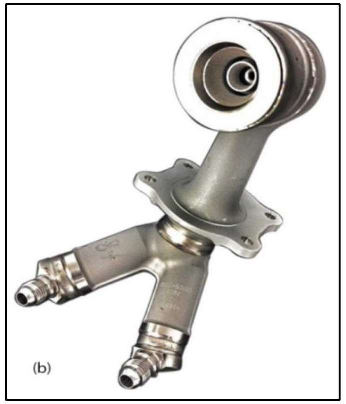


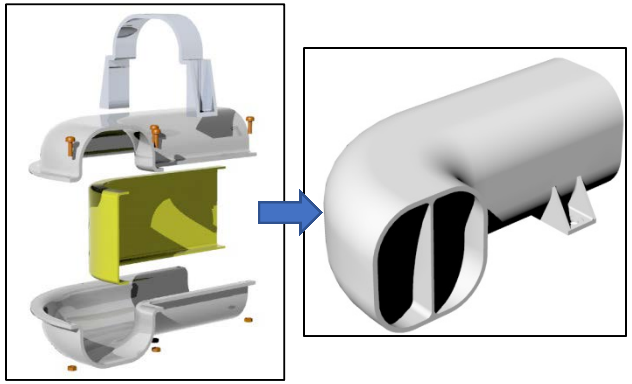


Topology Optimization

Customization

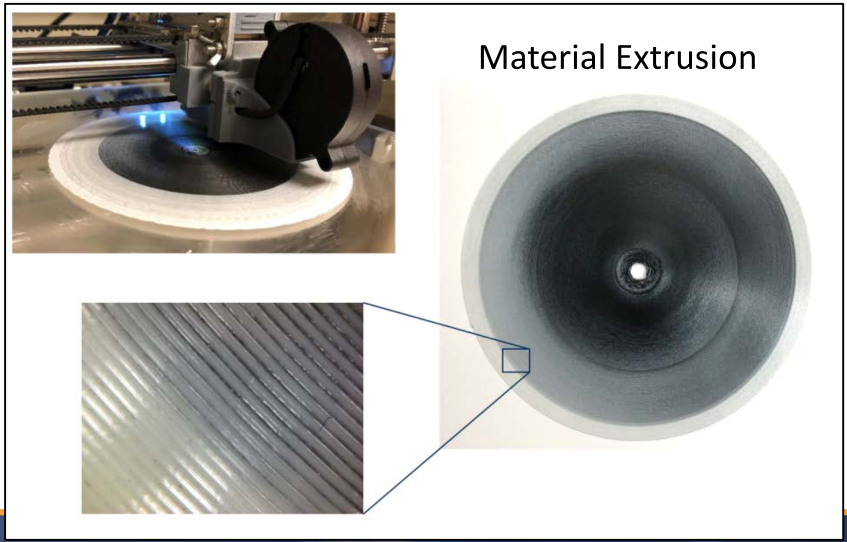
Part Consolidation





Multiple & Functionally Graded Materials

Material Jetting

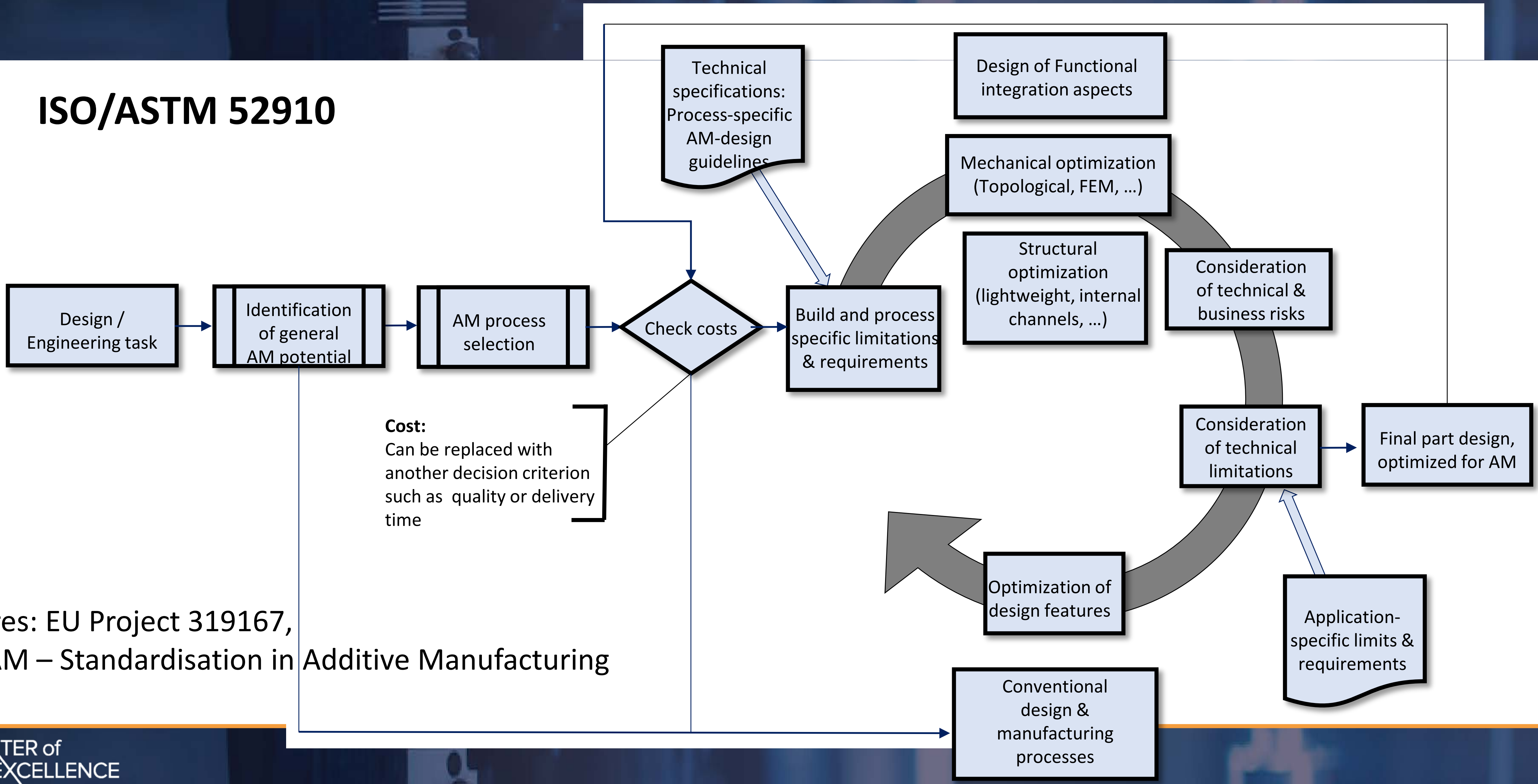


ISO/ASTM 52910 Standard Guidelines for Design for Additive Manufacturing

- Design Strategies and Processes
- Design Opportunities and Limitations
  - Many operations, can fine-tune each one
  - Geometric complexity: custom, lattice, honeycombs, foams, etc.
  - Material complexity
  - Optimization: topology, shape
- Limitations: anisotropy, discretization, post-processing issues, etc.
- Design Considerations
  - Product considerations: design effectiveness, part consolidation, multi-part mechanisms, etc.
  - Product use considerations: thermal, chemical, radiation environments
  - Sustainability considerations: reduce, reuse, recycle
  - Business considerations: costs, materials, number of parts, machine usage, post-processing, etc.
  - Geometry considerations: file formats, discretization, feature sizes, accuracy, surface finish, etc.
  - Material property considerations: mechanical, thermal, electrical properties, etc.
  - Process considerations: specific processes (7 classes…), post-processing, qualification, inspection
  - Communication considerations: design intent, process limitations
- Warnings to Designers: overhangs, abrupt thickness transitions, trapped volumes, layering

Design Process in Design Guide

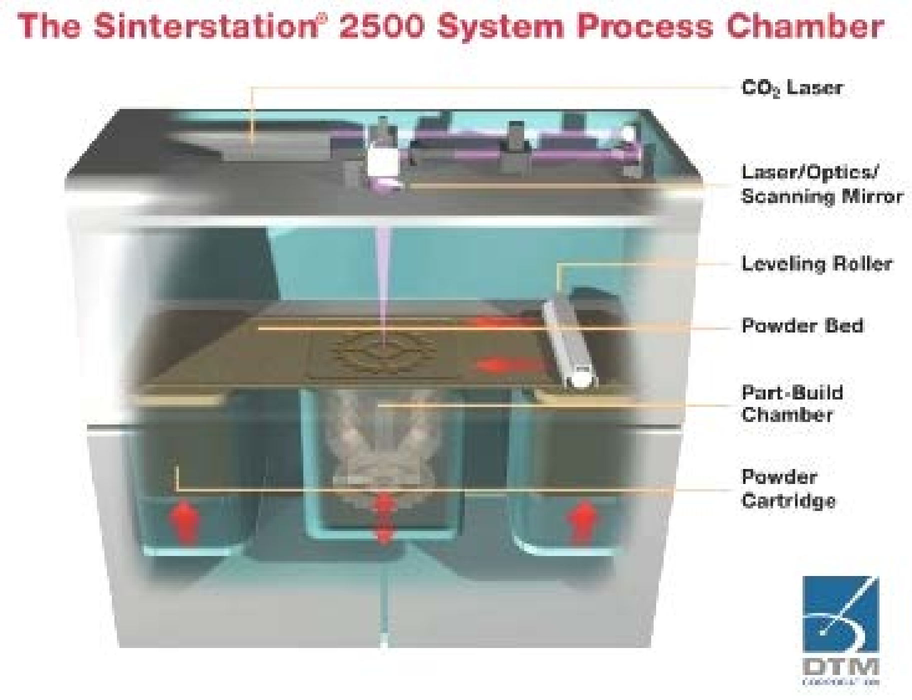
ISO/ASTM 52910



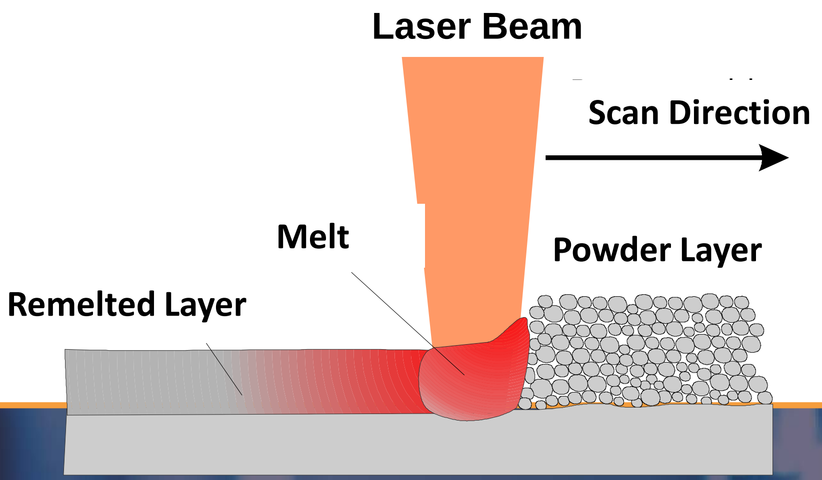
Figures: EU Project 319167,
SASAM – Standardisation in Additive Manufacturing

Design Guide: Powder Bed Fusion

- ISO/ASTM 52911-1 AM – Technical design guideline for powder bed fusion, Part 1: Laser-based, metals
- ISO/ASTM 52911-2 AM – Technical design guideline for powder bed fusion, Part 2: Laser-based, polymer
- 52911-3 AM – Technical design guideline for powder bed fusion, Part 3: Electron-beam-based metals

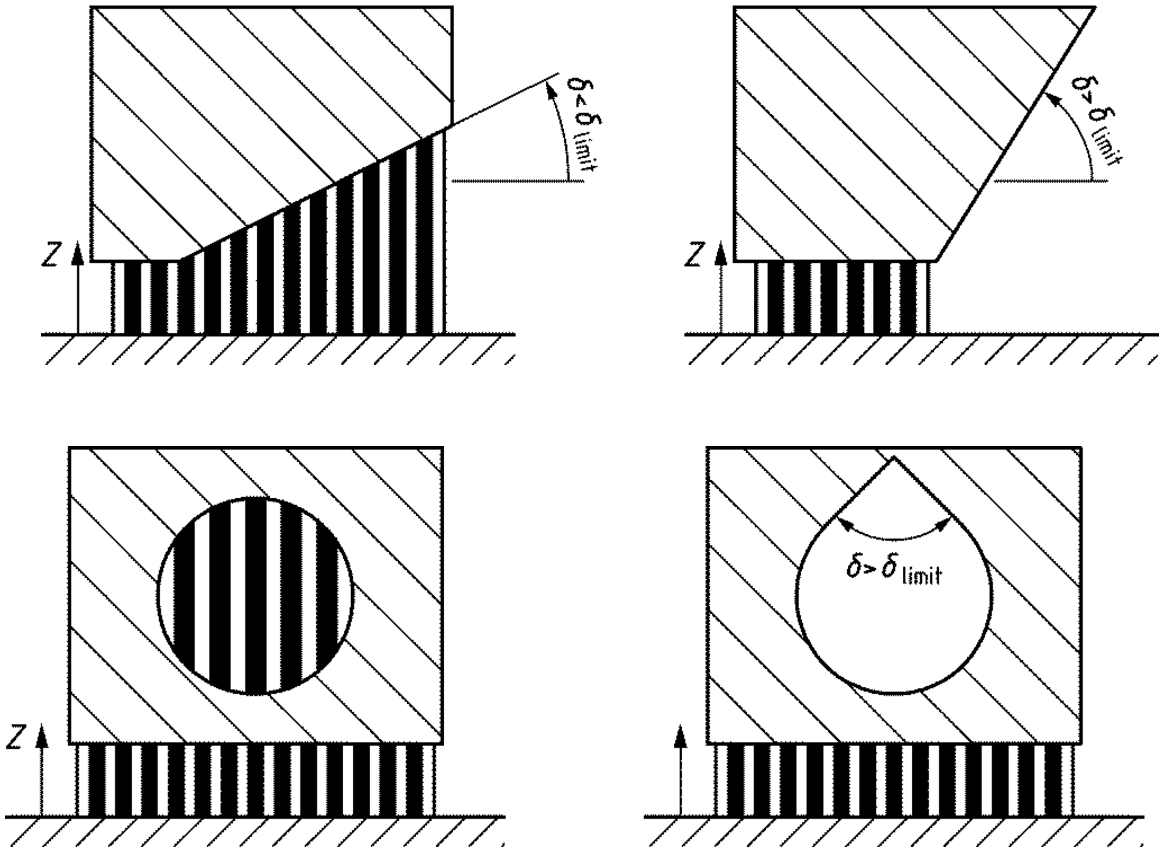


F3303-18 Metal PBF Process
F3091/F3091M-14 PBF of Plastic Materials



Guidance on Support Structures

ISO/ASTM 52911 Design guide for powder bed fusion – metals



Source: VDI 3405 Part 3:2015

Left: Faces with downskin angle $\delta < \delta_{limit}$ require support structures. Often, δ_{limit} is between 30° and 45°. δ_{limit} is dependent on the material used, the process strategy applied, and also the part characteristic (thickness, shape, etc.) above the regarded face.

Right: Faces with downskin angle $\delta > \delta_{limit}$ do not require support structures. The surface quality may be adversely affected, depending on the angle.

Left: Hole with internal support structure

Right: Shape of hole modified to avoid use of support structures as per Reference [7].

Comment: For many internal channels, this shape is difficult to machine. Hence, it might be better to reduce diameter of hole (often no need for support below diameter of 8 mm) in order to be built without support and drill after or even do not include a hole and fully drill instead (e.g. titanium).

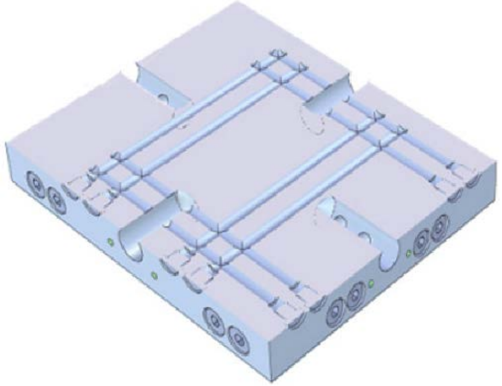
Examples

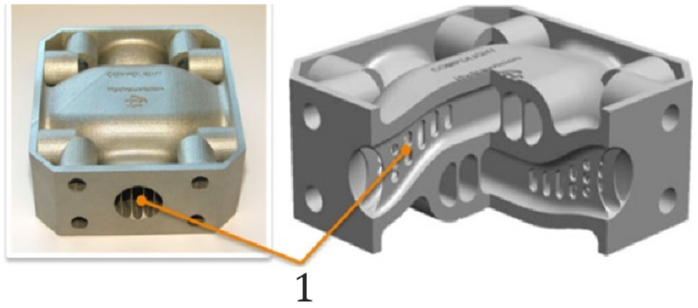
Component of rotating machine to produce cables – CETIM

Reference design topology optimized

Design fine-tuned to avoid support structures, struts > 45 degrees

Hydraulic manifold – TNO





reference design

fluid flow and lightweight optimized design

Weight: 20kg to 1kg

Significantly reduced pressure loss

Support structures remain to improve structural integrity

Screw threads not built using AM

ASTM AM Center of Excellence (CoE)

Mission and Vision

About the CoE

The AM CoE brings together industry, government, and academia to coordinate R&D that supports AM standards development, to support related education and training, and more.

By tightly linking these efforts, standards and other tools can quickly get into the hands of those who need them, reducing time-to-market and increasing widespread adoption.

ASTM CENTER of EXCELLENCE Research to Standards

Mission

The Center bridges standards development with R&D to better enable efficient development of standards, education and training, certification and proficiency testing programs.

Vision

The Center facilitates collaboration and coordination among government, academia, and industry to advance AM standardization and expand ASTM International's and our partners' capabilities.

AM CoE R&D: High Priority Areas

AM CoE R&D Themes

CoE R&D Areas

Topics are crosslinked to create synergy!

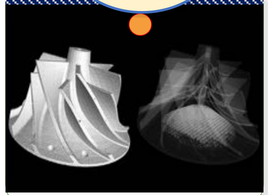
F42.07 Applications

- Design, Data, and Modeling


- AM Feedstock

- AM processes/ Post Process

- AM Testing

- Qualification (NDT, etc.)


- F42.01 Test Methods
- F42.04 Design
- F42.05 Materials and Processes
- F42.06 Environment, Health, and Safety
- F42.07 Applications
- F42.xx Future subs

- Defined based on the input of the CoE R&D team
- Project type
  - Short-term
  - Highly-focused
  - High-priority (linked to AMSC roadmap and Committee F42)
- Aligned with America Makes projects (America Makes)
- Coordination/collaboration with NIST (NIST)

Guide to Post-Processing for Designers

The why / Impact on AM Standardization

- **Why:** Good AM design requires consideration of the entire AM manufacturing process chain, including post-processing operations. In spite of the rapidly growing interest from the industry in laser powder-bed fusion for metals, currently, there is a lack of guidance of how and why post-processing is carried leading to inefficient designs, expensive post-processing, high non-conformity and scrap rates.

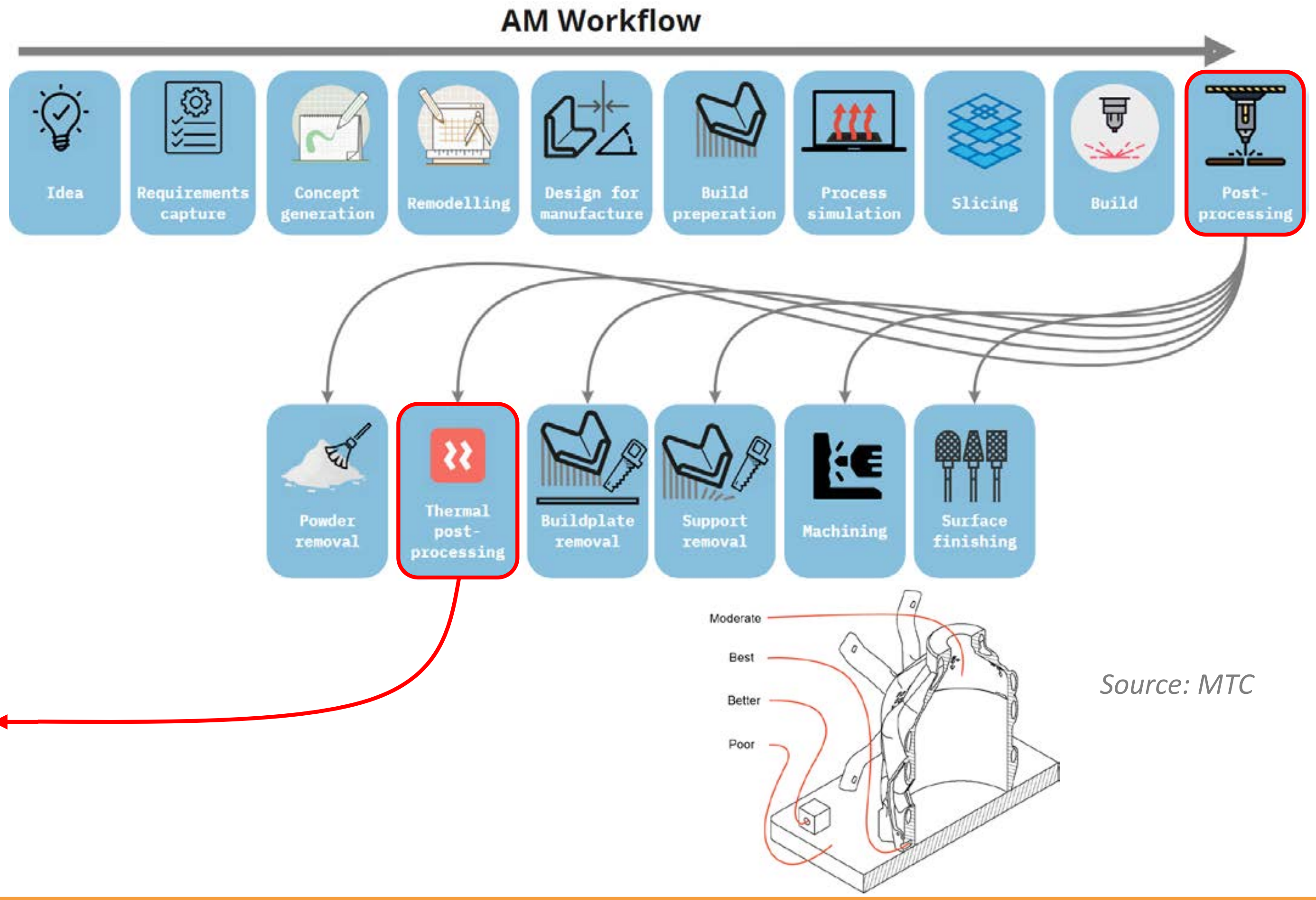
- **Gap** in the standardisation AMSC roadmap being addressed: Gap D7: Design Guide for Post-processing

- **Solution:** The proposed solution is a guide that addresses the chain of post-processing operations for metal L-PBF and present design considerations, for each type of post-processing operation.
  Topics included:
  - An explanation of the most common post-processing steps used in metal L-PBF method and why they are used
  - Challenges in carrying out each post-processing operation
  - Addressing challenges by design

A Guide to Post-Processing for Designers

Technical Update (topical example)

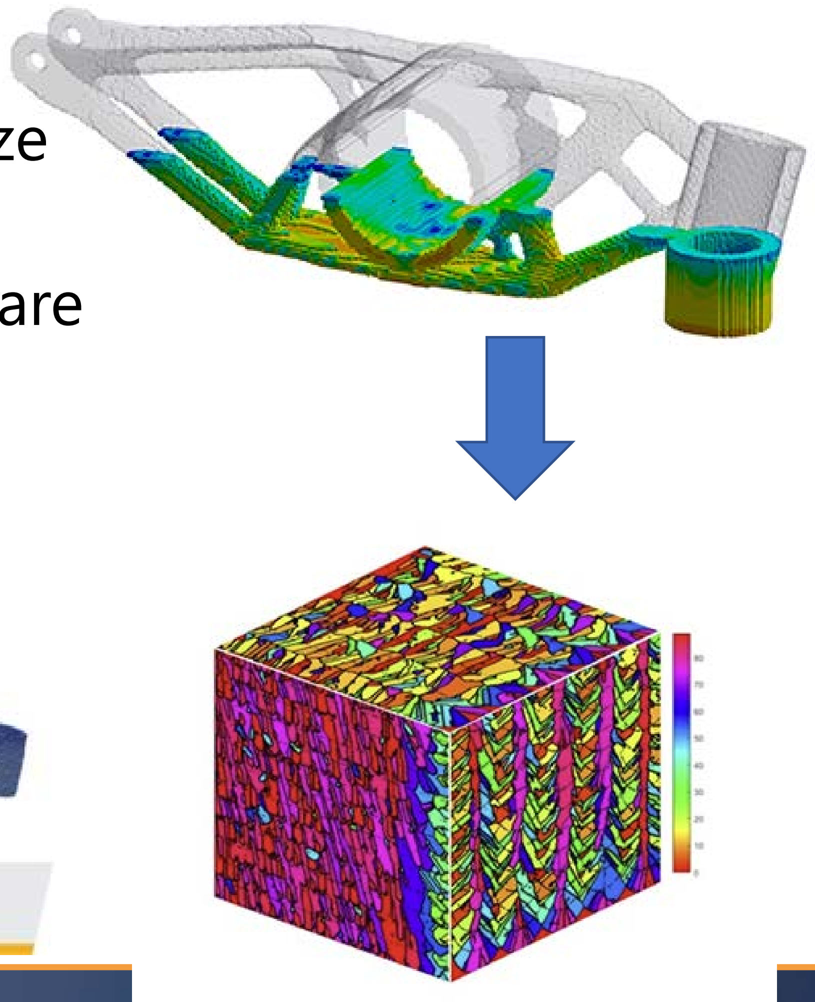
Design consideration	Description
Stock material	Parts could distort with thermal post-processing and may go out of the required tolerance. Stock material can be added to the areas prone to distortion and can be then machined to the required accuracy. Suitable simulation approaches may be utilised to predict the amount of distortion.
Material properties	Thermal post-processing could affect the mechanical properties of materials and therefore should be accounted for during the design stage. The composition will affect how the material responds to the whole AM process, phase diagram and cooling curves for each material should be consulted for indication of material properties expected from thermal post-processing.
Thin-walled parts	Thin-walled parts may distort during thermal post-processing and will need careful consideration. Distortion may be avoided by thickening sections and adding ribbing for instance. Suitable simulation approaches may be utilised to predict the amount of distortion.
Temperature monitoring	Thermal treatment providers will use thermocouples to monitor the temperature profiles of the components going through a cycle. Best position for a thermocouple placement on a component should be considered, this may include adding features in the design to accommodate a thermocouple or a sacrificial anchoring location alongside the build. Figure 5 shows possible thermocouple placement locations with their expected outcome.
Trapped powder	Leftover entrapped metal powder in components might become an issue during thermal processing, as it can consolidate in undesirable places. This could happen in features such as internal channels, or cavities during a HIP cycle. Features should be added to the design to allow ease in powder removal.
Supports	To minimise part distortion during thermal post-processing, factors such as part orientation and how the part will be supported in the furnace must be considered.
Build Plate	The build plate offers support to the part, preventing distortion and allowing easier handling, therefore it should remain attached until after heat treatment. If components on a build plate require different heat treatments the build plan should be designed to allow the build plate to be carefully sectioned leaving the parts attached.



Source: MTC

AM Process Simulation

- ANSYS: Additive Suite: Print, Science, …
- Metal PBF and DED: residual stress, deformations; optimize build orientation, optimize support structure
- Opportunities for standards: validation of software, software usage guide, process qualification, part qualification, analysis for topology optimization usage guide, etc.



- Proposed workflow:

Q&A

AM Design Standards & Work Items

- Standards
  - ISO/ASTM 52915-16 Standard Specification for Additive Manufacturing File Format (AMF) Version 1.2
  - ISO/ASTM 52910 Standard Guidelines for Design for Additive Manufacturing
  - ISO/ASTM 52911 – Technical design guideline for powder bed fusion, Part 1: Laser-based, metals
  - ISO/ASTM 52911 – Technical design guideline for powder bed fusion, Part 2: Laser-based, polymer
  - ISO/ASTM 52912 (TR) – Design for Functionally Graded Materials
  - ASTM F3413 (ISO 52922) Design guideline for Directed Energy Distribution processes
- Work items
  - Design guideline for Material Extrusion processes (JG55)
  - Design guideline for powder bed fusion, Part 3: Electron-beam based, metals (JG57)
  - Design decision support guide (JG54)
  - Guide for Principles of Design Rules in AM
  - AMF Support for Solid Modeling (JG 64)
  - Digital Product Definition & Data Management (JG73)
  - Design for post-processing

Additive Manufacturing Standardization Collaborative (AMSC)

- 20 gaps/recommendations have been identified as high priority,
- 50 as medium priority,
- 24 as low priority.
- 65 require research
- ASTM is already positioned to address 82 gaps in conjunction with ISO.

America Makes
National Additive Manufacturing Innovation Institute

ANSI
American National Standards Institute

- Design
- Process and Materials
  - Precursor Materials
  - Process Control
  - Post-Processing
  - Finished Material Properties
- Qualification & Certification
- Non Destructive Evaluation
- Maintenance

AMSC Design Gaps

Gap	Title	R&D?	Priority	AMSC Status	F42.04 Status
D1	Decision Support: Add vs. Sub	TBD	Medium	ISO/ASTM, AWS, SAE, SME	JG54: WK64190
D2	Decision Support: Additive Processes	Yes	Medium	ISO/ASTM; Govt labs for R&D	JG54: WK64190
D3	Process-Specific Design Guides	No	Medium	ISO/ASTM	JG57, WK62876, WK62946
D4	Application-Specific Design Guides	TBD	High	ISO/ASTM, ASMEW, SAE,…	No applications specified. Medical?
D5	Support for Customizable Guidelines	Yes	Medium	ISO/ASTM	Operational guidance for specific parts?
D6	Software-encodable/Machine readable guidelines	Yes	Medium	ISO/ASTM, ASME, IEEE-ISTO	WK54856 is start
D7	Design guide for post-processing	Yes	Medium	ASME B46, ISO/ASTM	ASTM COE project
D8	Machine Input & Capability Report	No	Medium	Industry consortium, ISO/ASTM	JG73 is start; Good idea, but detailed info?
D11	Design for 3D Printed Electronics	No	Medium	IPC 2292	Closed: IPC
D12	Imaging Consistency	No	Medium	RSNA, ISO/ASTM, JG70	JG70 (medical imaging)
D13	Image Processing, 2D-3D Conversion	Yes	Medium	NEMA/MITA, ASME, F4, F42/TC261	??
D14	Designing to be Cleaned (medical, lattice structures)	Yes	Medium	AAMI, F4, F42/TC261, TC198, ASME, FDA	Good idea
D17	Contents of a TDP	Yes	High	ASME Y14.47, F2, AFRL, NIST	JG73
D18	New Dimension&Tolerance Reqs	No	High	ASME Y14.46, Y14.48, NIST	leave for ASME
D19	Organization Schema Reqs & Configuration Control	No	High	ASME Y14.47, TC10, ISO/ASTM	JG73??
D21	New Terminology in Design Docs	No	Medium	ASME, ISO/ASTM	52900 incomplete?
D22	In-Process Monitoring	Yes	Medium	ISO/ASTM, IEEE ISTO	Validate predictive models
D24	Acquisition Specification	No	Medium	ISO/ASTM	Closed: PAMP
D26	Design for Measurement/Verify Feature Designs (lattices)	Yes	Medium	ISO/ASTM, E07.01, E07.02, ASME	Good idea
D27	Standardized Design for AM Process Chain	Yes	Medium	ISO/ASTM, JG73, NIST	JG73++
D28	Specification of Surface Finish	Yes	Medium	ASME	Leave for ASME?

AMSC Design Gaps

Gap	Title	R&D?	Priority	F42.04 Status
D1	Decision Support: Add vs. Sub	TBD	Medium	JG54: WK64190
D2	Decision Support: Additive Processes	Yes	Medium	JG54: WK64190
D3	Process-Specific Design Guides	No	Medium	JG57, WK62876, WK62946
D4	Application-Specific Design Guides	TBD	High	No applications specified. Medical?
D5	Support for Customizable Guidelines	Yes	Medium	Operational guidance for specific parts?
D6	Software-encodable/Machine readable guidelines	Yes	Medium	WK54856 is start
D7	Design guide for post-processing	Yes	Medium	ASTM COE Project
D17	Contents of a TDP	Yes	High	JG73
D18	New Dimension&Tolerance Reqs	No	High	leave for ASME
D19	Organization Schema Reqs & Configuration Control	No	High	JG73??