



# ADDITIVE REPAIR COMMITTEE

## EASA-FAA AM Event WG's 1 and 3

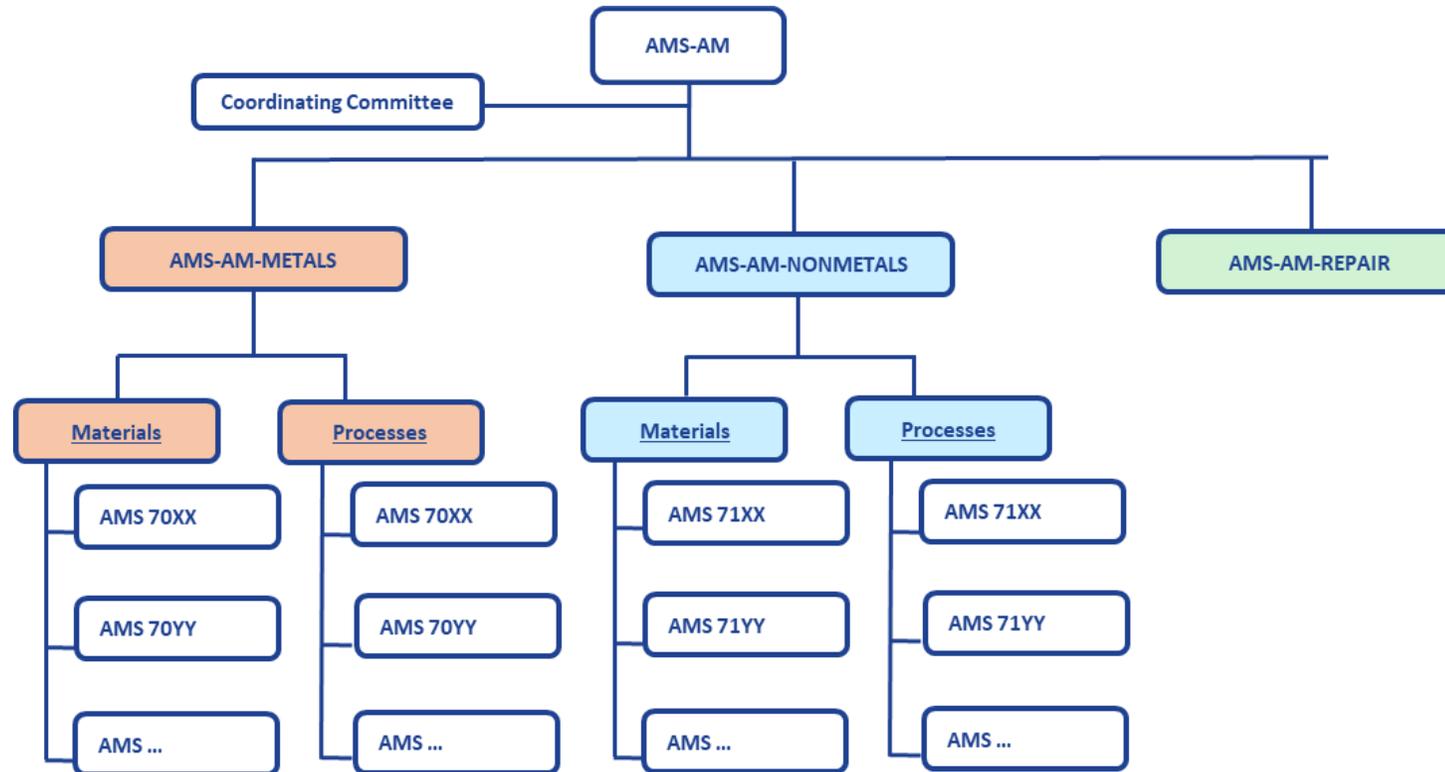
November 8-12, 2021

David Abbott  
GE Aviation  
SAE AMS-AM Repair Subcommittee Chair



# SAE AMS-AM Repair Working Group

- Scope:
  - To develop and maintain aerospace material and process specifications for additive manufacturing repair...



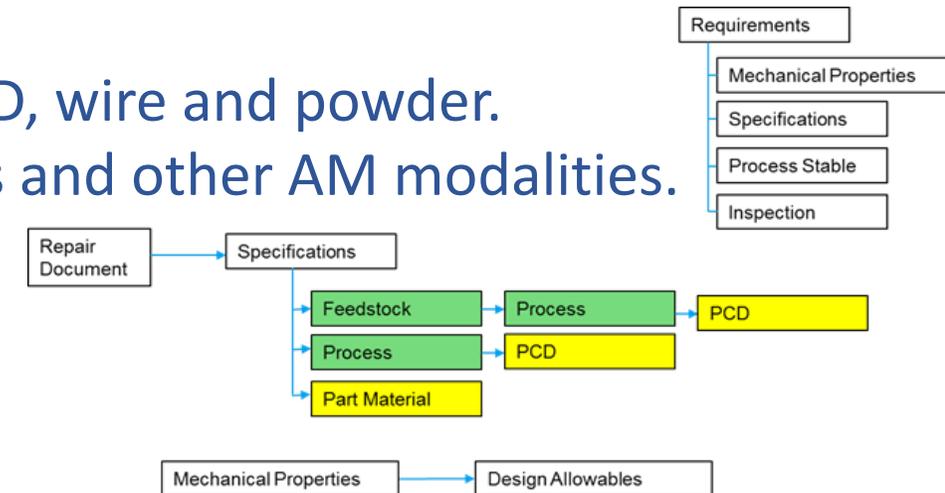
# Overview

- Started meeting regularly Fall 2019.
- Currently have ~70 members.
- Developing overall approach:
  - Single document:
    - Section 1: Additive repair considerations and development.
    - Section 2: Additive repair process guidance.
    - Appendix: Example repair scenarios.
- Monthly Rhythm: First Wednesday every month except Spring and Fall FTF mtg months.
- Next telecom: Wednesday December, 2021 11:30-12:30 PM ET US.



# Repair Subcommittee

- Status
  - Currently establishing the specification framework for repair applications
    - Creating repair scenario. Developing into guidance document.
    - Currently including three types of repair scenarios (repair of conventional part, repair of an additive part, the additive part is 'consumed' by the repair, e.g., incorporated into an assembly)
    - Repair Scenario:
      - Ti-64, DED. Considering PA and Laser DED, wire and powder.
      - Easily extendable to other DED processes and other AM modalities.
      - Conventional part / additive repair
- Looking for members and collaboration.



# Repair WIP

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- Was working one document, which evolved into two documents.
- Combined into one with example repair scenario as an appendix for guidance doc.

Additive Repair  
Development  
Document

Additive Repair  
Guidance  
Document

Additive Repair  
Example

\*\*\*ATTENTION\*\*\*

## Part Criticality.

- Effect of repair on performance characteristics of part.
- Effect on **qualification** requirements.

# Repair Guidance Document - Outline

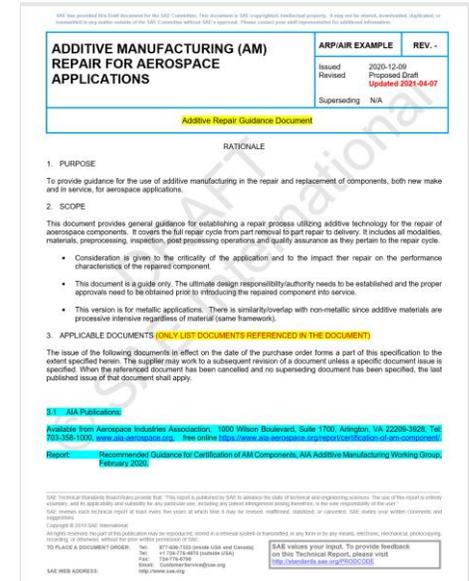
• Currently 8 sections:

- 1) Purpose
- 2) Scope
- 3) Applicable Documents
- 4) Repair Considerations
- 5) Repair Development and Qualification
- 6) Repair Process
- 7) Appendix 1 – Example Repair Scenarios
- 8) Appendix 2 – Useful References

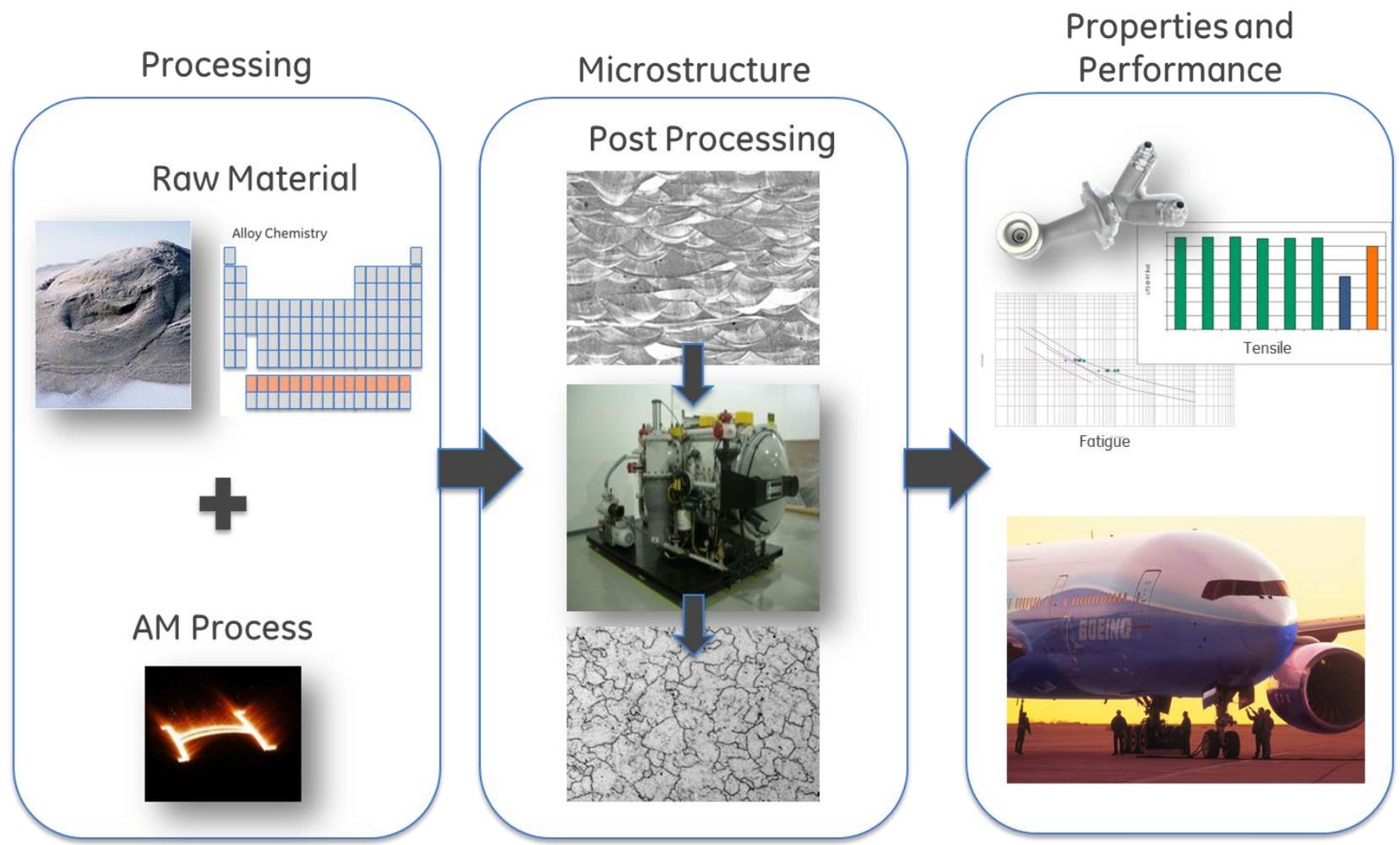
Section	Topic
1	Purpose
2	Scope
3	Applicable Documents
3.1	AIA
3.2	ASTM
3.3	ISO
3.4	SAE
4	Repair Considerations
4.1	Repair versus Replacement
4.2	Part Criticality
4.3	Part Performance
4.4	Part Functionality
4.5	Qualification and Certification
4.6	Types of Repair
4.7	Part Size and complexity
4.8	Material type
4.8.1	Component alloy
4.8.2	Feedstock Material
4.9	Design Requirements
4.10	Repair supplier
4.11	Post processing

Section	Topic
5.0	REPAIR DEVELOPMENT AND QUALIFICATION
5.1	Design Evaluation
5.2	Modality Selection
5.3	Material Selection
5.4	Repair Process Design/Planning
5.4.1	Part Preparation
5.4.2	Initial NDI
5.4.2.1	Part/Repair Alignment to the Digital Model
5.4.2.2	
5.4.3	Toolpath Generation
5.4.4	AM-Process Development
5.4.5	Repair Process
5.4.5.1	Repair Trials - Basic
5.4.5.2	Evaluation
5.4.5.3	Heat Treat Trials
5.4.5.4	Evaluation
5.4.5.5	Repair Trials - Representative Geometry
5.4.5.6	Evaluation
5.4.5.7	Machining Trials
5.4.5.8	NDI
5.5	Qualification - Parameters/Schedule
5.5.1	Microstructure
5.5.2	Chemistry
5.5.3	Mechanical Properties
5.6	Repair Document
5.6.1	Creation
5.6.2	Approval

Section	Topic
6	Repair Process
6.1	Part Removal
6.2	Part Cleaning/Prep for NDI
6.3	NDI
6.4	Machine Program/Deposition Program
6.5	Machine Prep
6.6	Verification
6.7	Deposit
6.8	Heat Treat
6.9	Machine
6.10	NDI
6.11	Surface enhancement/coating
6.12	Lot acceptance testing (chem, mech test)
6.13	Final inspection (visual, dimensional, functional)
6.14	Deliver
7	APPENDIX 1- EXAMPLE REPAIR SCENARIOS
7.1	Example Repair 1 - L-DED Wire Ti-64 Structural Component - Wrought
7.2	Example Repair 2 - LPBF Blade Tip (proposed)
7.3	Example Repair 3 - Blisk repair
7.4	Example Repair 4 - Sliver repair
7.5	Example Repair 5 -
7.6	Example Repair 6 -
8	APPENDIX 2 - USEFUL REFERENCES

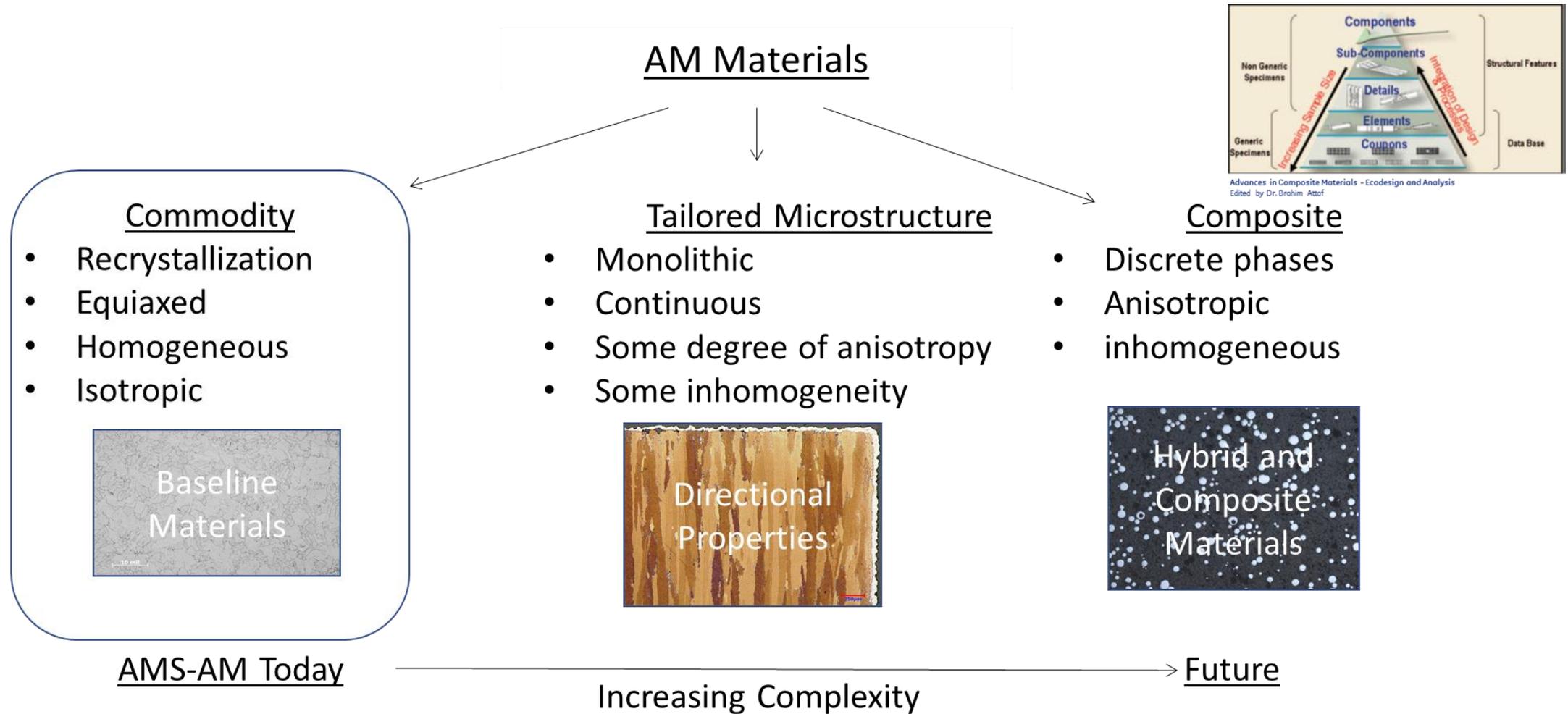


# Additive Manufacturing Process Basics – Also Applies to Repair



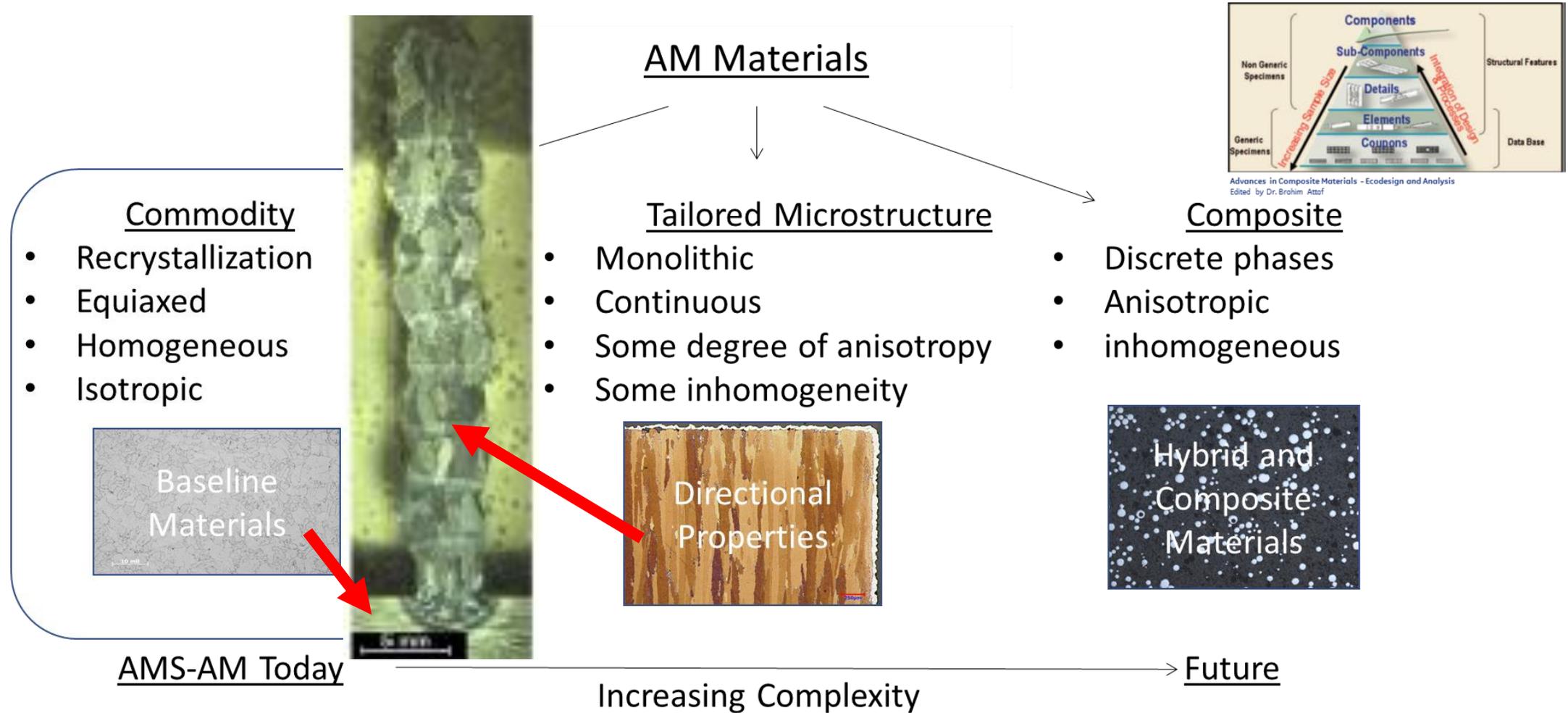
**Control = Quality + Consistency**

# Spectrum of Materials and Material Systems...



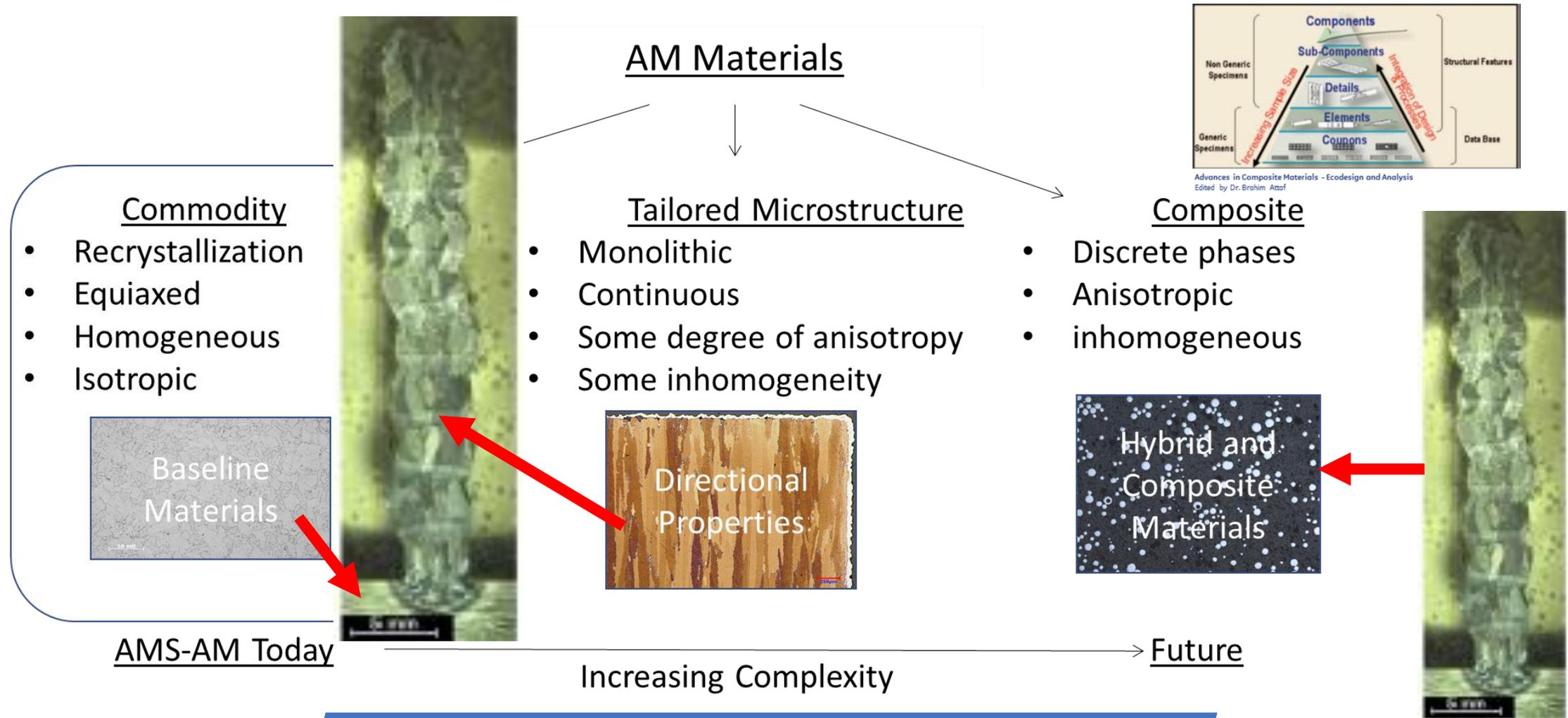
Keeping an Eye on the Future.

# Similar Spectrum for Additive Materials and Material Systems...



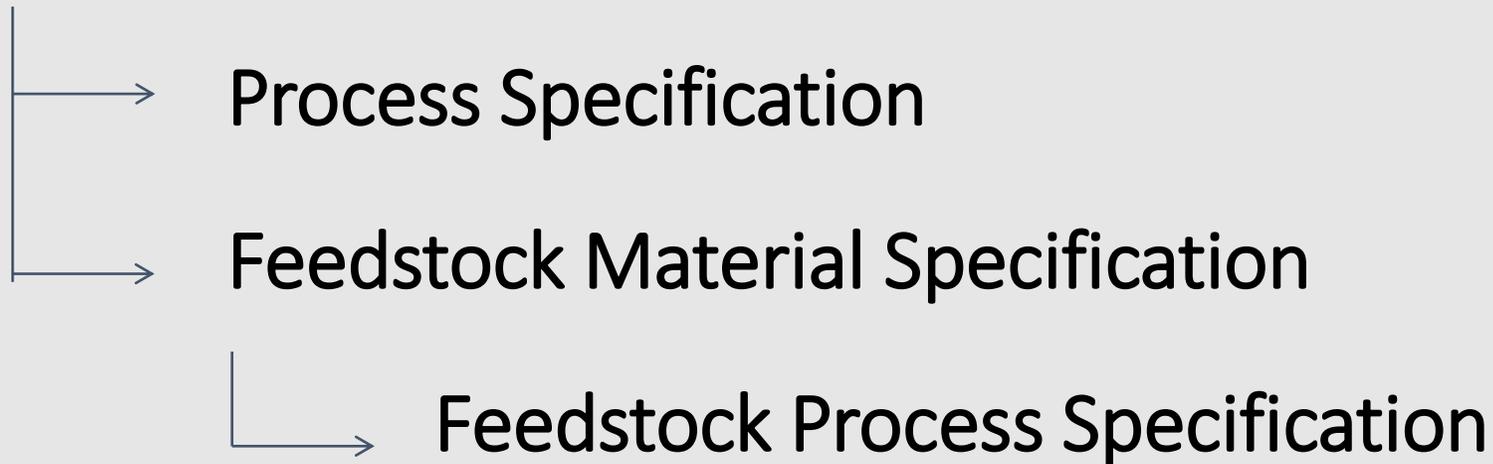
Keeping an Eye on the Future.

# Similar Spectrum for Additive Materials and Material Systems...



Keeping an Eye on the Future.

## Material Specification



- Hierarchical
- Defines requirements and establishes controls
- Performance-based and Pseudo-prescriptive

## Material Specification – AMS 7000 LPBF Alloy 625

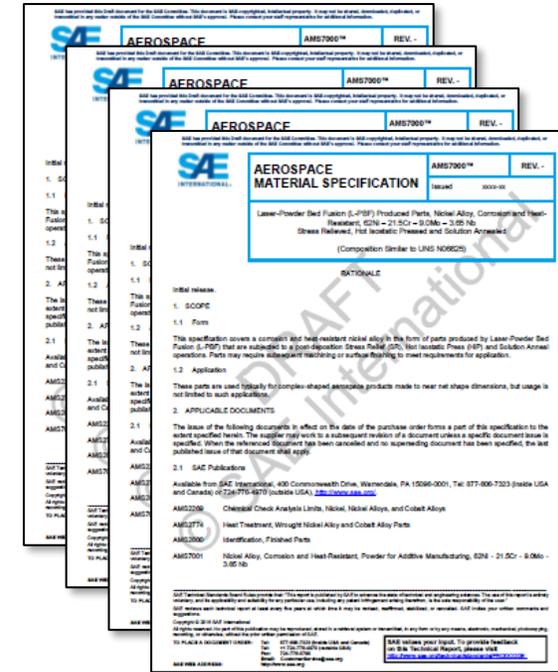
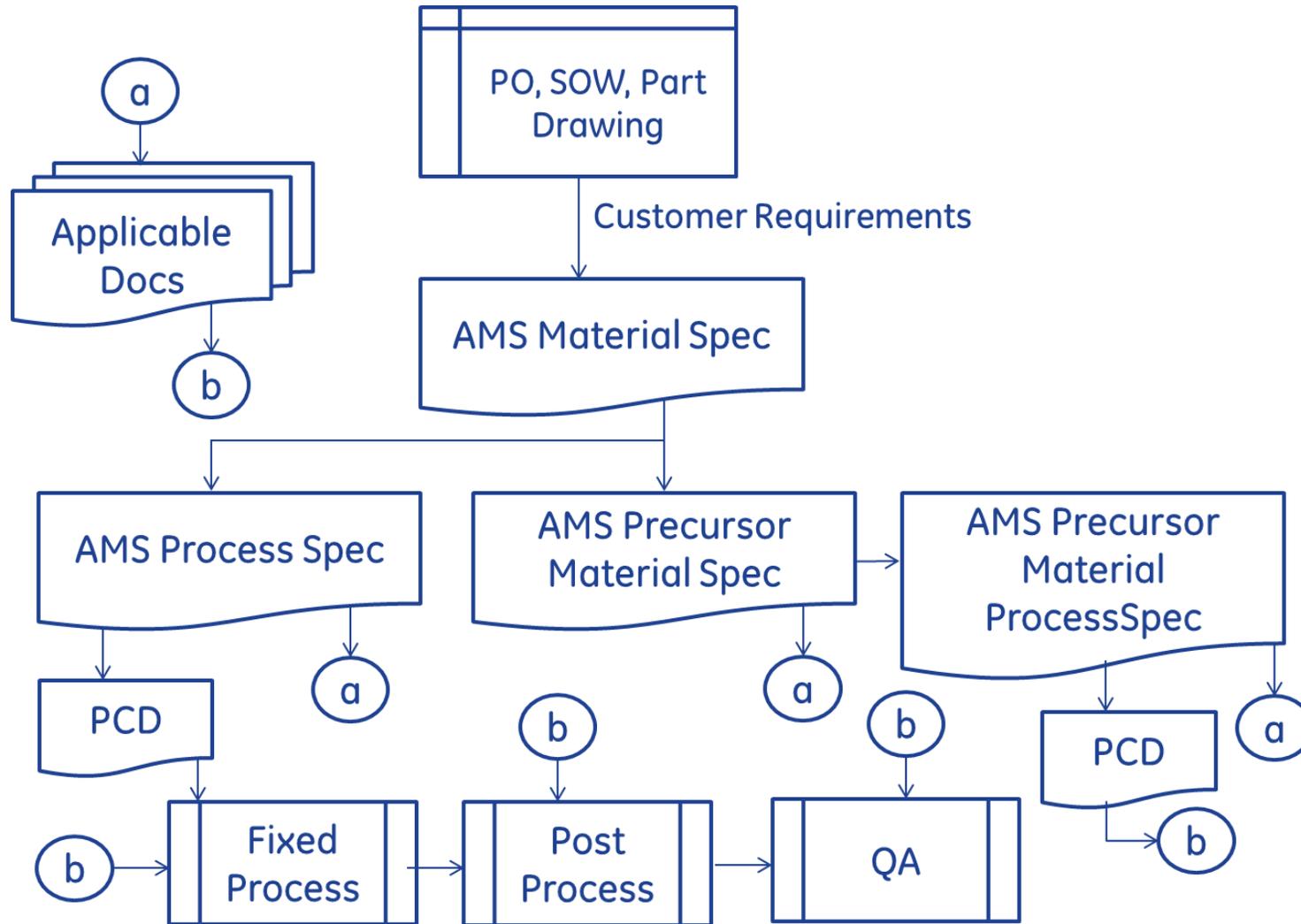
→ Process Specification – AMS 7003 LPBF Process

→ Feedstock Material Specification – AMS 7001 Alloy 625 Powder

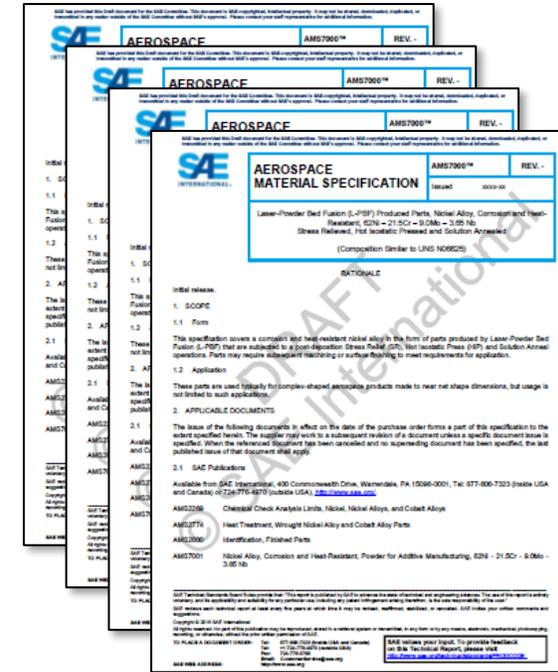
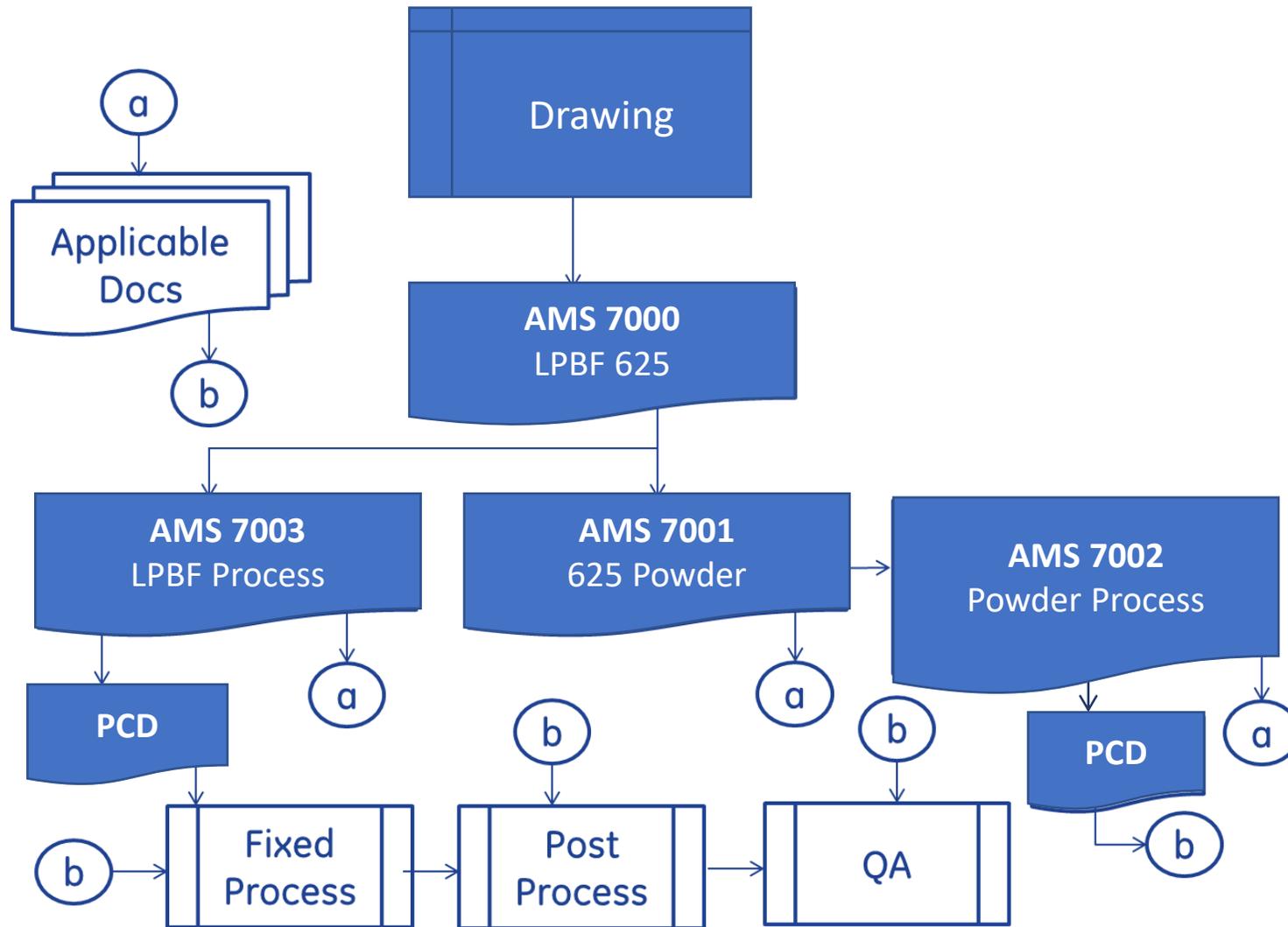
→ Feedstock Process Specification – AMS 7002 Powder Process

- The SAE AMS-AM Specification Framework establishes the control of the AM component manufacturing process from the feedstock through the finish product.
- There are both prescriptive and performance-based aspects to the framework.

# Representative Requirements Flowdown



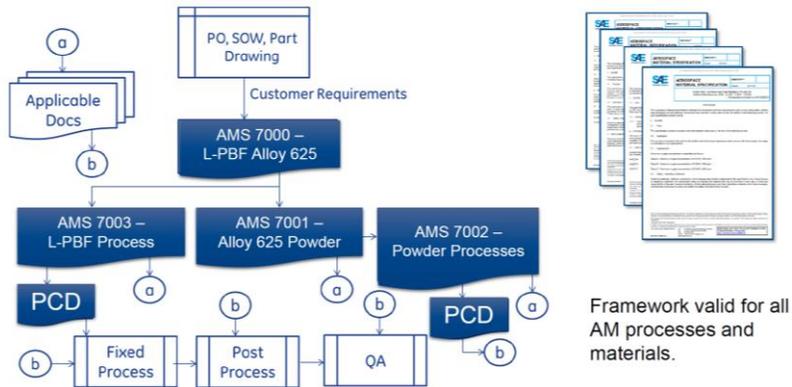
# Requirements Flowdown Applied to SAE AMS-AM Specifications



# Specification Hierarchy for Non-Repair Applications

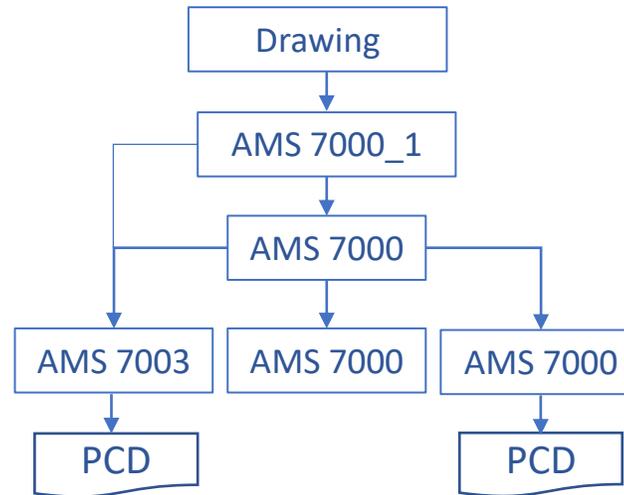
- Slight adjustment to the hierarchy:

## Current Hierarchy



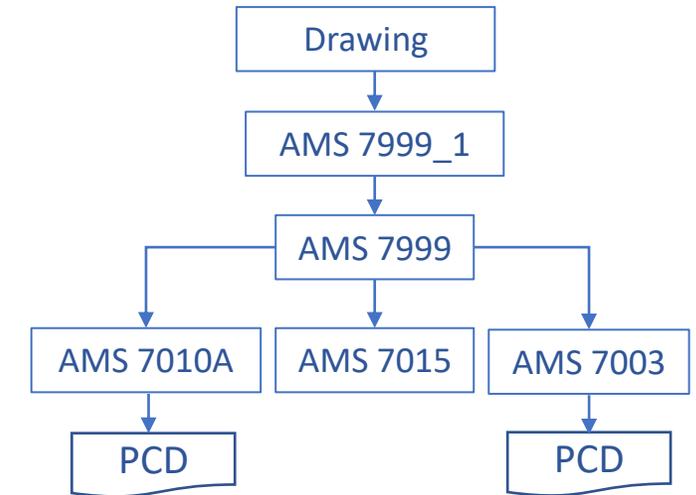
Topic	Standard	Example
AM Product	Material	AMS 7000
AM Modality	Process	AMS 7003
AM Feedstock	Material	AMS 7001
Feedstock Mfg	Process	AMS 7002

## Public PCD



Topic	Standard	Example
Public PCD	Slash sheet	AMS 7000_1
AM Product	Material	AMS 7000
AM Modality	Process	AMS 7003
AM Feedstock	Material	AMS 7001
Feedstock Mfg	Process	AMS 7002

## Specific Instance

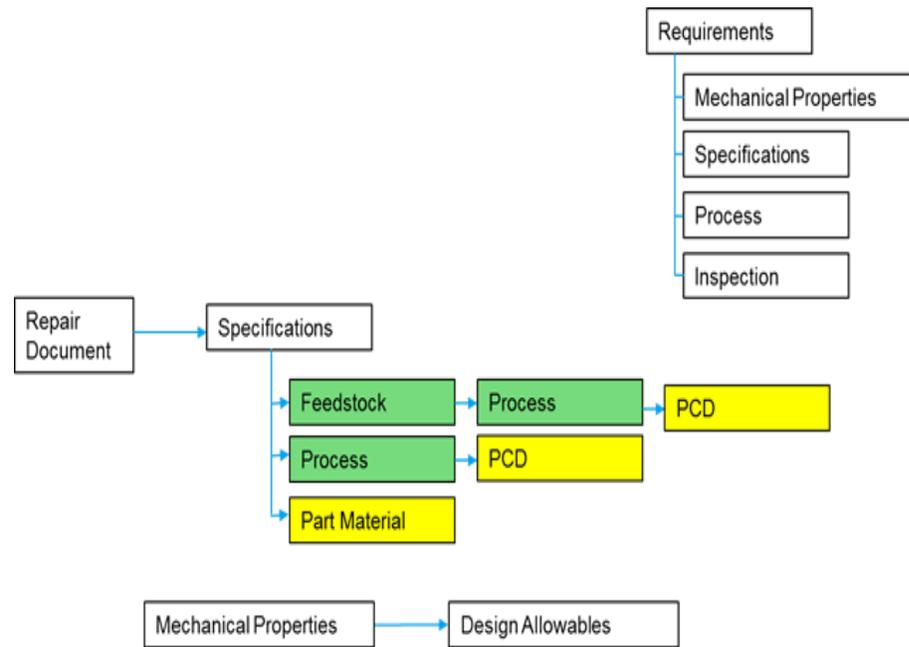


Topic	Standard	Example
Final HT = STA	Slash sheet	AMS 7999_1
AM Product	Material	AMS 7999
AM Modality	Process	AMS 7010A
AM Feedstock	Material	AMS 7015
Feedstock Mfg	Process	AMS 7002

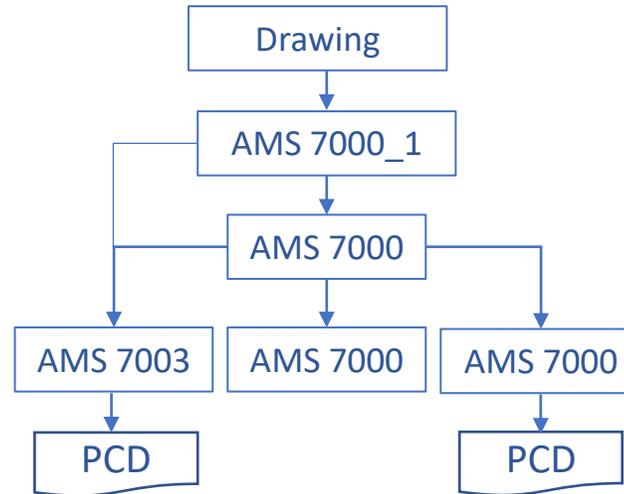
# Specification Hierarchy for Repair

- Slight adjustment to the hierarchy:

## Repair Hierarchy

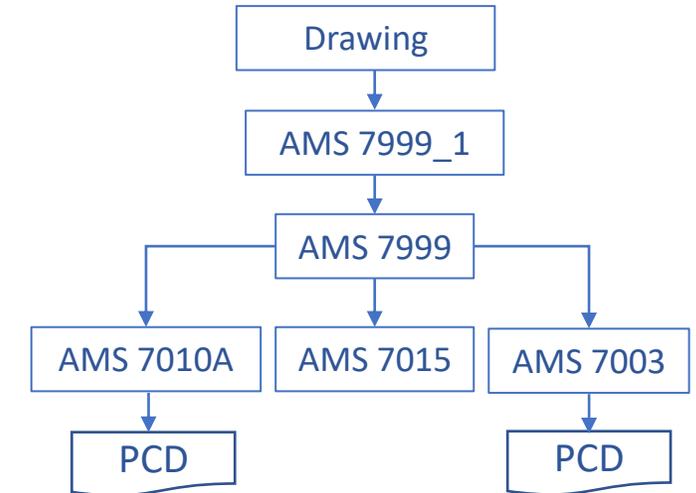


## Public PCD



Topic	Standard	Example
Public PCD	Slash sheet	AMS 7000_1
AM Product	Material	AMS 7000
AM Modality	Process	AMS 7003
AM Feedstock	Material	AMS 7001
Feedstock Mfg	Process	AMS 7002

## Specific Instance

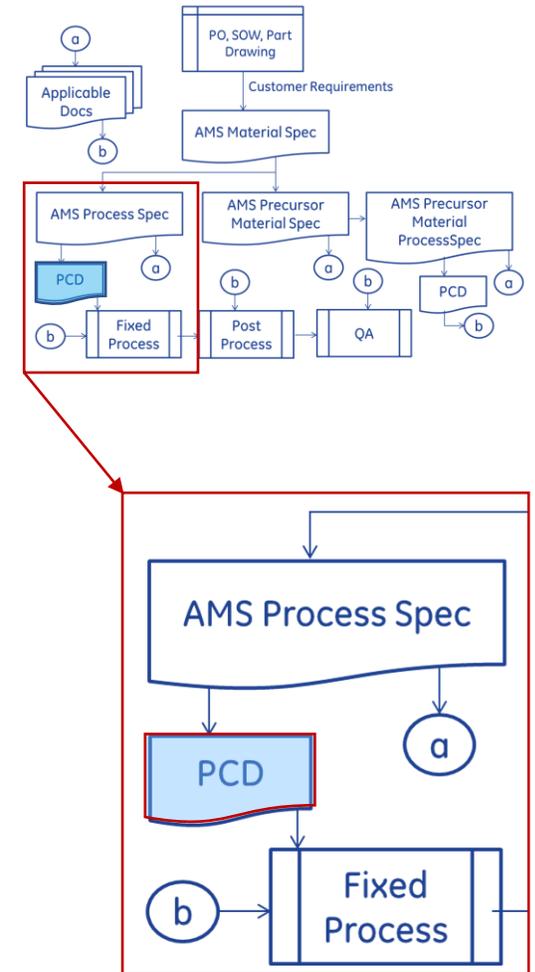


Topic	Standard	Example
Final HT = STA	Slash sheet	AMS 7999_1
AM Product	Material	AMS 7999
AM Modality	Process	AMS 7010A
AM Feedstock	Material	AMS 7015
Feedstock Mfg	Process	AMS 7002

# SAE AMS-AM Standards Hybrid Requirements

- There is **prescription** where appropriate.
  - Feedstock:
    - Chemistry
    - PSD
    - Method of Manufacture
    - Process Gas
  - Finish Product:
    - Chemistry
    - Microstructure
    - Min tensile properties
    - Heat treatment
- There are **performance-based** aspects for flexibility.
  - Process:
    - Process Control Documentation **PCD** → Fixed process specific to the application.
    - Proprietary or Public (slash sheets)

Flowchart – Specification Hierarchy



# Criticality and Qualification - Repair Document Outline

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## Chapter 4: Repair Considerations

- *This section will cover what should be evaluated when considering repairing a metal component. Considerations include:*
  - *Repair vs Replacement*
  - *Part Criticality*
  - *Part Performance*
  - *Part Functionality*
  - *Qualification / Certification*
  - *Types of Repair*
  - *Part Size and Complexity*
  - *Material Type*
    - *Component*
    - *Feedstock*
  - *Design Requirements*
  - *Repair Supplier*
  - *Post Processing*

# Criticality and Qualification - Repair Document Outline

## Chapter 5: Repair Development and Qualification

- *This section will cover the development of a repair process:*

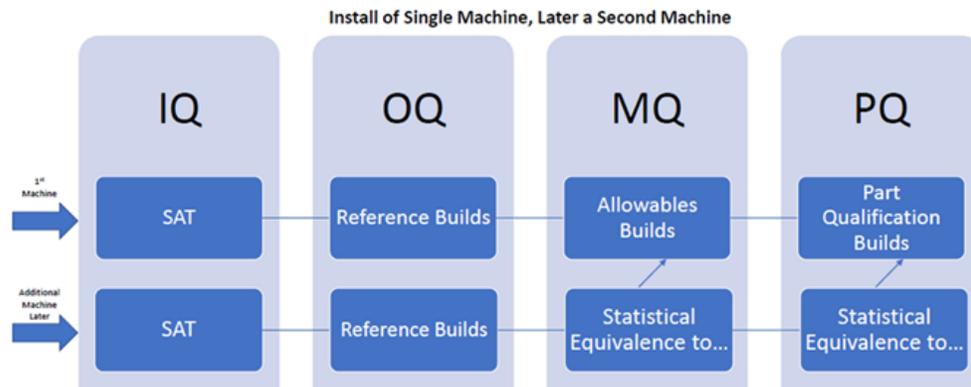
- *Design Evaluation*
- *Modality Selection*
- *Material Selection*
- *Repair Process Design/Planning*
  - *Part Prep*
  - *Initial NDI (defect verification, toolpath planning)*
  - *Toolpath Generation*
  - *AM Process Development*
  - *Repair Process:*
    - *Repair Trials - Basic*
    - *Evaluation*
    - *Heat Treat Trials*
    - *Evaluation*
    - *Repair Trials - Representative Geometry*

- *Repair Process (cont):*
  - *Evaluation*
  - *Machining Trials*
  - *NDI*
  - **Qualification** - *Parameters/Schedule*
    - *Microstructure*
    - *Chemistry*
    - *Mechanical Properties*
  - *Repair Document*
    - *Creation*
    - *Approval*

# Repair Document Outline

- Part Criticality

- Criticality drives
  - Repair versus replace decisions
  - Minor versus major repair
  - Qualification Requirements
    - Materials and Processes



Criticality Level	IQ	OQ	MQ	PQ
1-Non-critical	Situation A,B = SAT, OEM defined	X	X	X
2-Mission Critical	Situation A,B = SAT, Supplier defined	XX	XX	XX
3-Flight Critical	Situation A,B = SAT, Supplier defined	XXX	XXX	XX

## Aircraft Repair and Alteration Decision Chart

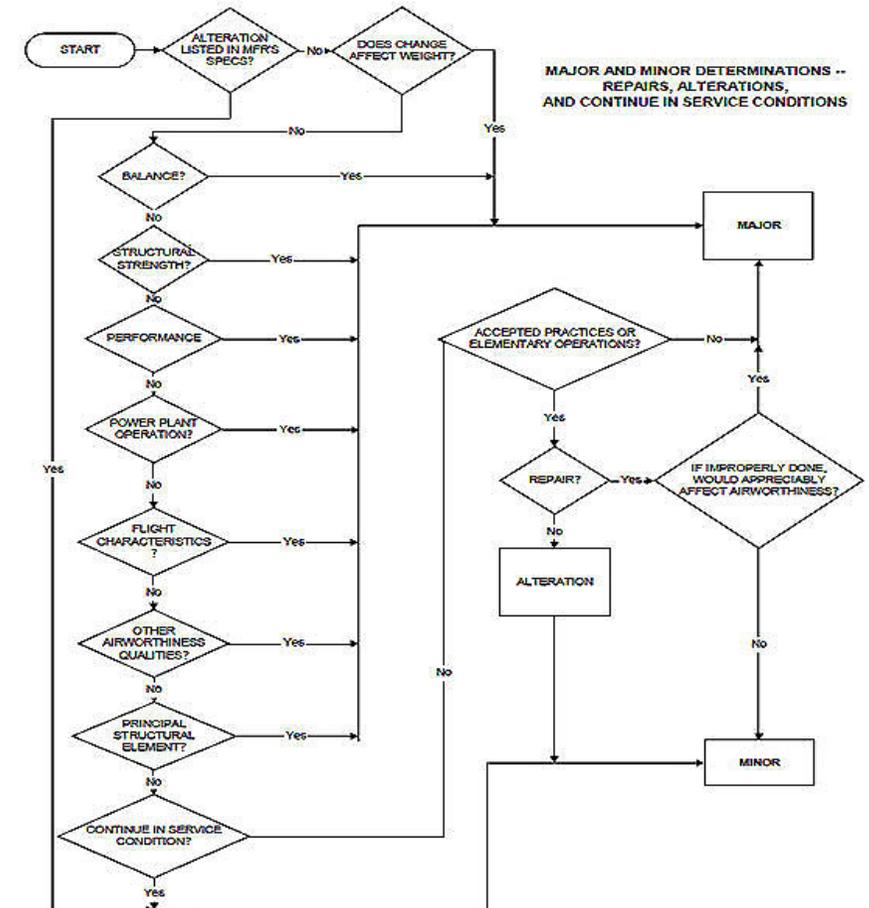


Figure from Aviation Safety Bureau (<http://www.aviation-safety-bureau.com/aircraft-repair.html>)

# SAE AMS-AM Repair Working Group Discussions

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- **Criticality** Classification

- Many lengthy, healthy discussions.
- Direction seems to be aligned with other similar efforts. Interest in CPL/HA/RAS approaches.
- Continue to develop as we go along.
- Currently considering only the most critical parts (Cat 1 and 2). No door handles.

- **Qualification**

- Qualification vs Certification
  - Qualification: verification that repair satisfies the requirements
  - Certification: approval to perform repair and enter part back into service
- Application -> Classification -> Level of effort
- Establishing substantiation requirements will always be a challenge.
- Two examples:
  - Bob Grant's presentation (CAT 1-3 and CPL).
  - AMRDEC 2015 presentation (Qualification from DoD perspective).

# Questions?

If interested in participating, contact:

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