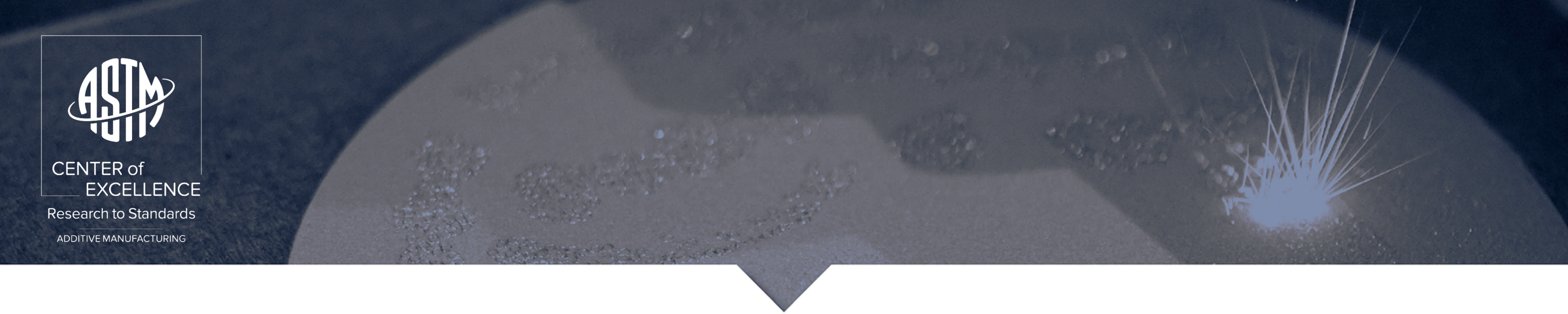

ASTM INTERNATIONAL
Additive Manufacturing Center of Excellence

AM Materials Data – Challenges & Opportunities

NRC Workshop on Advanced Manufacturing Technologies for Nuclear Applications
October 24-26, 2023

www.amcoe.org

ASTM Additive Manufacturing Center of Excellence

CENTER of EXCELLENCE
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Research & Development

Conducts R&D identified and prioritized by the top minds in the field to significantly accelerate standards development.

Certification & Proficiency Testing

Supports development of the AM standards roadmap, transitioning R&D to standards and technical publications, proficiency testing and certification programs.

Education & Workforce Development

Develops comprehensive education and training programs built on standardization and certification expertise that prepares the AM workforce of the future at all levels.

Industry Consortium

Develop and standardize the requirements and best practices for AM material data generation and create high-pedigree shared datasets for use by members to support design and rapid qualification.

Market Intelligence & Advisory Services

Support successful AM implementation globally through a range of business strategy and technical advisory services from market intelligence, strategy and planning, to operations execution through Wohlers Associates.

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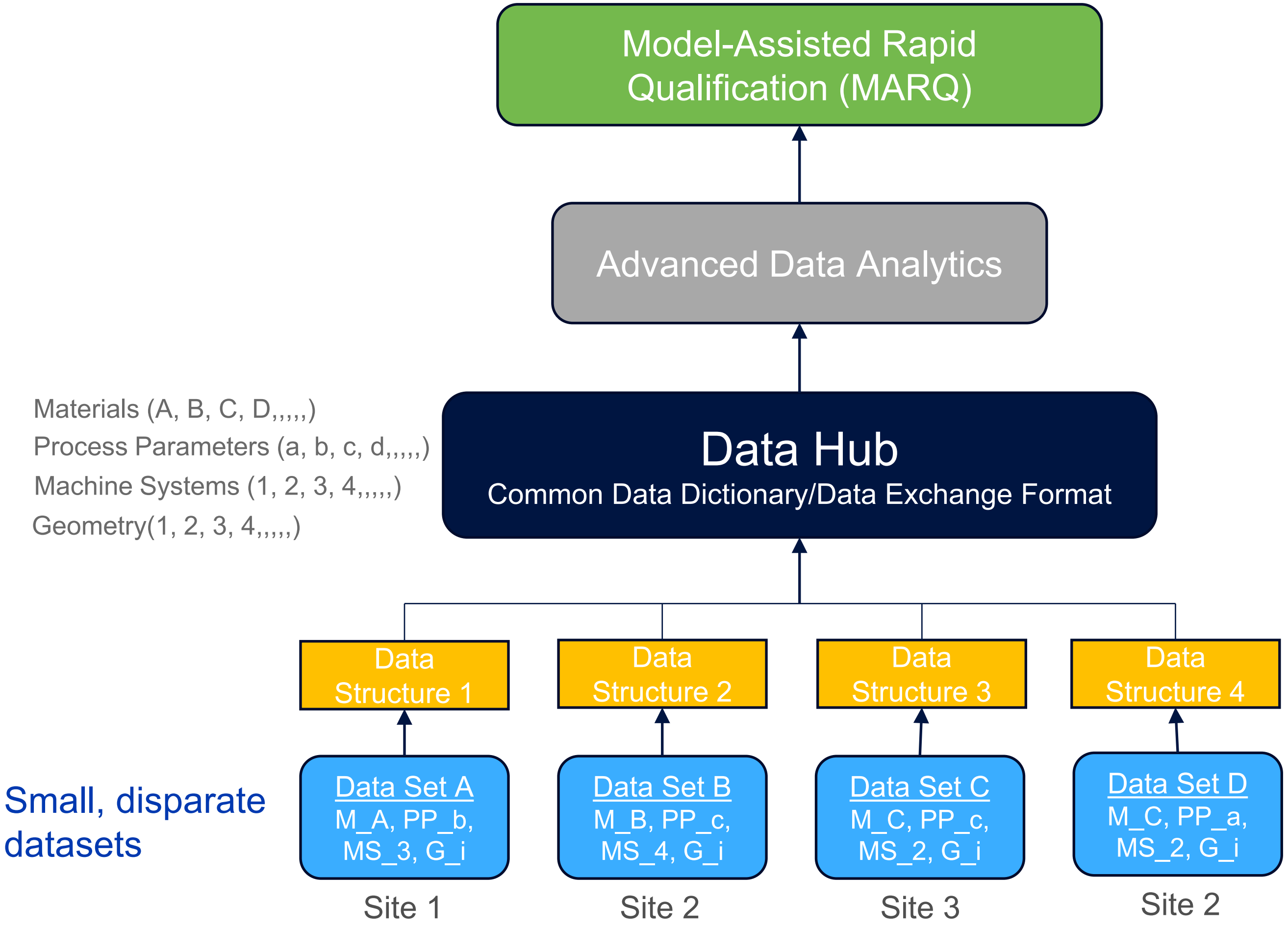
AM Materials Data - Challenges

Large Number of AM Systems and Process Variables

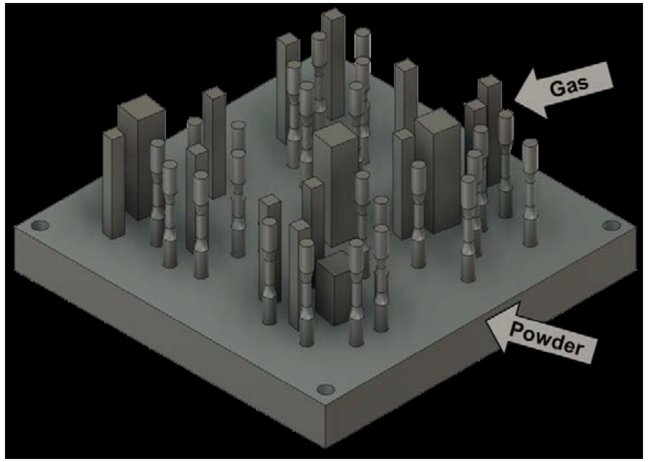
- Powder/Feedstock
  - Chemistry, Size, Shape
- Part Geometry/Size
- Build Layout
  - Location, Orientation, Quantity
- Machine Systems
  - Recoater, Gas Flow, Temperature, etc.
- AM Process Parameters
- Post-processing

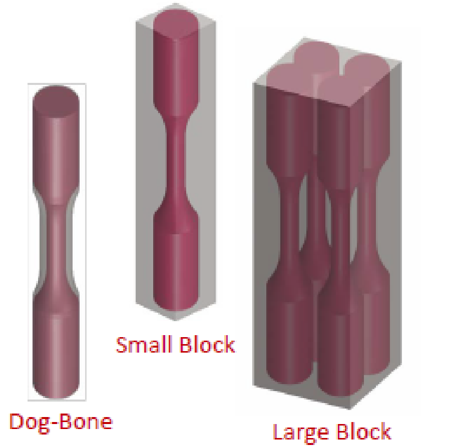


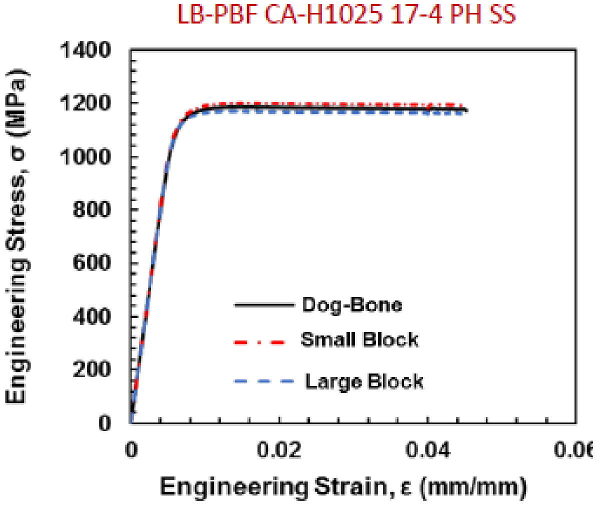
AM Materials Data - Challenges

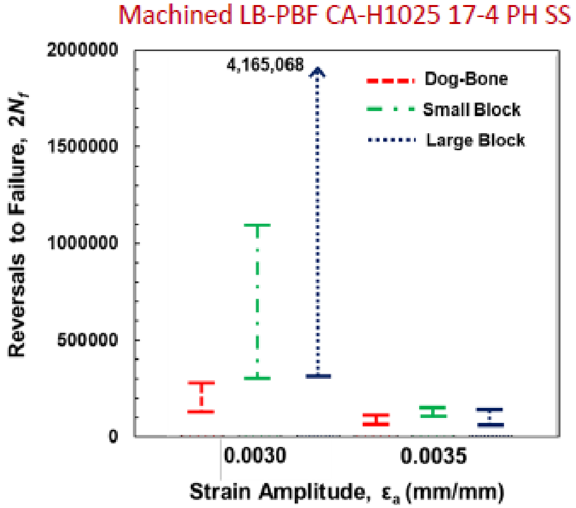
Effects of Geometry, Size and Time

- Three sets of LB-PBF 17-4 PH SS parts (dog-bone, small block, large block)
- All parts machined to similar geometry and polished to minimize surface effects
- CA-H1025 heat treatment was used to homogenize the microstructure
- No effect on tensile behavior was observed, however, effect of geometry on fatigue behavior was noticeable, especially in the high cycle fatigue regime



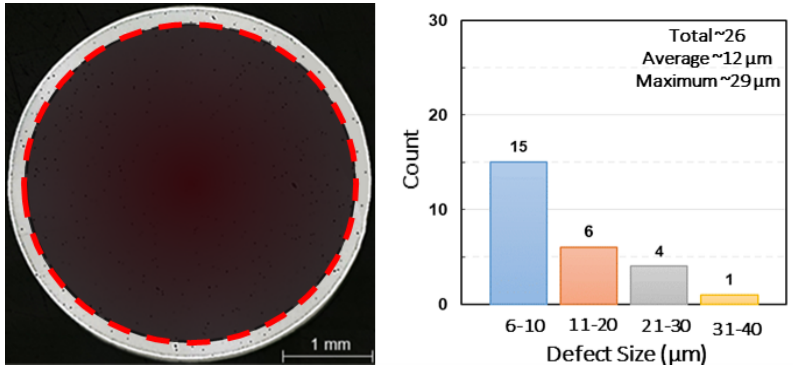




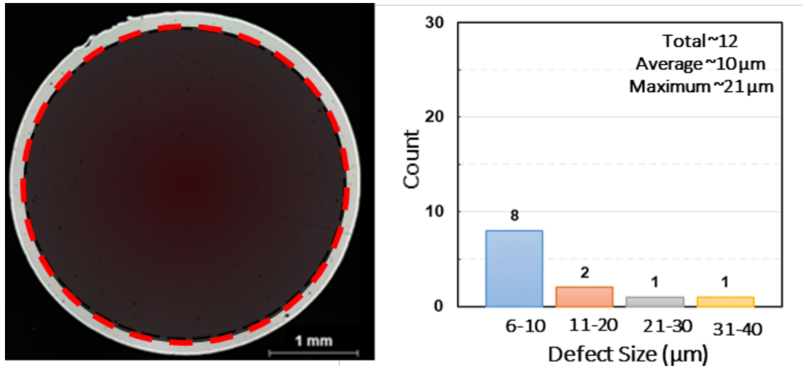


R Shrestha, N Shamsaei, M Seifi, N Phan, "An investigation into specimen property to part performance relationships for laser beam powder bed fusion additive manufacturing." Additive Manufacturing 29, 100807, 2019.

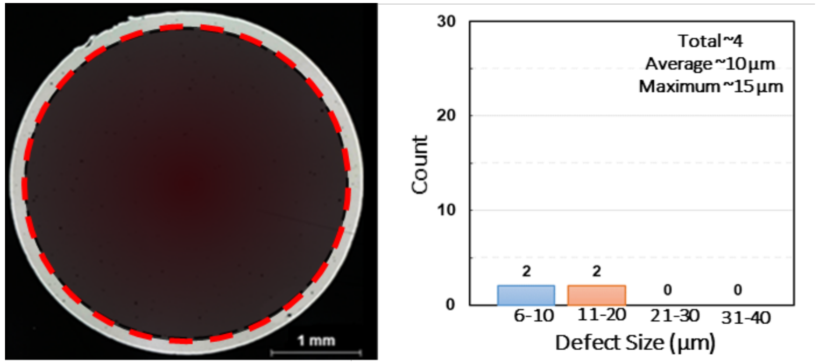
Effects of Geometry, Size and Time



Dog-Bone



Small Block

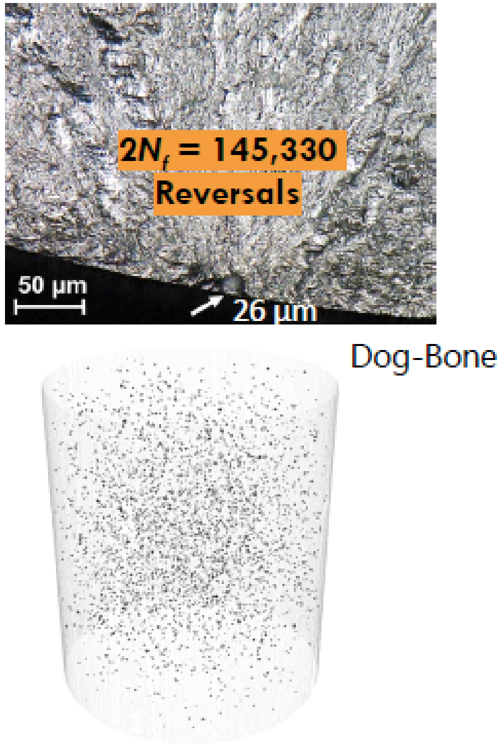


Large Block

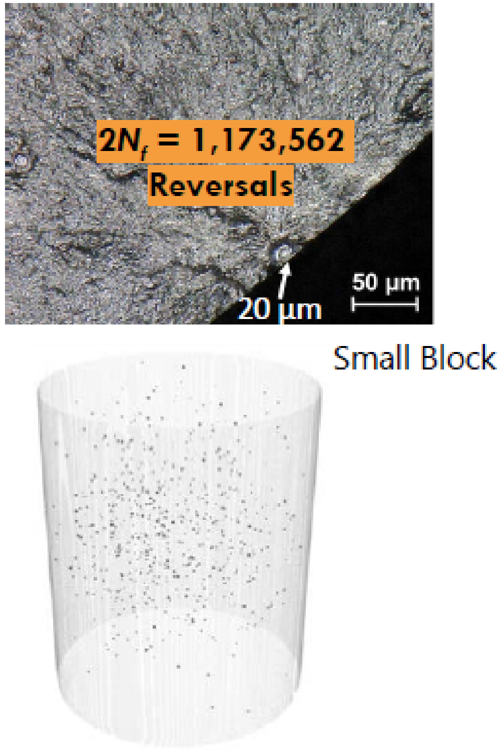
- Highest amount of porosity was observed in dog-bone specimen, followed by small block specimen
- The maximum defect size was smallest in large blocks and largest in dog-bone parts
- Only considered the area within ~100 µm from surface

R Shrestha, N Shamsaei, M Seifi, N Phan, "An investigation into specimen property to part performance relationships for laser beam powder bed fusion additive manufacturing." Additive Manufacturing 29, 100807, 2019.

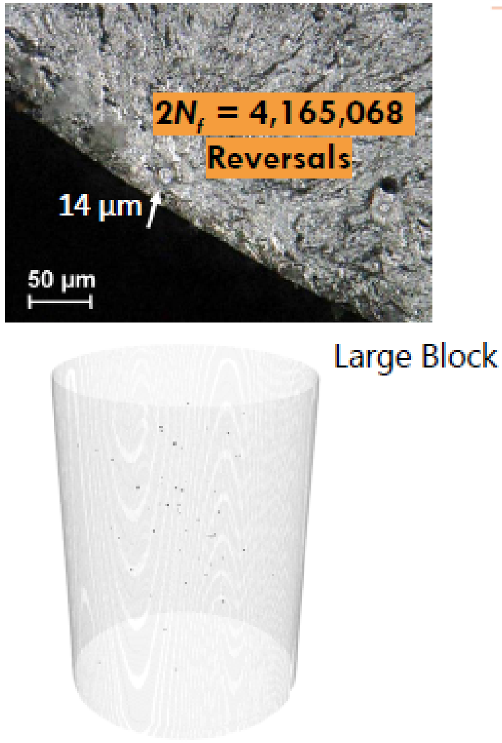
Effects of Geometry, Size and Time



Total ~ 99
Max ~ 29 µm
Density ~ 99.96%



Total ~ 26
Max ~ 21 µm
Density ~ 99.98%



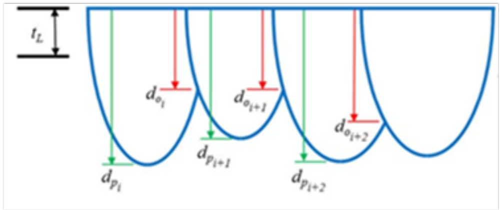
Total ~ 8
Max ~ 17 µm
Density ~ 99.99%

R Shrestha, N Shamsaei, M Seifi, N Phan, "An investigation into specimen property to part performance relationships for laser beam powder bed fusion additive manufacturing." Additive Manufacturing 29, 100807, 2019.

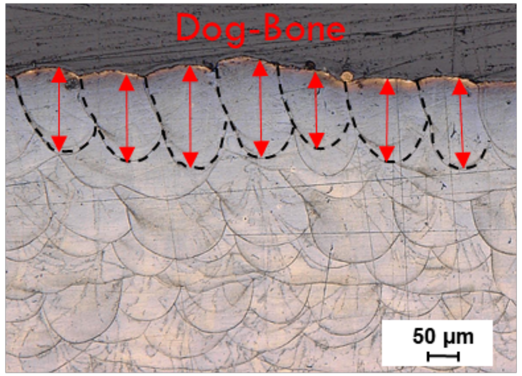
Effects of Geometry, Size and Time

- Some effect of part geometry was noticed in the size of the melt pool
- Longer melt pools were observed in large block specimens, while the shortest melt pools were noticed in dog-bone specimens
- Differences in melt pool size suggest cooling rate is highest in dog-bone specimens and lowest in large block specimens
- Values of dp/tL & do/tL > 1 explain the absence of lack of fusion defects

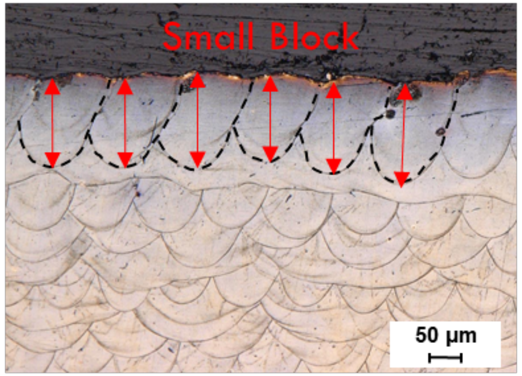
National Aeronautics and Space Administration. (2017). Specification for control and qualification of laser powder bed fusion metallurgical processes. MSFC-SPEC-3717.



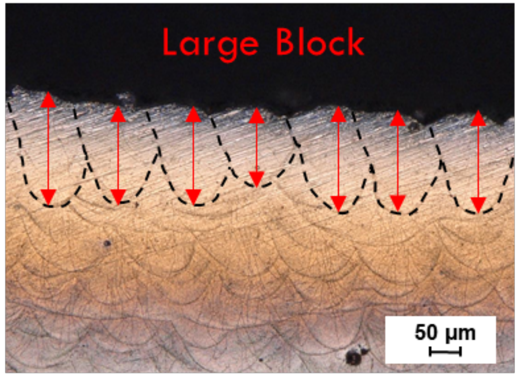
t_L = Layer Thickness
d_p/t_L & d_o/t_L
Melt pool characteristics is indicative of health of the process



Melt pool depth ~ 142 µm
d_p/t_L = 3.6 & d_o/t_L = 2.1



Melt pool depth ~ 156 µm
d_p/t_L = 3.9 & d_o/t_L = 2.0

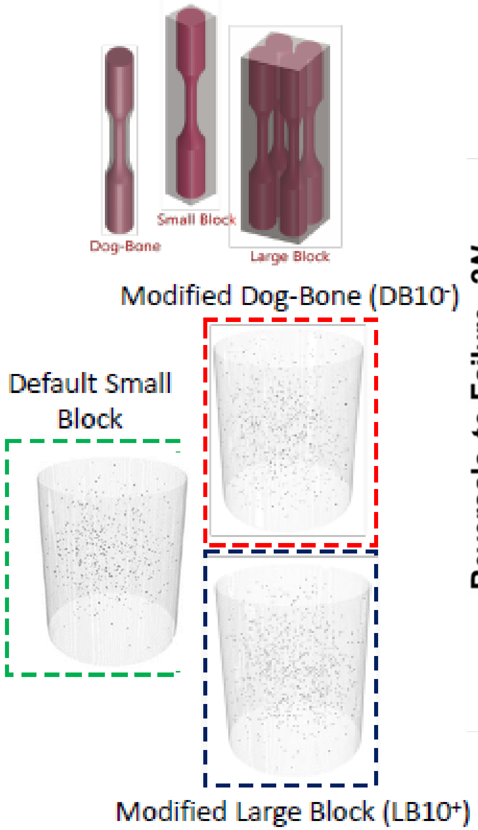


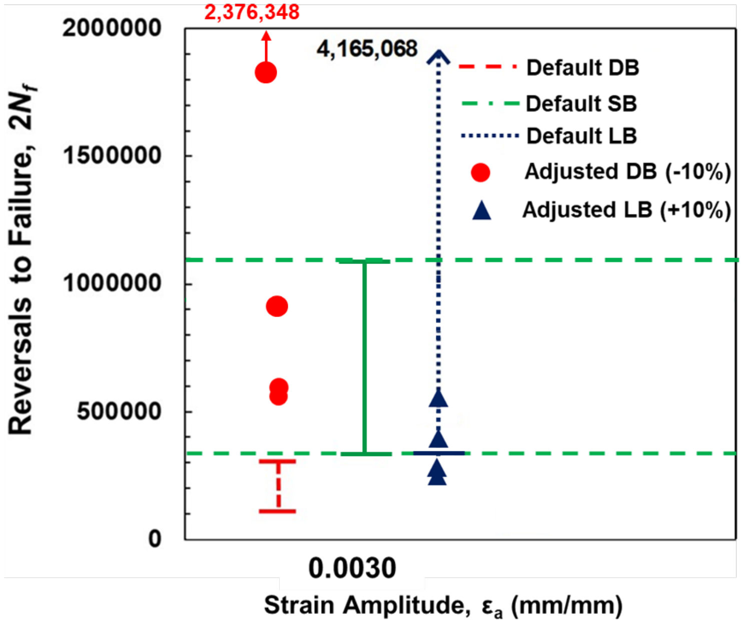
Melt pool depth ~ 162 µm
d_p/t_L = 4.1 & d_o/t_L = 1.9

R Shrestha, N Shamsaei, M Seifi, N Phan, "An investigation into specimen property to part performance relationships for laser beam powder bed fusion additive manufacturing." Additive Manufacturing 29, 100807, 2019.

Effects of Geometry, Size and Time

- ➢Similar defect distribution between different geometries was achieved by adjusting the process parameters
- ➢As a result, similar fatigue lives were obtained for these three different geometries
- ➢Achieving similar thermal histories in different geometries can result in comparable defect content as well as part performance
  - **Optimal parameters are based on the geometry being printed**

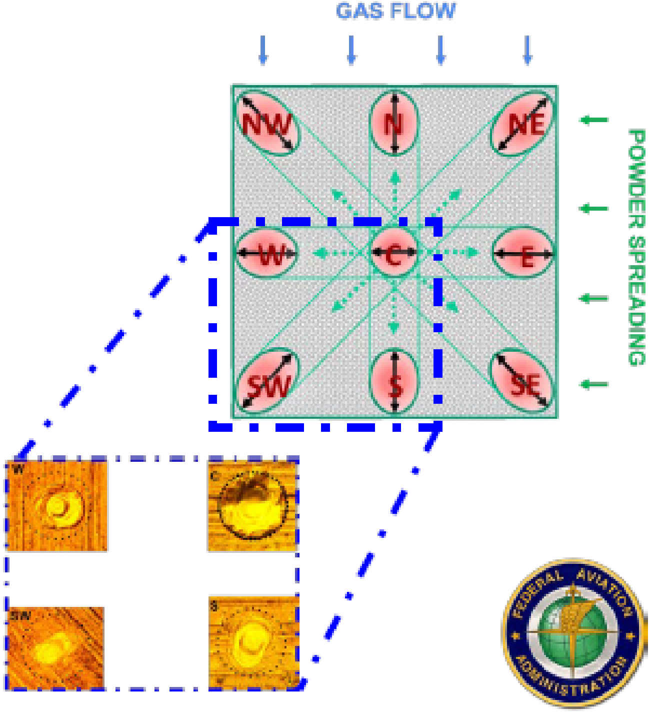


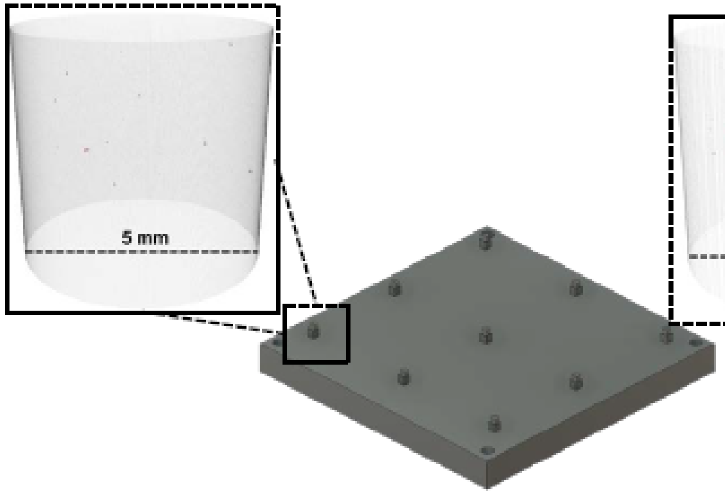


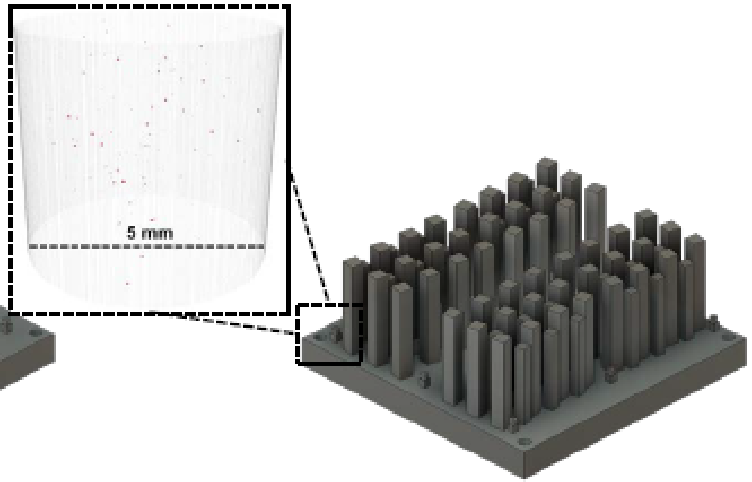
Build Layout

- Laser spot elongation (i.e., area, shape), powder packing state, and gas flow can vary at different locations on the build plate
- The build plate density (i.e., total part area/build plate area) can affect the defect population as a result of varying scan times and spattering

Laser Spot Elongation



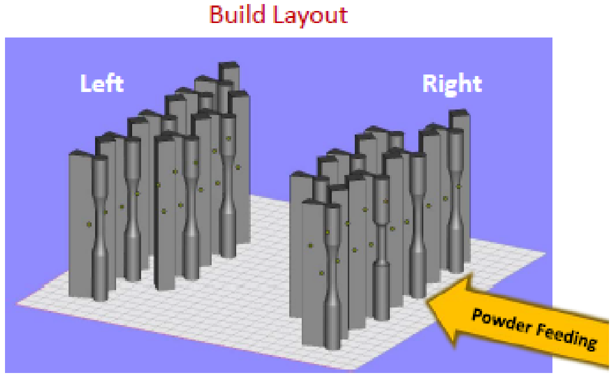


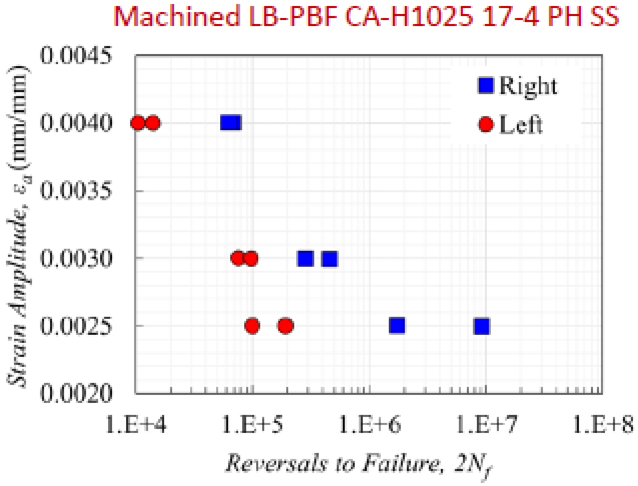


AM Materials Data - Challenges

Build Layout

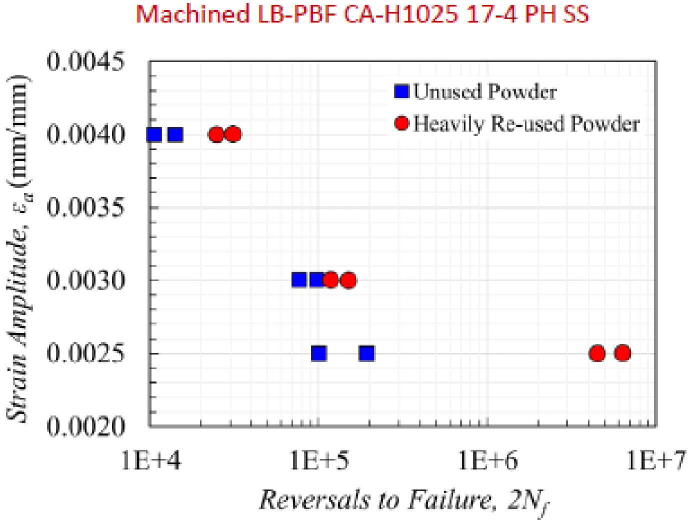
- Fatigue resistance of AM parts, even on the same build plate, was different as a result of powder flowability, packing density and the resultant defect formation
- Tensile properties were insensitive to the location of the parts on the build plate





Powder Reuse

- Effects of powder re-use on tensile properties and fatigue performance in as-built surface condition were negligible
- Re-using the powder did not considerably affect low and mid cycle fatigue regimes of machined specimens due to less sensitivity to process-induced defects
- Fatigue performance of machined specimens was improved significantly in the high cycle fatigue regime due to less presence of smaller particles and agglomerates



Shamsaei et. al., Additive Manufacturing, 36: 101398, 2020.

AM Materials Data - Challenges

ASTM CENTER of EXCELLENCE Research to Standards ADDITIVE MANUFACTURING

- Companies from across a broad range of industries need to develop extensive material datasets to support implementation of Additive Manufacturing into the design and production of innovative products.

Creating datasets is very expensive and can be prohibitive for many companies

Difficult to impossible to directly transfer data and lessons learned between companies and across machine platforms, creating duplicate efforts within and across industry verticals

Lack of standardized approaches to data generation, pedigree and management leads to significant waste

Dataset generated with Method 1 ≠ Dataset generated with method 2 ???

AM Materials Data - Opportunity

- ASTM officially launched a Global Consortium for Materials Data and Standardization (CMDS) in 2022, which in coordination with members and with input from regulatory agencies, will accelerate adoption of AM technologies through standardization by:

REQUIREMENTS & BEST PRACTICES

- Terminology, Pedigree, Specimen Geometry, Build & Test Plans
- Identify Process-Structure-Property Relationships
- Equivalency/Combinability of new or existing data

GENERATE HIGH-PEDIGREE DATA

- Consortia-funded R&D projects create *shared* high-pedigree “reference” material datasets to drive process-based material specifications

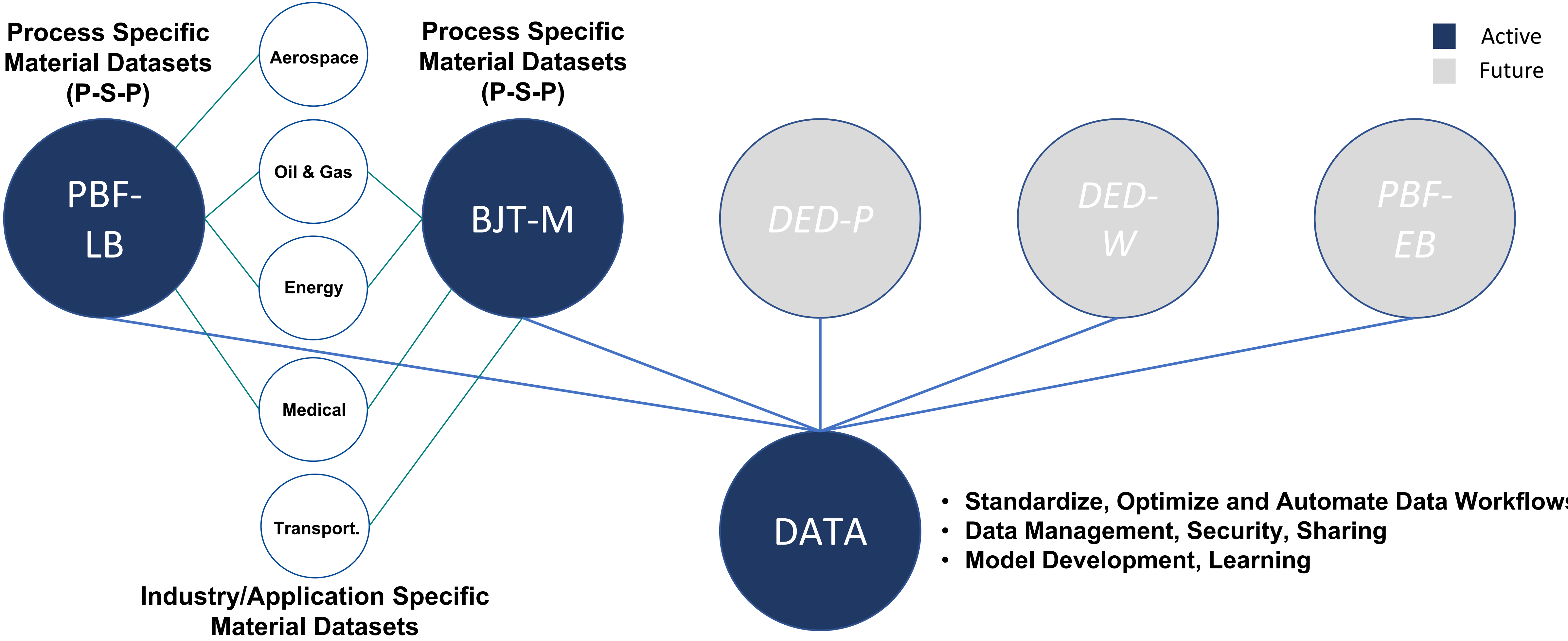
DATA MANAGEMENT SYSTEM

- Secure, Access-controlled Data Management System
- Establishing/Following standard data principles (e.g., CDD, CMD, CDEF, FAIR*)

STANDARDS DEVELOPMENT

- Transferring lessons learned and consortium approved materials data to standardization committees

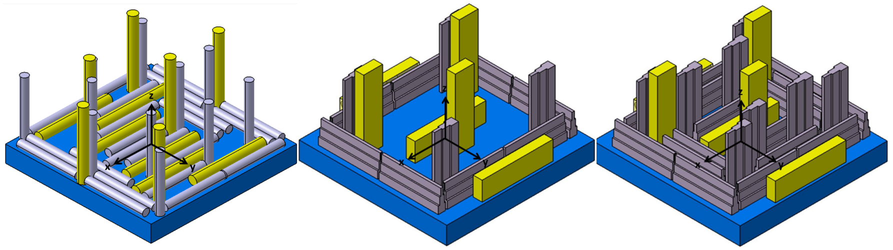
AM CoE CMDS – Workstream Structure



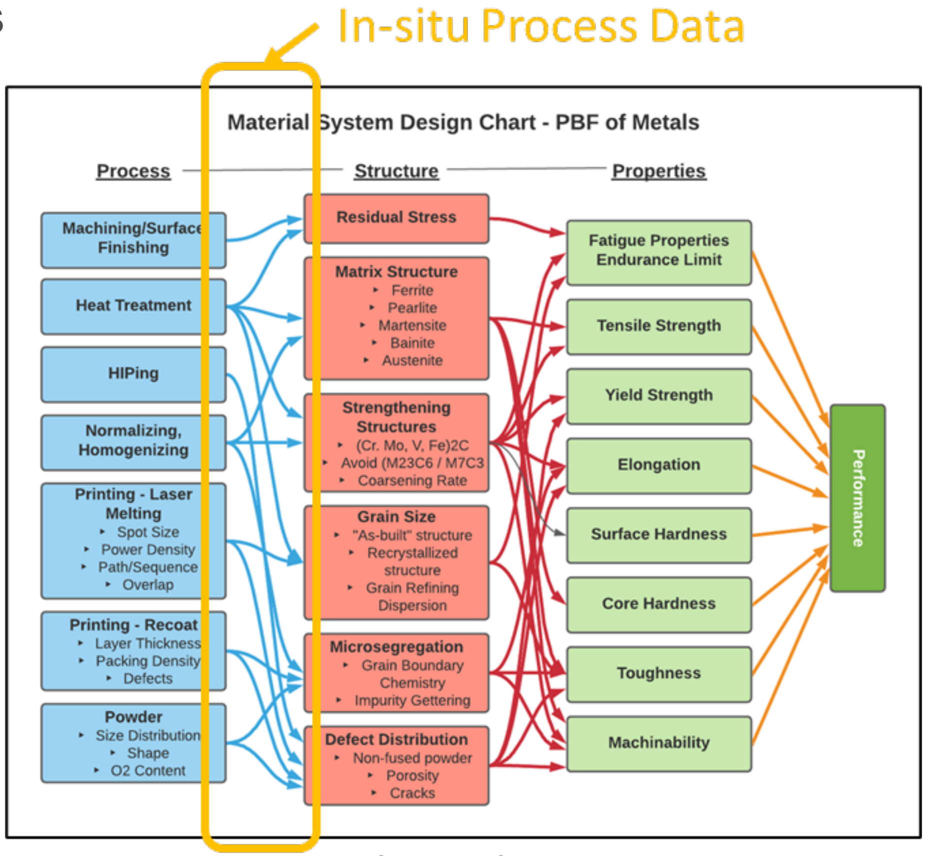
- **Standardize, Optimize and Automate Data Workflows**
- **Data Management, Security, Sharing**
- **Model Development, Learning**

AM CoE CMDS – Process Workstreams

- Define and Generate high-pedigree and high-value AM Materials Data of interest
- Identify Process-Structure-Property (P-S-P) relationships for AM Materials
  - Population of data representing typical process variables/variations
  - Linkage of “specimen” data to “part production” data
    - Geometry Size/Shape
    - Build layout/density
    - Feedstock
    - Machine systems
    - Printing Parameters
    - Post-processing



- Establish “Equivalency” of material data (combinability)
  - Equivalency requires similar microstructure
  - Material is in family with specification/class
- Define material allowables and specification values
- Feature Based Process/Parameter Design
- Model-Assisted Rapid Qualification (MARQ)



Powder Bed Fusion

AM CoE CMDS – Process Workstream Active Projects

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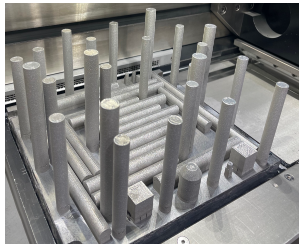
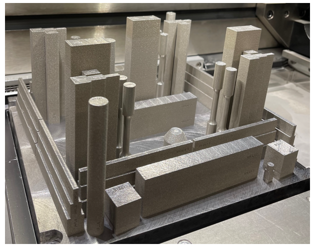
Powder Bed Fusion (PBF)

- UNS N07718 Project In-Process
  - Tensile & Fatigue Properties
  - Room Temperature & Elevated Temperature
  - Four (4) different AM machines
  - Study includes size, location and orientation effects on material properties
  - Expected Standardization Deliverables:
    - ***New/Updated material standard with updated structure-property requirements for two heat treat grades.***
    - ***New guide for materials data generation for ASTM material specifications***
- UNS A03600 Project In-Process
  - Tensile & Fatigue Properties
  - Two (2) AM machine platforms
  - Study includes size, location and orientation effects on material properties
  - Expected Standardization Deliverables:
    - ***New/Updated material standard with updated structure-property requirements for additional stress relief condition.***

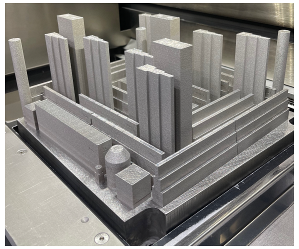
Build A – EOS M290/1

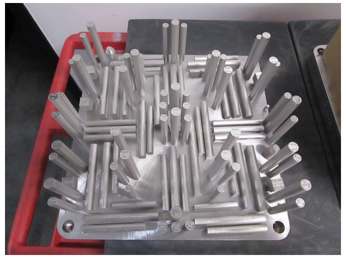


Build B – EOS M290/2

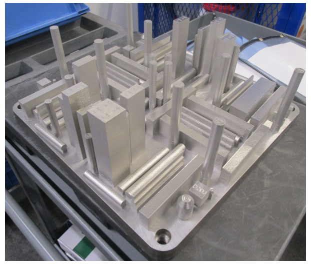


Build C – EOS M290/1

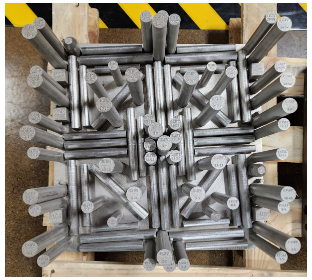




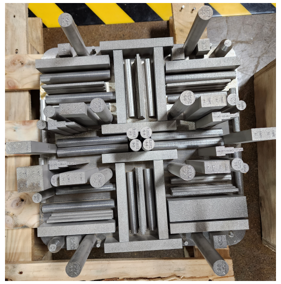
Build D1 – EOS M400-4



Build D2 – EOS M400-4



Build E1 – FormUp 350



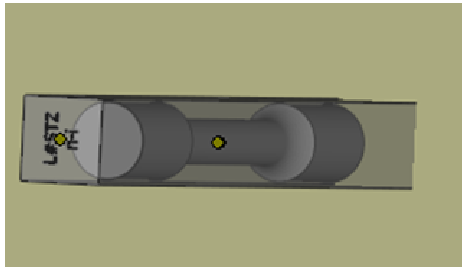
Build E2 – FormUp 350

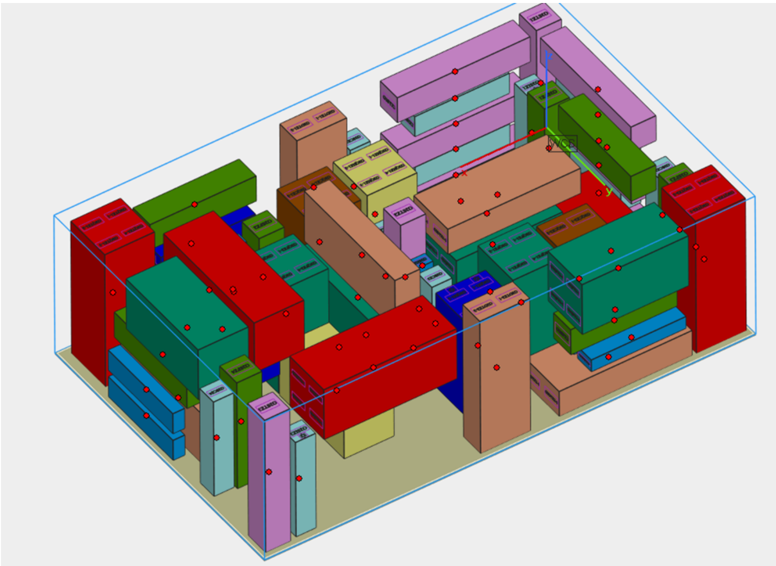
CMDS UNS N07718 PROGRAM			AM MACHINE							
			M290			M400-4		FormUp 350-2		
	TEST CONDITION	HEAT TREATMENT	Build A	Build B	Build C	Build A	Build C	Build A	Build C	TOTALS
TENSILE TEST	Room Temp	P-TS 101/102	32	2	2	10	5	10	5	66
TENSILE TEST	Room Temp	P-TS 103/102				9		9		18
TENSILE TEST	Elevated Temp	P-TS 103/102				25	9	25	9	68
TENSILE TEST (2 mm DB)	Room Temp	P-TS 101/102		40	12		3		3	58
TENSILE TEST (4 mm DB)	Room Temp	P-TS 101/102			12		3		3	18
TENSILE TEST (6 mm DB)	Room Temp	P-TS 101/102			12		3		3	18
LOW CYCLE FATIGUE TEST	Room Temp	P-TS 101/102	12	12	12	12	12	12	12	84
HIGH CYCLE FATIGUE TEST	Room Temp	P-TS 101/102				10	20	10	20	60
LOW CYCLE FATIGUE TEST	Elevated Temp	P-TS 103/102				12	12	12	12	48
CREEP	Elevated Temp	P-TS 103/102				6	6	6	6	24
		TOTALS	44	54	50	84	73	84	73	462

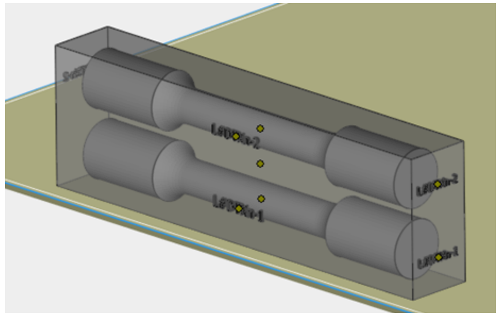
AM CoE CMDS – Process Workstream Active Projects

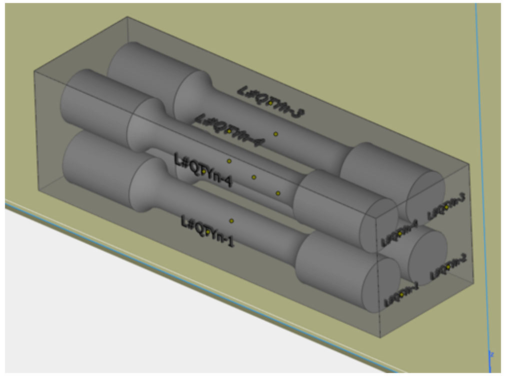
Binder Jetting Technology (BJT)

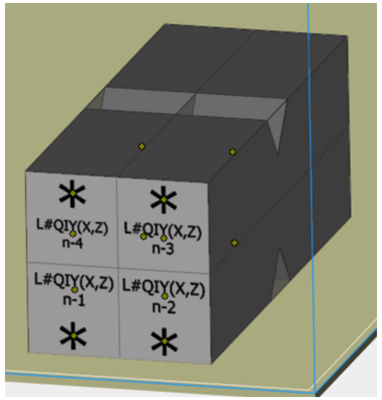
- UNS S17400 Type 630 Project In-Process
  - Tensile, Fatigue, Impact and Corrosion room temperature Properties
  - Three (3) different AM machine platforms
  - Study includes size, location and orientation effects on material properties
  - Expected Standardization Deliverables:
    - ***New (first) BJT material standard with two heat treat grades.***
    - ***Input from BJT perspective on guide for materials data generation for ASTM material specifications***

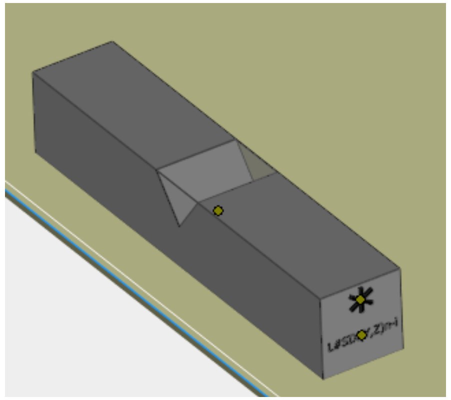




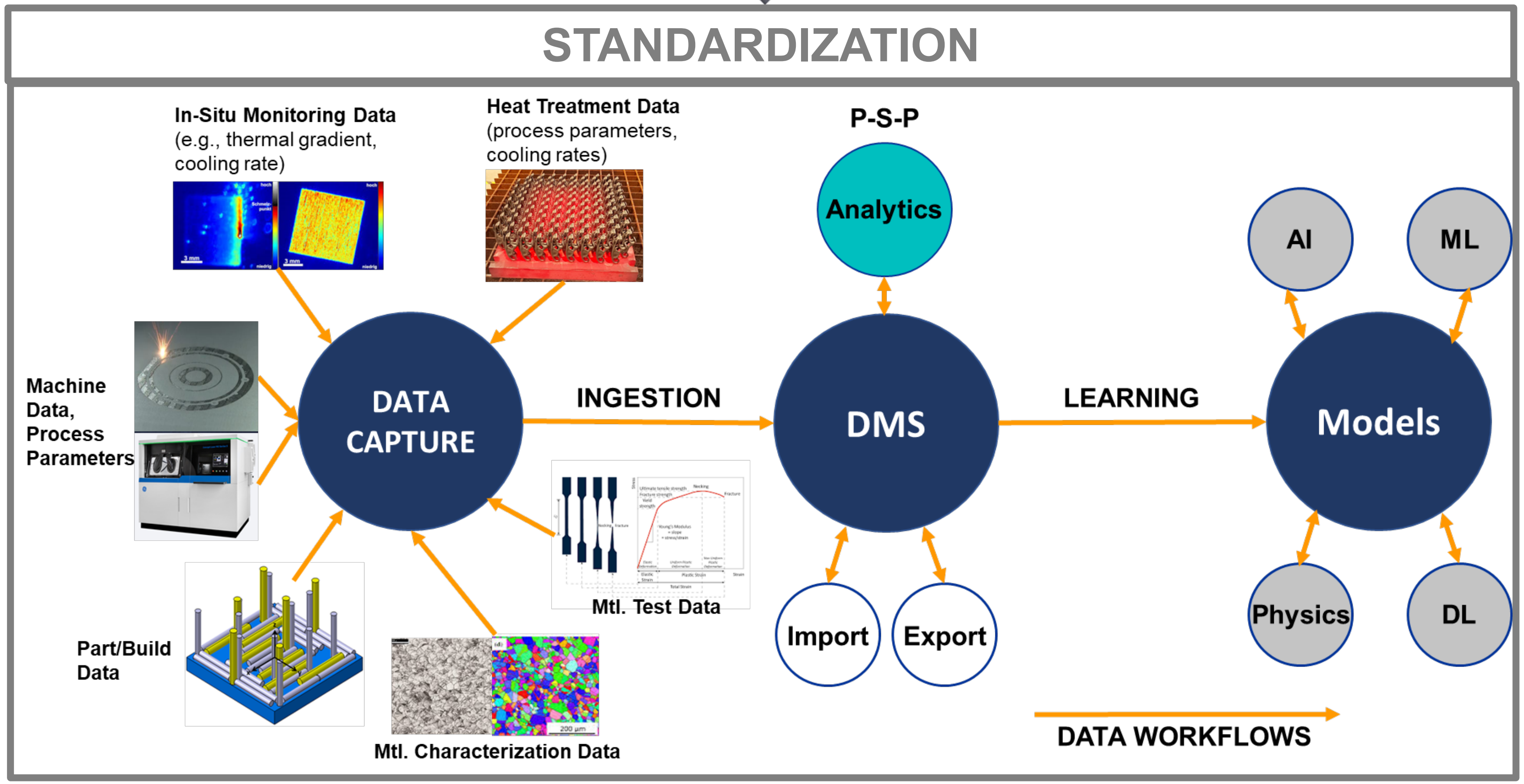








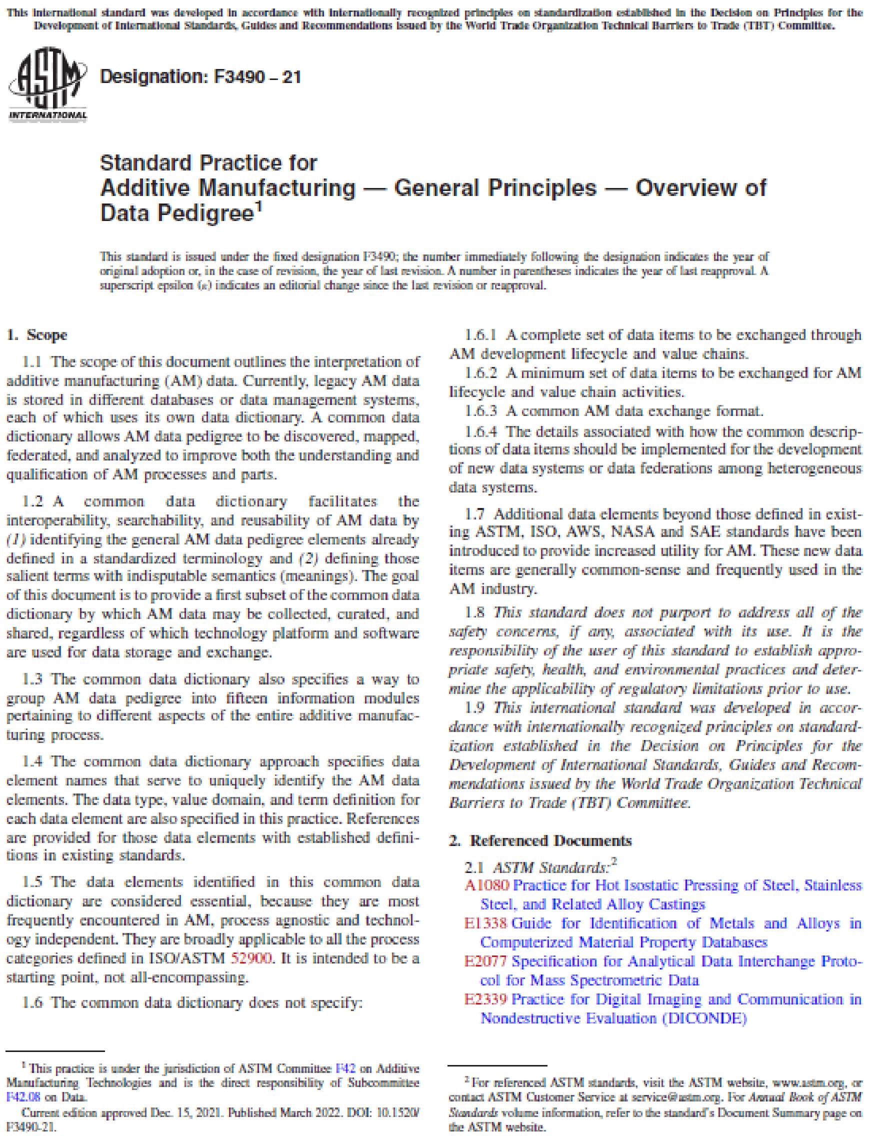
AM CoE CMDS – Data Workstream



- Standardize, Optimize and Automate Data Workflows
- Data Management, Security, Sharing
- Model Development, Learning
- Utilize FAIR, CDD, CDM, CDEF principals

Common Data Dictionary (CDD)

- The objective of the AM CDD is to provide definitions of a common set of concepts, data elements in a domain which define the basis of AM data collection, integration, management and exchange.
  - Use of common data dictionaries supports the ease of data collection, curation, analysis, storage and exchange.
  - Build a foundation for the subsequent development of common data exchange formats and standard data governance for a more streamlined AM development lifecycle and value chain management.



This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Designation: F3490 – 21

Standard Practice for Additive Manufacturing — General Principles — Overview of Data Pedigree[1]

This standard is issued under the fixed designation F3490; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 The scope of this document outlines the interpretation of additive manufacturing (AM) data. Currently, legacy AM data is stored in different databases or data management systems, each of which uses its own data dictionary. A common data dictionary allows AM data pedigree to be discovered, mapped, federated, and analyzed to improve both the understanding and qualification of AM processes and parts.

1.2 A common data dictionary facilitates the interoperability, searchability, and reusability of AM data by *(1)* identifying the general AM data pedigree elements already defined in a standardized terminology and *(2)* defining those salient terms with indisputable semantics (meanings). The goal of this document is to provide a first subset of the common data dictionary by which AM data may be collected, curated, and shared, regardless of which technology platform and software are used for data storage and exchange.

1.3 The common data dictionary also specifies a way to group AM data pedigree into fifteen information modules pertaining to different aspects of the entire additive manufacturing process.

1.4 The common data dictionary approach specifies data element names that serve to uniquely identify the AM data elements. The data type, value domain, and term definition for each data element are also specified in this practice. References are provided for those data elements with established definitions in existing standards.

1.5 The data elements identified in this common data dictionary are considered essential, because they are most frequently encountered in AM, process agnostic and technology independent. They are broadly applicable to all the process categories defined in ISO/ASTM 52900. It is intended to be a starting point, not all-encompassing.

1.6 The common data dictionary does not specify:

1.6.1 A complete set of data items to be exchanged through AM development lifecycle and value chains.

1.6.2 A minimum set of data items to be exchanged for AM lifecycle and value chain activities.

1.6.3 A common AM data exchange format.

1.6.4 The details associated with how the common descriptions of data items should be implemented for the development of new data systems or data federations among heterogeneous data systems.

1.7 Additional data elements beyond those defined in existing ASTM, ISO, AWS, NASA and SAE standards have been introduced to provide increased utility for AM. These new data items are generally common-sense and frequently used in the AM industry.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.9 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A1080 Practice for Hot Isostatic Pressing of Steel, Stainless Steel, and Related Alloy Castings

E1338 Guide for Identification of Metals and Alloys in Computerized Material Property Databases

E2077 Specification for Analytical Data Interchange Protocol for Mass Spectrometric Data

E2339 Practice for Digital Imaging and Communication in Nondestructive Evaluation (DICONDE)

[1] This practice is under the jurisdiction of ASTM Committee F42 on Additive Manufacturing Technologies and is the direct responsibility of Subcommittee F42.08 on Data.

Current edition approved Dec. 15, 2021. Published March 2022. DOI: 10.1520/F3490-21.

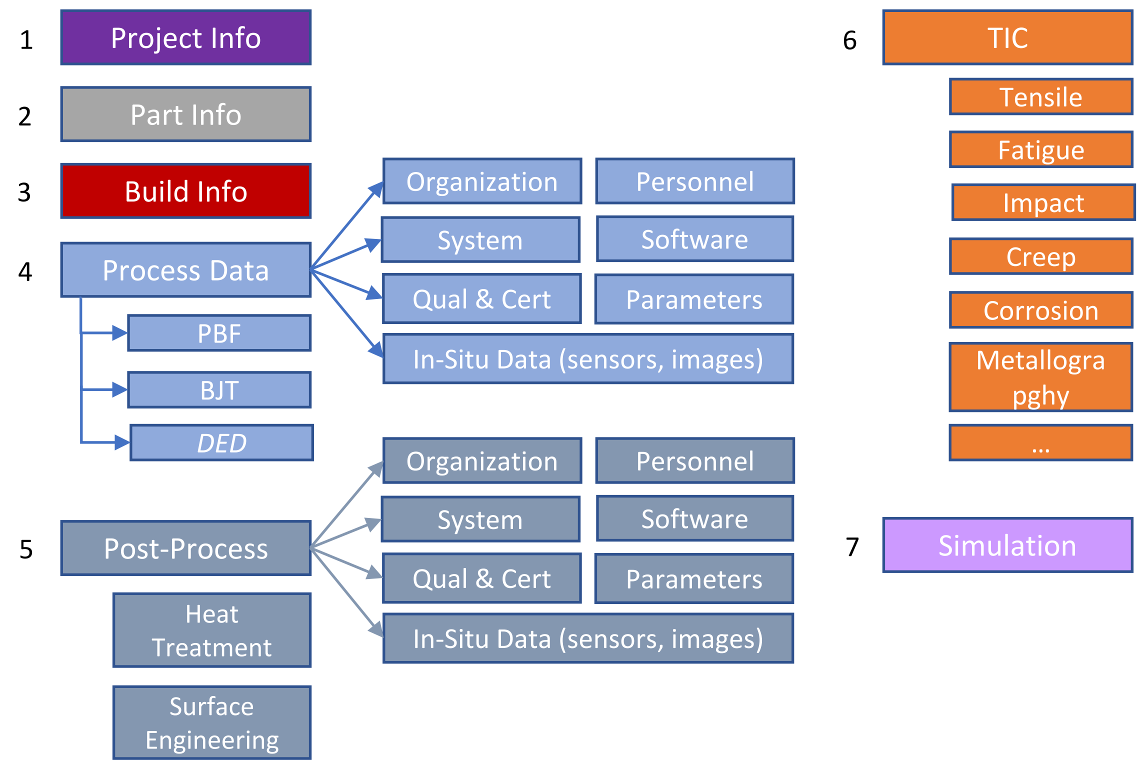
[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

- ASTM F4390 - Standard Practice for Additive manufacturing -- General principles -- Overview of data pedigree

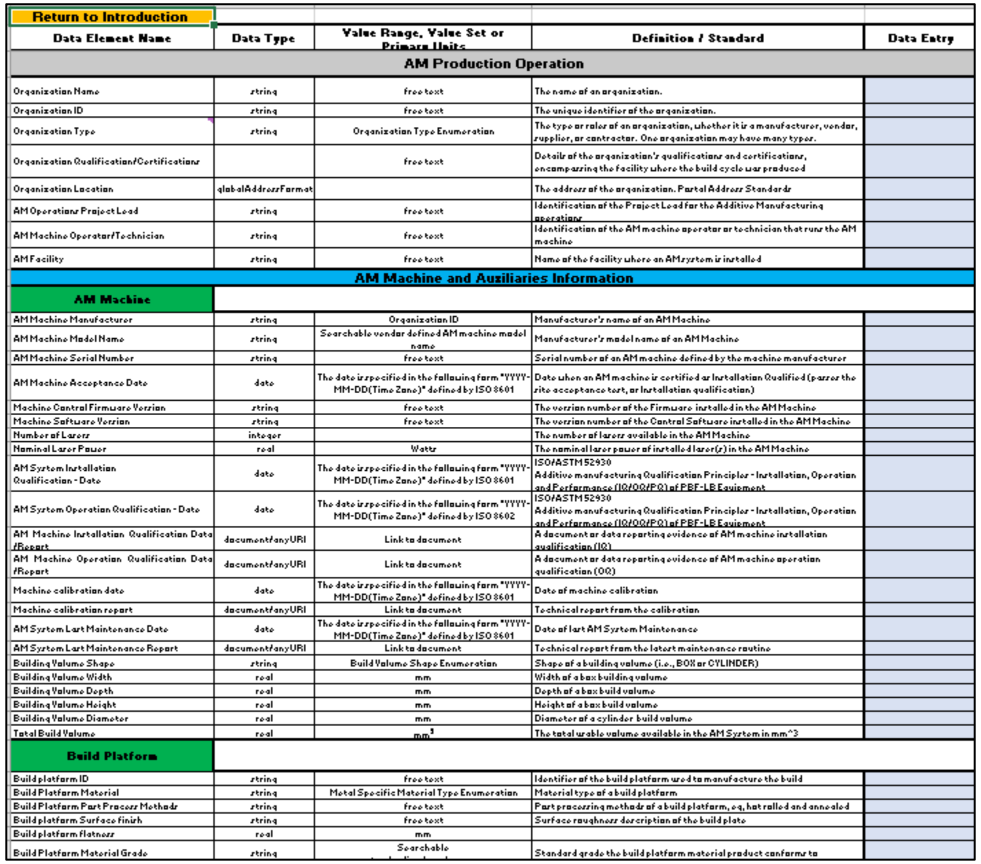
AM CoE CMDS – Data Acquisition

Common Data Dictionary (CDD) Template

2000+ data elements are being collected by CDD



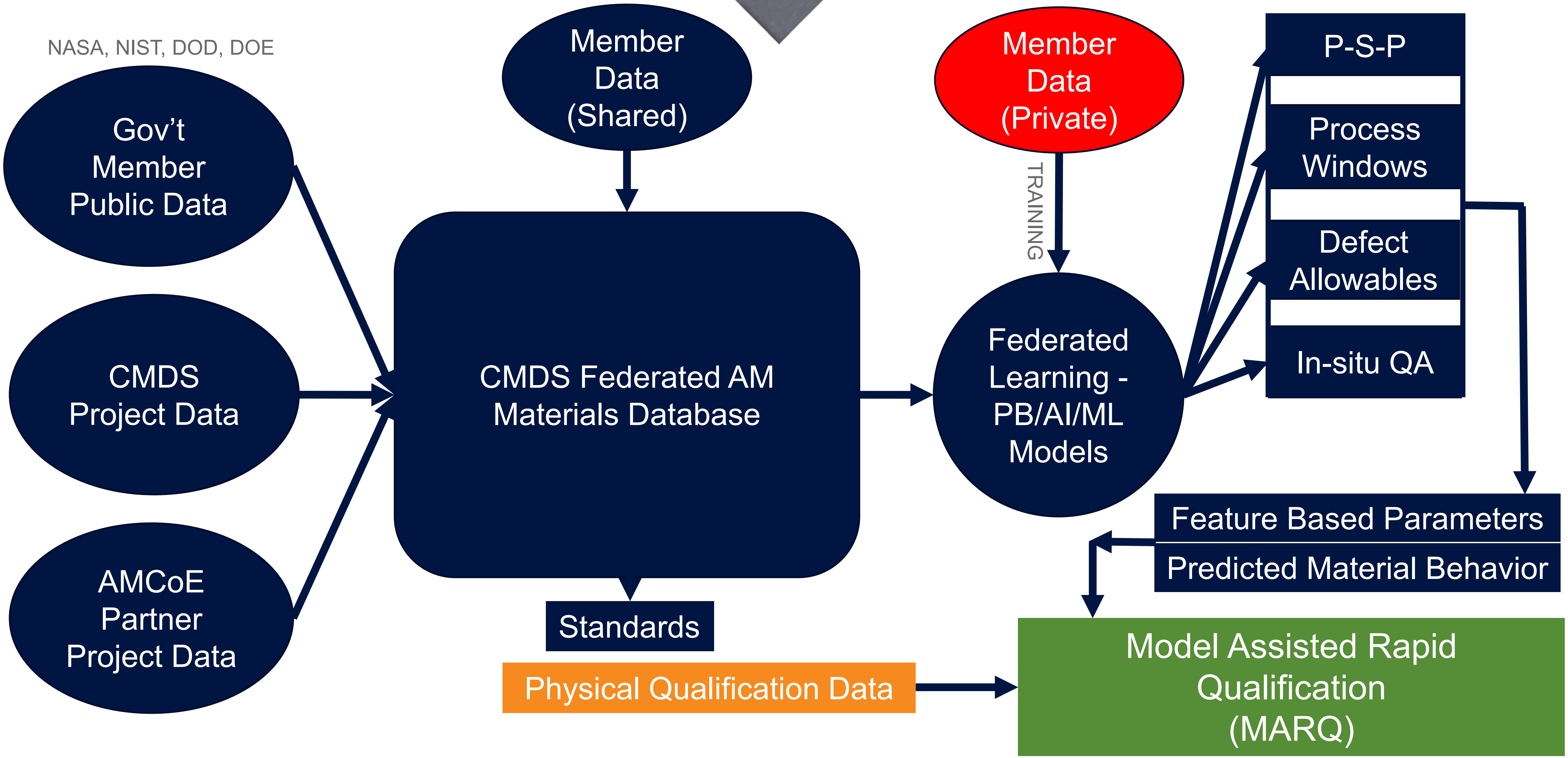
- CMDS leveraged this standard (ASTM F3490, Overview of Data Pedigree), and has developed a standard template for data acquisition.



Return to Introduction

Data Element Name	Data Type	Value Range, Value Set or Primary Units	Definition / Standard	Data Entry
AM Production Operation				
Organization Name	string	free text	The name of an organization.	
Organization ID	string	free text	The unique identifier of the organization.	
Organization Type	string	Organization Type Enumeration	The type or roles of an organization, whether it is a manufacturer, vendor, supplier, or contractor. One organization may have many types.	
Organization Qualification/Certifications		free text	Details of the organization's qualifications and certifications, encompassing the facility where the build cycle was produced	
Organization Location	globalAddressFormat		The address of the organization. Postal Address Standards	
AM Operations Project Lead	string	free text	Identification of the Project Lead for the Additive Manufacturing operations	
AM Machine Operator/Technician	string	free text	Identification of the AM machine operator or technician that runs the AM machine	
AM Facility	string	free text	Name of the facility where an AM system is installed	
AM Machine and Auxiliaries Information				
AM Machine				
AM Machine Manufacturer	string	Organization ID	Manufacturer's name of an AM Machine	
AM Machine Model Name	string	Searchable vendor defined AM machine model name	Manufacturer's model name of an AM Machine	
AM Machine Serial Number	string	free text	Serial number of an AM machine defined by the machine manufacturer	
AM Machine Acceptance Date	date	The date is specified in the following form "YYYY-MM-DD(Time Zone)" defined by ISO 8601	Date when an AM machine is certified or Installation Qualified (passes the site acceptance test, or Installation qualification)	
Machine Control Firmware Version	string	free text	The version number of the Firmware installed in the AM Machine	
Machine Software Version	string	free text	The version number of the Control Software installed in the AM Machine	
Number of Lasers	integer		The number of lasers available in the AM Machine	
Nominal Laser Power	real	Watts	The nominal laser power of installed laser(s) in the AM Machine	
AM System Installation Qualification - Date	date	The date is specified in the following form "YYYY-MM-DD(Time Zone)" defined by ISO 8601	ISO/ASTM 52930 Additive manufacturing Qualification Principles - Installation, Operation and Performance (IQ/OQ/PQ) of PBF-LB Equipment	
AM System Operation Qualification - Date	date	The date is specified in the following form "YYYY-MM-DD(Time Zone)" defined by ISO 8602	ISO/ASTM 52930 Additive manufacturing Qualification Principles - Installation, Operation and Performance (IQ/OQ/PQ) of PBF-LB Equipment	
AM Machine Installation Qualification Data /Report	document/anyURI	Link to document	A document or data reporting evidence of AM machine installation qualification (IQ)	
AM Machine Operation Qualification Data /Report	document/anyURI	Link to document	A document or data reporting evidence of AM machine operation qualification (OQ)	
Machine calibration date	date	The date is specified in the following form "YYYY-MM-DD(Time Zone)" defined by ISO 8601	Date of machine calibration	
Machine calibration report	document/anyURI	Link to document	Technical report from the calibration	
AM System Last Maintenance Date	date	The date is specified in the following form "YYYY-MM-DD(Time Zone)" defined by ISO 8601	Date of last AM System Maintenance	
AM System Last Maintenance Report	document/anyURI	Link to document	Technical report from the latest maintenance routine	
Building Volume Shape	string	Build Volume Shape Enumeration	Shape of a building volume (i.e., BOX or CYLINDER)	
Building Volume Width	real	mm	Width of a box building volume	
Building Volume Depth	real	mm	Depth of a box build volume	
Building Volume Height	real	mm	Height of a box build volume	
Building Volume Diameter	real	mm	Diameter of a cylinder build volume	
Total Build Volume	real	mm^3	The total usable volume available in the AM System in mm^3	
Build Platform				
Build platform ID	string	free text	Identifier of the build platform used to manufacture the build	
Build Platform Material	string	Metal Specific Material Type Enumeration	Material type of a build platform	
Build Platform Part Process Methods	string	free text	Part processing methods of a build platform, eg, hot rolled and annealed	
Build platform Surface finish	string	free text	Surface roughness description of the build plate	
Build platform flatness	real	mm		
Build Platform Material Grade	string	Searchable	Standard grade the build platform material product conforms to	

AM CoE CMDS – To-Be Vision



October 30 - November 3 | Washington D.C.

Addressing application specific requirements of various industry sectors in addition to covering the fundamentals of advanced manufacturing processes with the goal of transitioning *research to application through standardization*.

GENERAL STATISTICS

- **700+** total presentations
- **26** symposia
- **10** live panel discussions
- **08** keynotes

1000+ registered attendees

- **25.3%** from Academia
- **8.1%** from Government
- **53.7%** from Industry
- **12.9%** from Research Institutes

420+ participating organizations

- 27.9% Academia
- 5.6% Government
- 59.6% Industry
- 6.8% Research Institutes

- **33** organizations with 5 or more attendees
- **08** organizations with 10 or more attendees
- **04** organizations with 15 or more attendees

AM Standards Forum

- This one-day workshop at Formnext 2023 is dedicated to discussing the standardization needs for additive manufacturing and will enable you to engage with experts to discuss standard practices and overcome implementation challenges.

Organized by: U.S. Commercial Service, United States of America Department of Commerce; ASTM International; ISO International Organization for Standardization; America Makes

Consortium for Materials Data & Standardization (CMDS)

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Research to Standards
ADDITIVE MANUFACTURING

➢ Global Consortia for Materials Data & Standardization enables companies of all sizes from across the entire Additive Manufacturing ecosystem to collaborate on standardizing the requirements and best practices for high-pedigree materials data generation and creating, curating and managing the data needed to accelerate the industrialization and full adoption of AM technologies.

- OEM/LSI End Users
- AM Equipment Manufacturer
- AM Contract Manufacturer/Supplier
- AM Materials/Feedstock Producer
- AM Post-processing and Testing Service Provider
- AM Software
- AM Process/Health Monitoring
- Industrial Equipment Producer (e.g., Furnace, Powder Handling Equipment,…)
- Government Agencies and Laboratories (DoD, DOE, NASA, NIST)

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Thank you.

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