Joint Metal Additive Database Definition (JMADD)

5511.001

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Overview

Driven by…

Project Call - Additive Manufacturing for High Temperature Metals

Contract ID : FA8650-20-2-5700 P00007 (ACRN: AC, SUBCLIN: 000103)

Technology Roadmap Swimlane Alignment : Materials

- Materials – M.1 Define Standard AM Material Requirements (M.1.2), M.3 Develop AM Materials (M.3.1), M.5 Establish DoD-wide AM data repository, M.6 Develop model-based approaches to accelerate materials and qual and cert
- Process – P.1 Develop and Validate NDE Capabilities, P.2 Establish Stable and Robust AM processes (P.2.1, P.2.2, P.2.3, P.2.4)

Period of Performance: October 1, 2020, thru Oct 31, 2024

Total funding: $4.24M

Total Government Funding: $1.8M

Total Cost Share: $2.44M

Funding Organization: OSD ManTech

Project Objective

Driven by…

To produce a set of publicly available statistically substantiated material property data of bulk material properties for metallic AM material with a corresponding material and process specification as well as a framework for future database development projects.

The selection of a single material and process is necessary to manage the scope of such project, and to begin the work of identifying a standard process to develop material allowables and design data for Metal AM. The initial process and material combination for the scope of this project is Laser Powder Bed Fusion (L-PBF) of Ti-6Al-4V grade 5 alloy.

The overall objective is to achieve B and A-basis (T90 and T99) design allowable data and establish a best practice for developing AM allowables and specifications that is publicly available for L-PBF of Ti-6Al-4V.

Task 2 Results – Qualification 1 (Virgin)

Driven by…

Task 2 was initiated in December 2022 and will be completed in April 2024

Machine architecture: EOS M290

Three Ti-6Al-4V grade 5 powder suppliers (AP&C, ATI, and Tekna)

Three fabrication sites: (1) Beehive industries, (2) Boeing Commercial Airplanes, and (3) NIAR – Wichita State University

19 feedstock lots total (10+ req'd)

10+ unique heats

Lot release tensile test from each build

Static, fatigue, RTA to 700°F ETA testing

Physical testing

Feedstock testing

NDI by X-CT for a subset of specimens

Four build designs

Fully pedigreed data

Site/site, run/run, lot/lot, and build design comparisons

Microstructure evaluation

All specimens are will be tested as-machined

D11

D12

D13

D14

Qualification 1 Updates

Driven by…

Fabrication plan

All Qualification 1 specimens have been fabricated and machined

Of the approximately 1733 total specimens defined for Qualification 1 testing, 1599 specimens have been inspected and processed through QC to mechanical test.

Testing for the fabricated, HIP, and machined specimens is ongoing. (Preliminary reduced data presented in the following slides)

Test results from the blended reuse powder from all three fabricators were received from NSL Analytical (Test results will be presented in the following Task 3 results slides)

“Before-blend reuse” powder will also be sampled and tested (powder testing is in process)

Qualification dataset 1 generation to be completed by the end of April 2024.

Qualification 1: ASTM B769 (Shear)

Driven by…

Includes all 95 tested ASTM B769 specimens across 7 NIAR builds and 3 Boeing builds were tested.
The data shows that specimens fabricated with ATI Lot 5 and Lot 7 yielded higher shear strength.
Between the orientation data groups, ZX specimens averaged higher results, followed by ZX45, then XY specimens. Similar trends were observed in the prequalification studies.

	Average Shear Strength (ksi)	Standard Deviation	Coefficient of Variation (%)
ZX	102.68	3.36	3.28
XY	100.41	3.18	3.17
ZX45	101.84	2.91	2.86

Qualification 1: ASTM E9 (Compression)

Driven by…

A total of 95 specimens were tested, across 7 NIAR builds and 3 Boeing builds.
There was a separation between the orientation data groups similar to the prequalification studies, with ZX and ZX45 specimens averaging higher UCS.
The data also displayed the similar trend as E8 and B769 tests, where specimens fabricated with ATI Lot 5 and Lot 7 averaged higher UCS

	Ultimate Compression Strength [ksi]	0.2% Offset Yield Strength (ksi)	Compression Modulus (Msi)
Average	211.63	160.16	17.65
Stand			

Average/ [.anC17. O17.f[

Qualification 1: ASTM E209 (Elevated temp.)

Driven by…

Eight specimens were tested at each elevated test temperature.
ETA degradation curve was generated per MMPDS Figure 5.4.1.1.2. utilizing the Qual 1 compressive yield strength of 160.16 ksi.
Upon reviewing the gathered compression data, the percent knock down of the average compressive yield strength are slightly lower when compared to MMPDS's temperature degradation curve knockdown (see table below).

Blue texts in table are CoV's (%)

Qualification 1: ASTM E238 (Bearing)

Driven by…

90 bearing specimens (E/D=2.0) were tested across 9 NIAR builds and 3 Boeing Builds. (E/D=1.5 will be tested in Qualification 2)
The data across builds performed similarly, except for build N9 and N12, which yielded higher results.
This is attributed to the higher interstitial elements within the ATI powder Lot 5 and Lot 7.
There was also a separation between the orientation data groups with ZX45 specimens averaging higher bearing strength, followed by ZX then XY specimens.

	Ultimate Bearing Strength (ksi)	2% Offset Bearing Strength (ksi)
Average	315.13	259.50
Standard Deviation	9.40	10.47
CoV [%]	2.98	4.03

Qualification 1: ASTM E399 (Fracture Toughness)

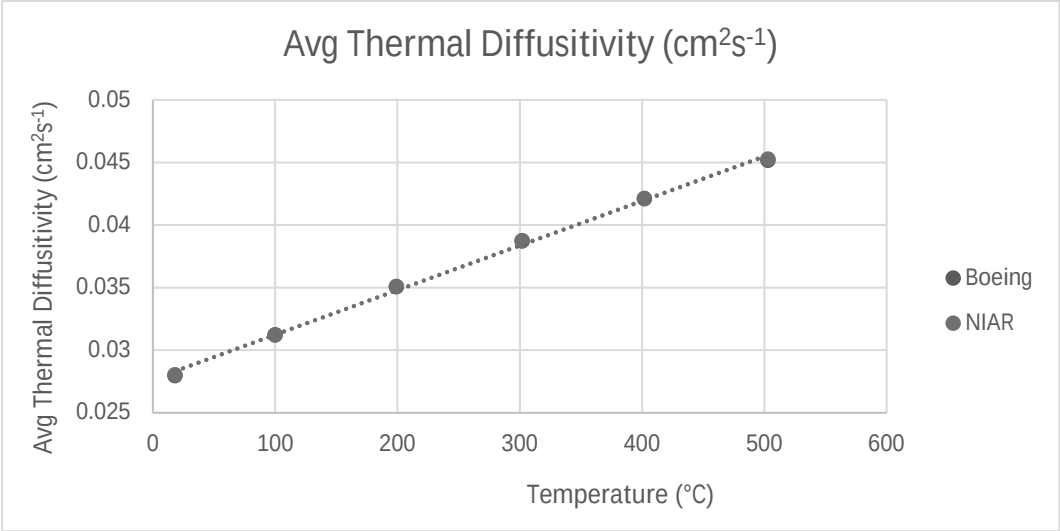
Driven by…

78 specimens were tested. (W=1 inch)
The fracture toughness (K1C) values reported compare closely to those of conventionally manufactured Ti64, which ranges between 40 to 60 ksi√in (Kumar, Prakash, & Ramamurty, 2018).
A separation between orientation data groups was observed, with XY orientation specimens yielding higher K1C values followed by ZX45, and then ZX. Similar trends observed by Kumar and Ramamurty (2019)
Researchers also reported lower K1C when the configuration of the crack growth occurs parallel to the

Qualification 1: Thermal Diffusivity and Conductivity

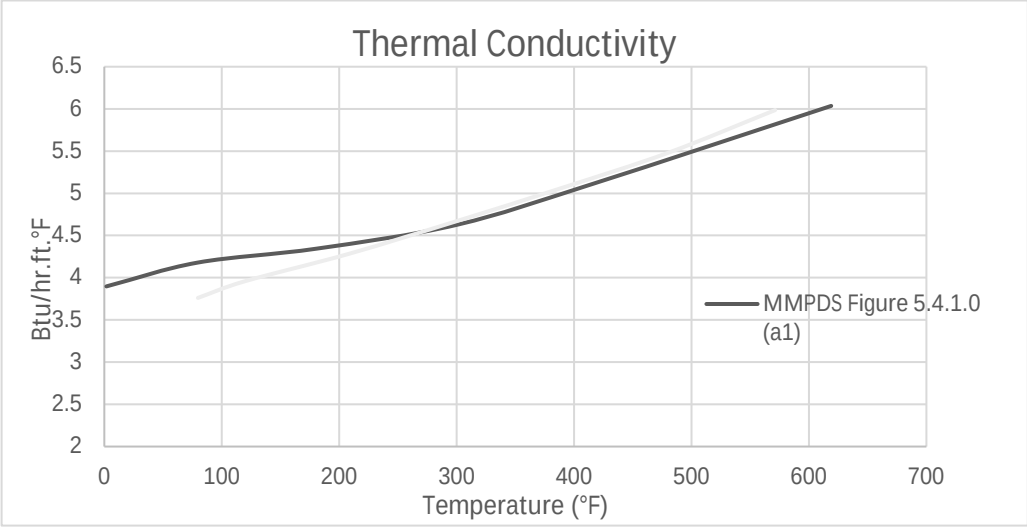
Driven by…

ASTM E1461



		Temperature (°C)					
		18	100	199	302	402	503
Boeing	Average (cm²s⁻¹)	0.0280	0.0312	0.0351	0.0387	0.0421	0.0452
	Standard Deviation	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002
	CoV (%)	0.4932	0.5228	0.5890	0.4449	0.3680	0.4354
NIAR	Average (cm²s⁻¹)	0.0280	0.0312	0.0351	0.0388	0.0421	0.0453
	Standard Deviation	0.0004	0.0005	0.0006	0.0006	0.0006	0.0007
	CoV (%)	1.5891	1.5893	1.5878	1.4818	1.4964	1.4639

ASTM E1530 (NIAR results only)



Mean specimen Temperature (°F)	Average BTU/**h·ft·**°F	CoV %
79.78	3.79	0.67
121.38	3.96	0.19
210.77	4.32	0.56
301.40	4.68	0.39
391.09	5.08	0.53
481.08	5.51	0.54
571.23	5.97	0.59

Qualification 2 (Virgin (50%) + Reuse (50%))

Task 3 was initiated in July 2023 and will be completed in October 2024

The qualification 1 test matrix is repeated for the qualification dataset 2

The build designs, powder suppliers, and fabricators are identical to qualification 1

Quali99m17i99m1cati99m1on 2 Updates

All qualification 2 fabrication is complete[redacted]

Elcan Industries has completed all sieving and blending work for all JMADD powder lots.

All fabricated Qual 2 builds are now undergoing the necessary JMADD post-processing steps before final specimen machining.

Testing for dataset 2 has begun (initiated December 19, 2023).

Preliminary test results will be presented in the following slides

[redacted]

Qualification 2: ASTM E8 (Tension)

Driven by…

Includes all 48 tested ASTM E8 specimens across 5 NIAR builds, and across five ATI powder lots.
The data across most builds performed closely, except for build N42 fabricated with ATI Lot 12 which yielded lower results.
Specimen fabricated with ATI lot 7-10 yielded higher results when compared to the Qualification 1 average tensile strength.
Between the orientation data groups, ZX specimens averaged higher performance, followed by ZX45, then XY. Similar trends observed in the Qualification 1 testing.

JMADD Metallography Discussion

Driven by…

Summary

Since TRX 2023:

- Prequalification work completed
- Qualification 1 fabrication complete
- Dataset generation for qualification 1 in process
- Qualification 2 fabrication completed, and testing is in process

Takeaways

- Mechanical properties across fabricators appear to perform closely (CoV’s

Next steps

Driven by…

Continue testing all specimens and analyzing reduced test results.

Once Qualification 1 dataset is populated, statistical analysis for NCAMP B-basis allowable determination will begin. (Data will be shared with MMPDS for S/C-basis analysis concurrently)

Qualification dataset 1 to be published at the end of April 2024.

Continue post-processing and machining fabricated Qualification 2 specimens.

Tested specimens will be outsourced for bulk material elemental analysis (ICP-AES) in the final material state.

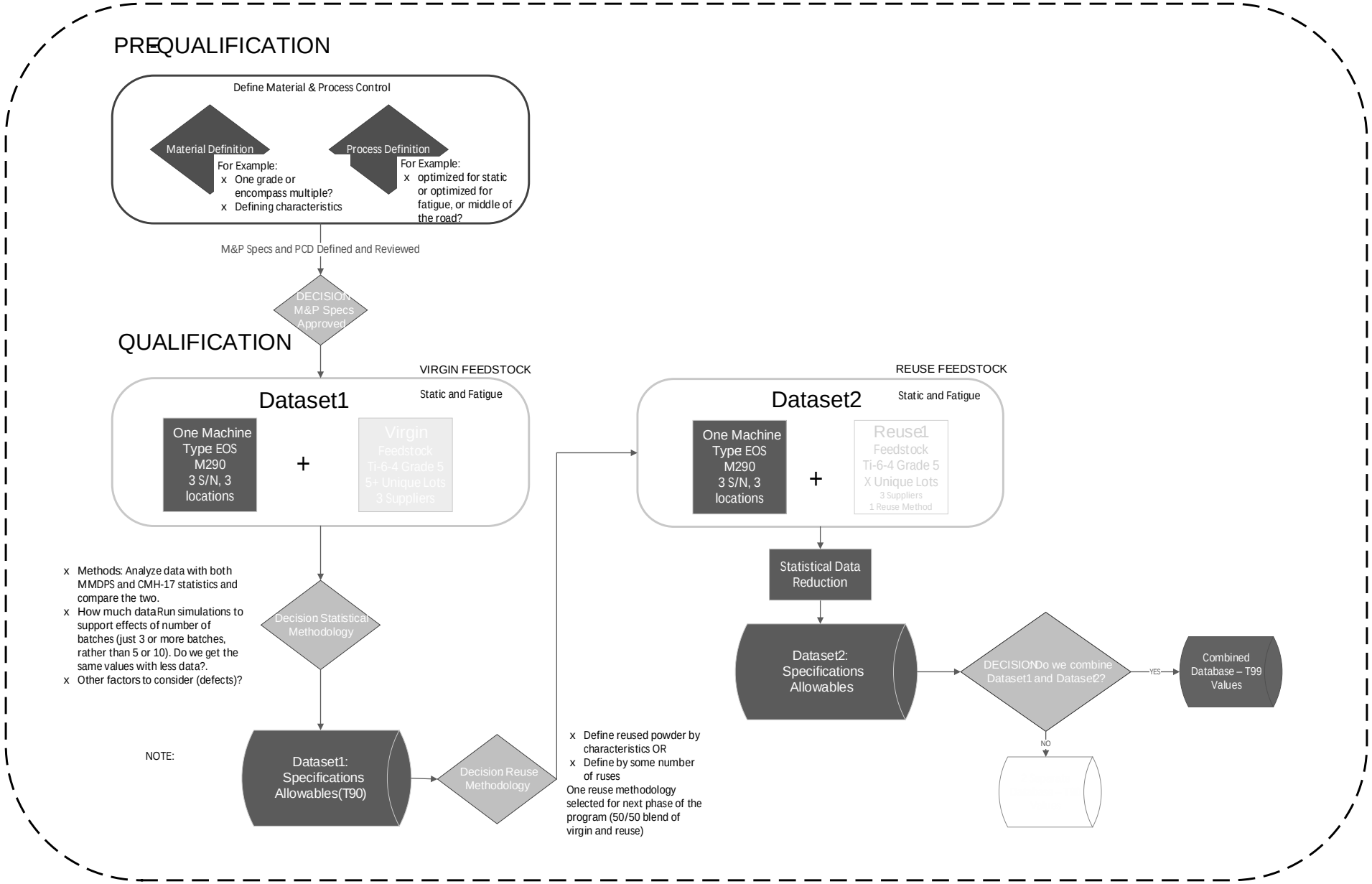
Continue to test, analyze, and populate qualification 2 dataset

Final publications

Backup/Appendix

Project Schedule

Driven by…


PREQUALIFICATION
Define Material & Process Control
Material Definition
For Example:
x One grade or encompass multiple?
x Defining characteristics
Process Definition
For Example:
x optimized for static or optimized for fatigue, or middle of the road?
M&P Specs and PCD Defined and Reviewed
DECISION: M&P Specs Approved
QUALIFICATION
VIRGIN FEEDSTOCK
Static and Fatigue
Dataset1
One Machine Type EOS M290 3 S/N, 3 locations
+
Virgin Feedstock Ti-6-4 Grade 5 5+ Unique Lots 3 Suppliers
x Methods: Analyze data with both MMDPS and CMH-17 statistics and compare the two.
x How much dataRun simulations to support effects of number of batches (just 3 or more batches, rather than 5 or 10). Do we get the same values with less data?.
x Other factors to consider (defects)?
Decision Statistical Methodology
NOTE:
Dataset1: Specifications Allowables(T90)
Decision Reuse Methodology
x Define reused powder by characteristics OR
x Define by some number of ruses
One reuse methodology selected for next phase of the program (50/50 blend of virgin and reuse)
REUSE FEEDSTOCK
Static and Fatigue
Dataset2
One Machine Type EOS M290 3 S/N, 3 locations
+
Reuse1 Feedstock Ti-6-4 Grade 5 X Unique Lots 3 Suppliers 1 Reuse Method
Statistical Data Reduction
Dataset2: Specifications Allowables
DECISION: Do we combine Dataset1 and Dataset2?
YES
Combined Database – T99 Values
NO

Qualification Cyclic Mechanical Tests

Driven by…

						Number of Heats x Number of Machines x Runs per Machine x Number of Specimens per build		
						Test Temperature / Moisture Condition		
Build Orientation	Test Type	ASTM Standard	R-Value	Stress Levels	Property	RTA (70°F/21 C)	ETA (600°F/316 C)	Coupons Fabricated and TestedBj -0.XY0 1 <</M