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Joint Metal Additive Database Definition (JMADD): Baseline Qualification and Expansion Activities

May 20, 2025

INDUSTRIAL MODERNIZATION OF MATERIALS & MANUFACTURING

Joint Centers of Excellence for Advanced Materials

Federal Aviation Administration

America Makes

CECAM center of excellence for composites and advanced materials

Research Team & Objectives

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John Tomblin, PhD
Senior Vice President for Industry and Defense Programs, WSU-NIAR Executive Director


Rachael Andrulonis
Director of Advanced Materials Research


Royal Lovingfoss
Director of Advanced Materials Lab


Mark Shaw
Chief Engineer, Defense Industrial Base Strategy


Lauren Tubesing
Business Development Leader, Advanced Manufacturing Strategy


Brandon Saathoff
Senior Engineering Manager, Advanced Materials Research


Eathan Devine
Research Engineer, Advanced Materials Research


Neville Tay
Research Engineer, Advanced Materials Research


Cindy Ashforth
Senior Technical Specialist for Advanced Composite Materials


Michael Gorelick
Chief Scientific and Technical Advisor for Fatigue and Damage Tolerance

Ahmet Oztekin, PhD
Advanced Materials Research Program Manager, JAMS Program Manager

Kevin Stonaker
Technical Monitor

PROJECT OVERVIEW

- **Project Partners:**
  - Boeing, Beehive Industries (specimen fabrication), ELCAN (powder sieve & blend), ATI, AP&C, & Tekna (powder suppliers), 100+ Public advisory committee members, 33 government steering committee members

- **PROJECT OBJECTIVES**
  - Establish a framework for developing statistically significant material databases of metal AM materials.
  - Expand the framework to additional AM machine types, powder reuse and other changes in the manufacturing process.
  - Generate allowables (T90 and T99) and specifications for Ti64 grade 5 and EOS M290 material-machine combination for publication in MMPDS.

FAA JAMS – Metal AM | Program Overview

M-JMADD	**JMADD** **Joint Metal Additive Database Definition**	Baseline qualification program for Ti-6-4/EOS M290 *Jointly funded with OSD ManTech*
M-JMADX	**JMADD Expansion**	• Generate data on 4th JMADD machine for dataset inclusion. • Development of fatigue curves for various post processing conditions.
M-MASFI	**Surface Inspection**	Investigate as-printed surface design values and bulk material inspection methods on fatigue sensitive LPBF components.
M-NANPQ	**New Alloy/Process Qualification**	Qualification of new alloy/process of interest to the FAA and related industry.
M-BBFLP	**Building Block**	Investigate feature-level performance debits for AM test articles via static test characterization.

Agenda

- Overview of Ti-6Al-4V Grade 5 Projects
- Reporting and Documentation Update
- JMADD Testing Updates
- JMADD Statistics Discussion
- Fatigue data updates
- Microstructure and Chemistry
- Lessons learned and Next Steps

Overview Ti-6Al-4V Grade 5 Projects

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JMADD (3 machines)

BEEHIVE INDUSTRIES BOEING NIAR

JMADX (4th machine)

NIAR

JMADD fifth machine

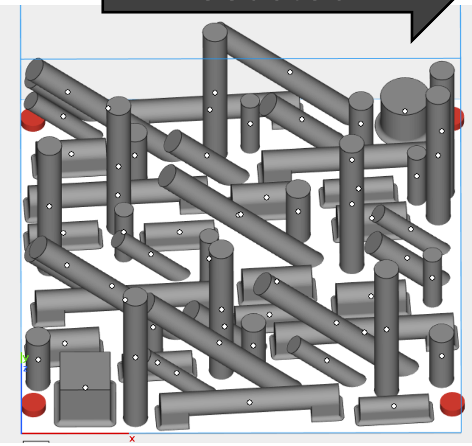
3D SYSTEMS

Test Type	Number of specimens tested *(across orientations and test temperatures)*					*5 machine total specimen count*	*MMPDS C- and D-Basis Requirements and Recommendations x 3 orientations (XY, ZX45, ZX)*
	NIAR (M290)	Beehive (M290)	Boeing (M290)	NIAR (GE-M2) *(in-process)*	3D Systems *(DMP Flex 350)* *(in-process)*		
E8 – Tension	369	292	104	132	132	**1029**	**100 x 3 = 300** Across 5 machines, 10 heats
E9 – Compression	175	143	51	66	66	**501**	**100 x 3 = 300** Across 5 machines, 10 heats
B769 – Shear	174	148	54	66	66	**508**	**100 x 3 = 300** Across 5 machines, 10 heats
E238 – Bearing	146	134	45	36	36	**397**	**100 x 3 x 2 (two e/D ratios) = 600** Across 5 machines, 10 heats
E399 – Fracture Toughness	154	130	39	36	36	**395**	**30 x 3 = 90** Across 3 machines, 3 heats
E606/466 – Fatigue	143	113	48	108	-	**412**	***Recommended*** • Load control: 6 test per stress ratio (R), 3 stress ratios, no minimum heat or lot requirements • Strain control: 10 tests for Rg = -1.0, 6 tests other strain ratios

JMADD Qualification Process Chain

Build Design

Feedstock



Fabrication

Build Inspection

CLEAN

SR 700 °C

SHIP

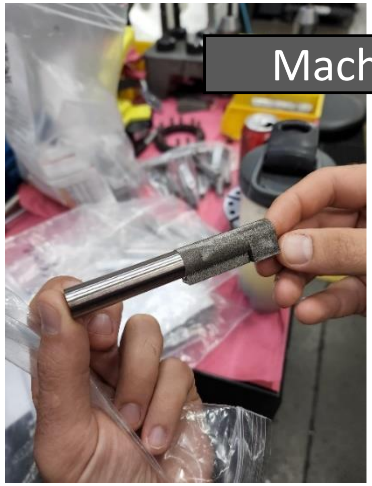
Wire-EDM

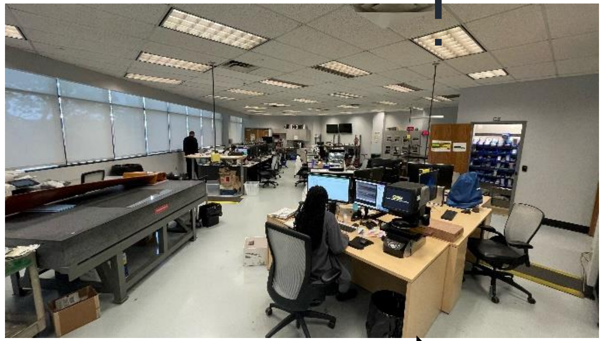
CLEAN

HIP

(195 MPa, 815°C)

Machining





Quality Control

Testing

All specimens are SR, HIP-ed, and Machined

Reporting Deliverables

Organization	Report/Specification	Contents	Status	Completion date
NCAMP	NAPS 065 - NCAMP Process specification (Rev A)	• This document defines the minimum requirements for control of the L-PBF process.	Revision in process	5/31/25
	NFS 064 - NCAMP Feedstock Specification (Rev A)	• This document provides the required test methods and specification limits for all feedstock powder.	Revision in process	5/31/25
	NAMS 064 - NCAMP Material specification (Rev A)	• This additive specification establishes the requirements for the finished printed material properties of LPBF Ti64.	Revision in process	5/31/25
	NPCD 81064 - NCAMP Process Control Document (Rev C)	• Process Control document for EOS M290	Revision in process	5/31/25
	NTP-AM-1064Q1 - NCAMP Test Plan (Rev C)	• Outlines number of specimens required for each test type	Uploaded	5/31/25
	NCAMP Material Property Data Report	• Compilation of all raw data with summary statistics (mean, SD, and CoV)	In Review	5/31/25
FAA	FAA Technical Report Parameter Set Comparison Study	• Results and recommendation on Parameter Set Comparison Study	Submitted to FAA	Submitted
	FAA Technical Report on Lessons Learned and Guidelines	• JMADD fatigue results, statistical guidelines, and lessons learned throughout project (prequal and qual)	In process	5/31/25
America Makes	1st Revision of Baseline JMADD Report on Static and Physical Properties *Future revisions will be made to this report to include:* • *JMADD 5th machine results* • *JMADD Fatigue + Corrosion results*	• Final report including objective, methodology and summary graphs and tables of test results (prequal and qual) with basic statistics (mean, SD, COV)	1st revision Submitted to America Makes	1st Revision Complete

JMADD Testing Status

Pre-Qualification (Task 1) Virgin powder fabrication	Qualification 1 (Task 2) Virgin powder fabrication			Qualification 2 (Task 3) Reuse (50/50) blend fabrication		
Parameter Comparison Study	Static mechanical testing			Static mechanical testing		
Orientation Down-selection study	Physical property testing			Physical property testing		
Site comparison study	Room temperature LCF and HCF			Room temperature LCF and HCF		
	Grain Size Analysis					
	Remaining tests:	**Progress (%)**	**Estimated Completion**	**Remaining tests:**	**Progress (%)**	**Estimated Completion**
	LCF @ 600°F	85%	End of May	EBSD, grain size analysis	60%	End of June
				LCF @ 600°F	7%	End of June

Completed
In-progress

Updates:

- Qualification 1 and 2 static data have been compiled and sent to MMPDS for statistical analysis.
- NIAR working on comparing statistical analysis between CMH-17 and MMPDS.
- Fatigue data analysis on-going (S-N curve generation and fractography).

MMPDS vs CMH-17 Allowables Comparison (Orientations Separated)

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PRESENTED ALLOWABLES ARE NOT FINAL!

		MMPDS S-basis values (3 machines)						CMH-17 ANOVA Method T90 = B-basis T99 = A-basis						AMS 4992 Investment Castings		AMS 4934 Extrsuion - Solution treated and aged		AMS 4928 bar and die forging		AMS 7028 Ti-6Al-4V, HIP (Low Temperature, High Pressure), Produced by Laser Powder Bed Fusion
		QUAL 1 ONLY n = 365		QUAL 2 ONLY n = 359		QUAL 1 + Qual 2 n = 724		QUAL 1 ONLY n = 365		QUAL 2 ONLY n = 359		QUAL 1 + Qual 2 n = 724		Thickness <0.500		Thickness <0.500		0.5-1.0		E8 specimen 3
Property	**(orientation)**	**T99**	**T90**	**T99**	**T90**	**T99**	**T90**	**T99**	**T90**	**T99**	**T90**	**T99**	**T90**	**T99**	**T90**	**T99**	**T90**	**T99**	**T90**	Minimum tensile properties
Ultimate Tensile Strength	(XY)	154	154	145	151	149	152	141	148	141	149	143	149	125	129	155	163	135	142	150
	(XY45Z)	153	154	143	151	148	152	141	148	141	149	142	149							
	(Z)	153	155	144	152	148	152	140	148	142	150	142	150							151
Yield Strength	(XY)	140	140	130	138	135	138	126	134	127	135	128	135	111	116	138	147	125	134	136
	(XY45Z)	140	141	132	139	135	138	126	135	126	135	127	136							
	(Z)	142	144	133	142	137	141	129	137	130	139	131	139							140
Elongation (%)	(XY)	12	13	10	12	11	13	11	13	11	12	11	13							11
	(XY45Z)	11	13	10	13	10	13	10	13	12	13	11	13							
	(Z)	15	16	13	15	14	16	15	16	14	15	15	16							14

		MMPDS ATII-12 removed n = 341		MMPDS ATI-12 removed n = 706		CMH-17 ATI - 12 removed n = 341		CMH-17 ATI-12 removed n = 706	
Property	**(orientation)**	**T99**	**T90**	**T99**	**T90**	**T99**	**T90**	**T99**	**T90**
Ultimate Tensile Strength	(XY)	147	152	150	152	143	150	143	150
	(XY45Z)	146	152	150	154	142	150	142	150
	(Z)	147	153	151	155	143	151	143	150
Yield Strength	(XY)	133	138	136	138	128	136	128	136
	(XY45Z)	132	139	136	141	127	136	127	136
	(Z)	136	143	141	144	131	140	131	139
Elongation (%)	(XY)	10	12	11	13	11	12	11	13
	(XY45Z)	11	13	10	13	12	13	11	13
	(Z)	13	15	14	16	14	15	14	16

Note: Secondary test speeds for tensile test used in JMADD and AMS7028 are different. Secondary speed in JMADD is 0.1 in/in/min. and AMS7028 were tested using 0.05 in/in/min. Comparisons are only for informational purposes.

T99 and T90 calculated omitting specimens fabricated by ATI powder lot 12. Oxygen (wt%) was below 0.11% (out of specification per AMS 7015)

MMPDS vs CMH-17 (Non-parametric) Allowables Comparison

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PRESENTED ALLOWABLES ARE NOT FINAL!

Property	(orientation)	MMPDS S-basis values (3 machines): QUAL 1 ONLY n=365 T99	T90	QUAL 2 ONLY n=359 T99	T90	QUAL 1 + Qual 2 n=724 T99	T90	CMH-17 Non-Parametric (T90 = B-basis, T99 = A-basis): QUAL 1 ONLY n = 365 T99	T90	QUAL 2 ONLY N = 359 T99	T90	QUAL 1 + Qual 2 N=724 T99	T90	AMS 4992 Investment Castings, Thickness <0.500 T99	T90	AMS 4934 Extrsuion - Solution treated and aged, Thickness <0.500 T99	T90	AMS 4928 bar and die forging, 0.5-1.0 T99	T90	AMS 7028 Ti-6Al-4V, Hot Isostatically Pressed (Low Temperature, High Pressure), Produced by Laser Powder Bed Fusion, E8 specimen 3: Minimum tensile properties
Ultimate Tensile Strength	(XY)	154	154	145	151	149	152	152	154	142	149	144	149							150
	(XY45Z)	153	154	143	151	148	152	151	154	143	150	146	150	125	129	155	163	135	142	
	(Z)	153	155	144	152	148	152	152	154	144	151	147	151							151
Yield Strength	(XY)	140	140	130	138	135	138	138	140	128	135	130	135							136
	(XY45Z)	140	141	132	139	135	138	138	140	131	137	133	137	111	116	138	147	125	134	
	(Z)	142	144	133	142	137	141	137	141	134	140	136	140							140
Elongation (%)	(XY)	12	13	10	12	11	13	11	13	7	10	7	10							11
	(XY45Z)	11	13	10	13	10	13	10	12	10	12	10	12							
	(Z)	15	16	13	15	14	16	12	15	11	13	11	13							14

Property	(orientation)	MMPDS ATI-12 removed N = 341 T99	T90	MMPDS ATI-12 removed N = 706 T99	T90	CMH-17 ATI -12 removed N = 341 T99	T90	CMH-17 ATI - 12 removed n = 706 T99	T90
Ultimate Tensile Strength	(XY)	147	152	150	152	146	151	148	151
	(XY45Z)	146	152	150	154	144	151	147	151
	(Z)	147	153	151	155	147	152	149	152
Yield Strength	(XY)	133	138	136	138	132	137	134	137
	(XY45Z)	132	139	136	141	131	138	134	138
	(Z)	136	143	141	144	136	142	138	141
Elongation (%)	(XY)	10	12	11	13	7	10	7	10
	(XY45Z)	11	13	10	13	10	12	10	12
	(Z)	13	15	14	16	11	13	11	13

Note: Secondary test speeds for tensile test used in JMADD and AMS7028 are different. Secondary speed in JMADD is 0.1 in/in/min. and AMS7028 were tested using 0.05 in/in/min. Comparisons are only for informational purposes.

T99 and T90 calculated omitting specimens (18) fabricated by ATI powder lot 12. Oxygen (wt%) was below 0.11% (out of specification per AMS 7015)

Build to Build Variation across Virgin and Reuse from same powder lot

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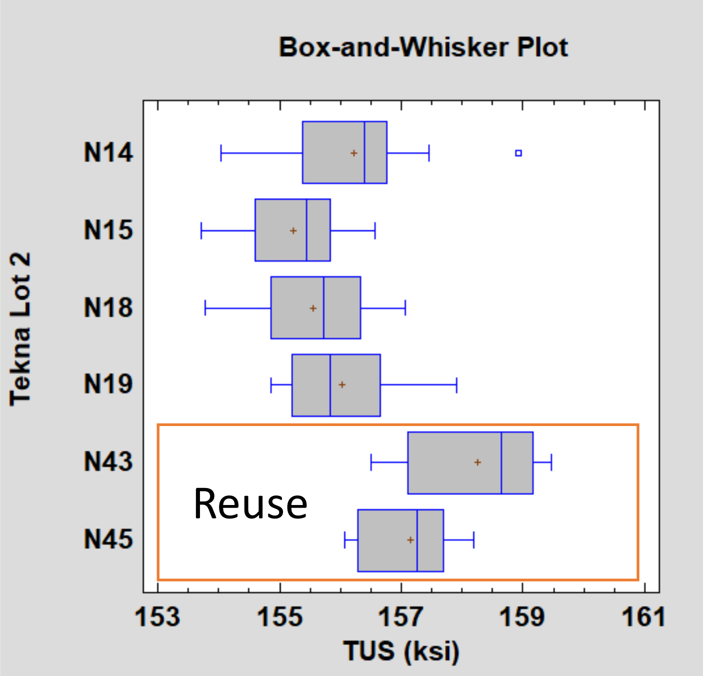
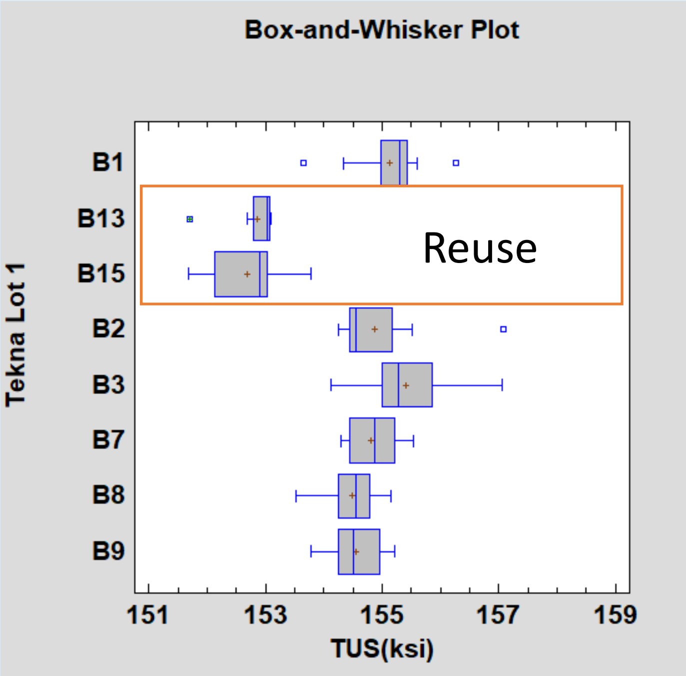
NIAR Builds

- 70 data points across 6 builds from same Tekna powder lot 2 (4 Virgin builds, 2 Reuse Builds)
- Data approximates a normal distribution
- ANOVA P-value = 0.0001 (**Significant difference between the mean**)
- Levene's test P-value 0.8622. There is not a statistically significant difference amongst the standard deviations



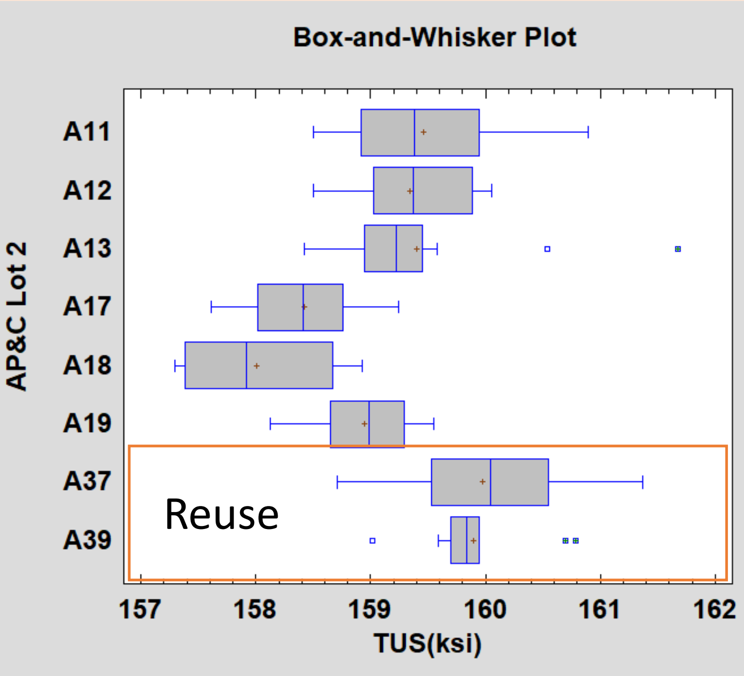
Boeing Builds

- 74 data points across 8 builds from same Tekna powder lot 1 (6 Virgin builds, 2 Reuse Builds)
- Data approximates a normal distribution
- ANOVA P-value = 0.0001 (**Significant difference between the mean**)
- Levene's test P-value 0.669. there is not a statistically significant difference amongst the standard deviations



Beehive Builds

- 82 data points across 8 builds from same AP&C powder lot 2 (6 Virgin builds, 2 Reuse Builds)
- Data approximates a normal distribution
- ANOVA P-value = 0.0001 (**Significant difference between the mean**)
- Levene's test P-value 0.7594. there is not a statistically significant difference amongst the standard deviations

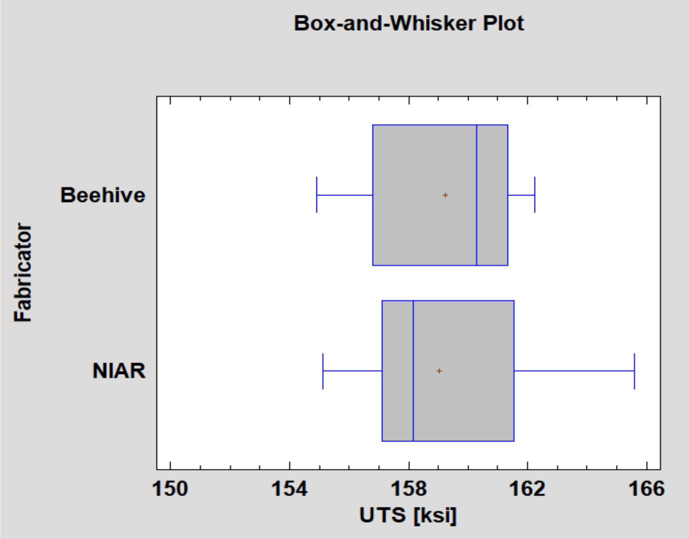


Machine to Machine variability

- Interstitial elements across 6 powder lots (5 virgin and 1 reuse):
  - Oxygen 0.142% - 0.15%
  - Nitrogen 0.009% - 0.02%
  - Carbon 0.006% - 0.022%

Results

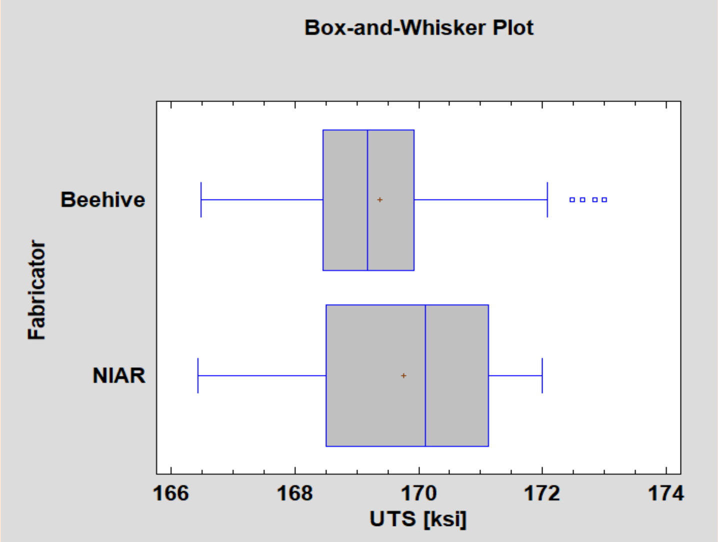
- 161 data points across 14 builds (6 Beehive builds, 8 NIAR Builds) were analyzed.
- Data **not normal** (Stnd. kurtosis out of ±2 range)
- K.W. P-value = 0.902 (**there is not a statistically significant difference amongst the medians at the 95.0% confidence level**)
- Levene's test P-value 0.4656. there is not a statistically significant difference amongst the standard deviations at the 95.0% confidence level.



- Interstitial elements across 8 ATI powder lots (6 virgin and 2 reuse):
  - Oxygen 0.188% - 0.20%
  - Nitrogen 0.023% - 0.039%
  - Carbon 0.031% - 0.044%

Results

- 114 data points across 12 builds (6 Beehive builds, 6 NIAR Builds) were analyzed.
- Data **approximates a normal distribution.**
- K.W. P-value = 0.144 (**there is not a statistically significant difference amongst the medians at the 95.0% confidence level**)
- Levene's test P-value 0.0212. there is a statistically significant difference amongst the standard deviations at the 95.0% confidence level.



Fatigue data (Q1 and Q2 Room Temperature data combined)

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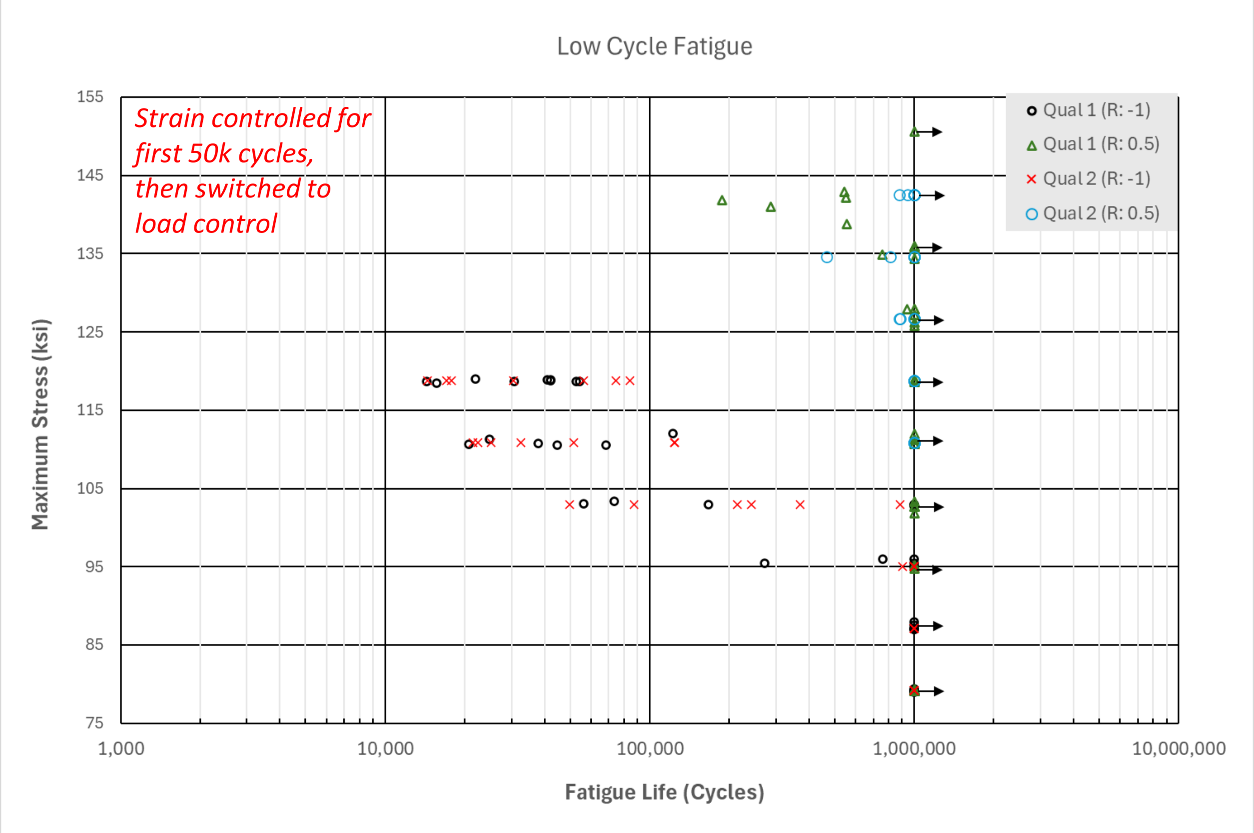
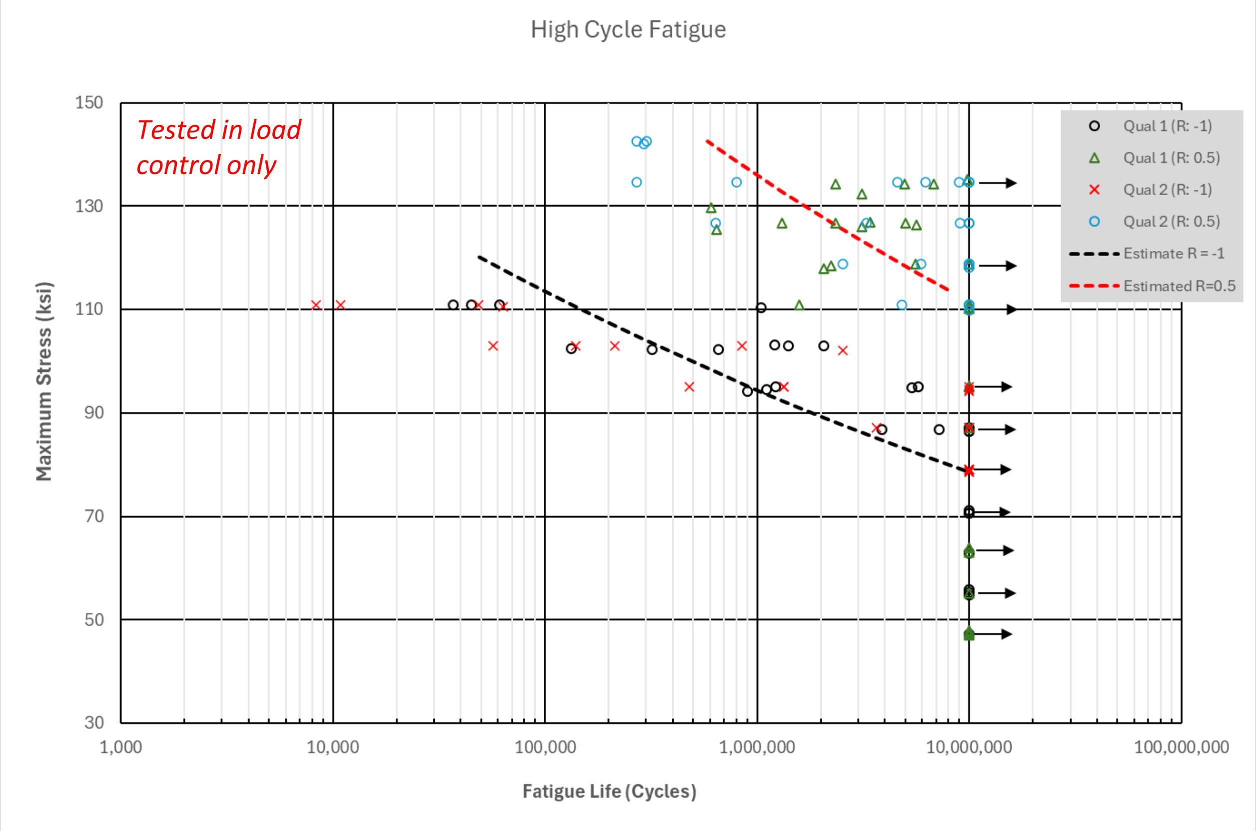
Low cycle fatigue data (Run out 1 million)



LCF estimated curves still in process

High cycle fatigue data (Run out 10 million)



- HCF estimated curves generated according to MMPDS section 9.6.

Fatigue (Qualification 1)	Failure Initiation Location	Occurrence Rate in Failed Specimens
LCF	Internally initiated	15%
HCF		47%

Qual 2 fractography ongoing

Preliminary Qual 1 LCF data at 600°F

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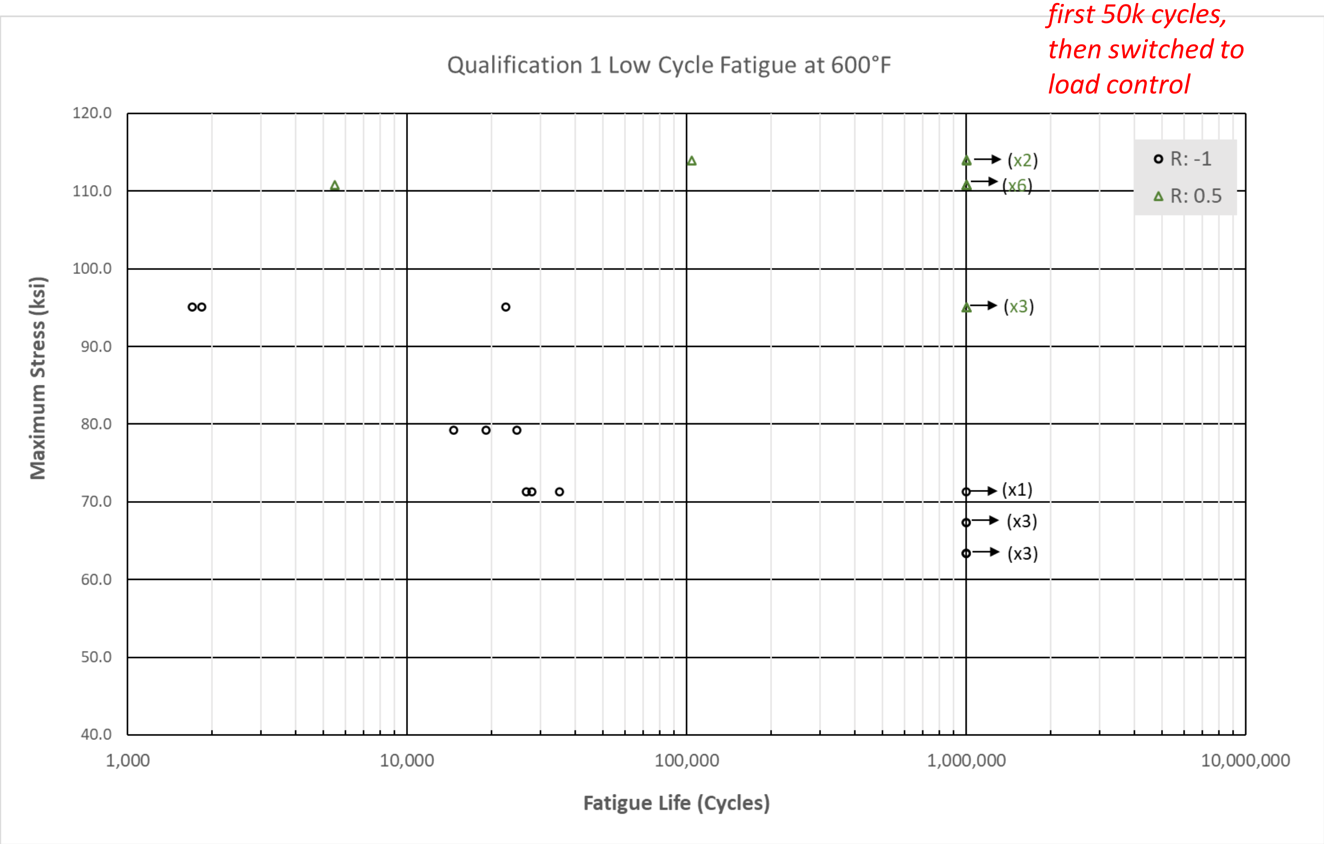
Low cycle fatigue data (Run out 1 million)

Strain controlled for first 50k cycles, then switched to load control



LCF at 600°F still in process
More data to follow

Extracted from MMPDS Vol I Handbook

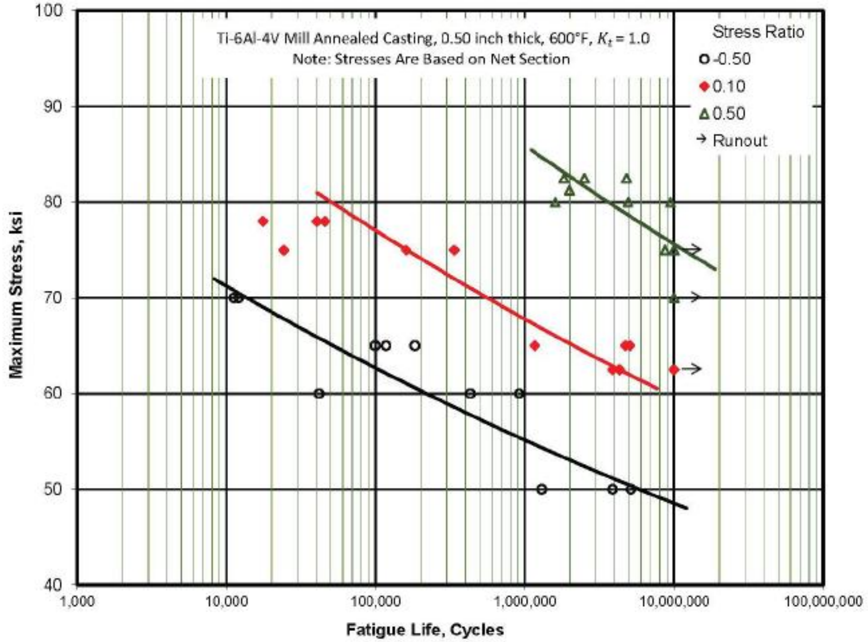
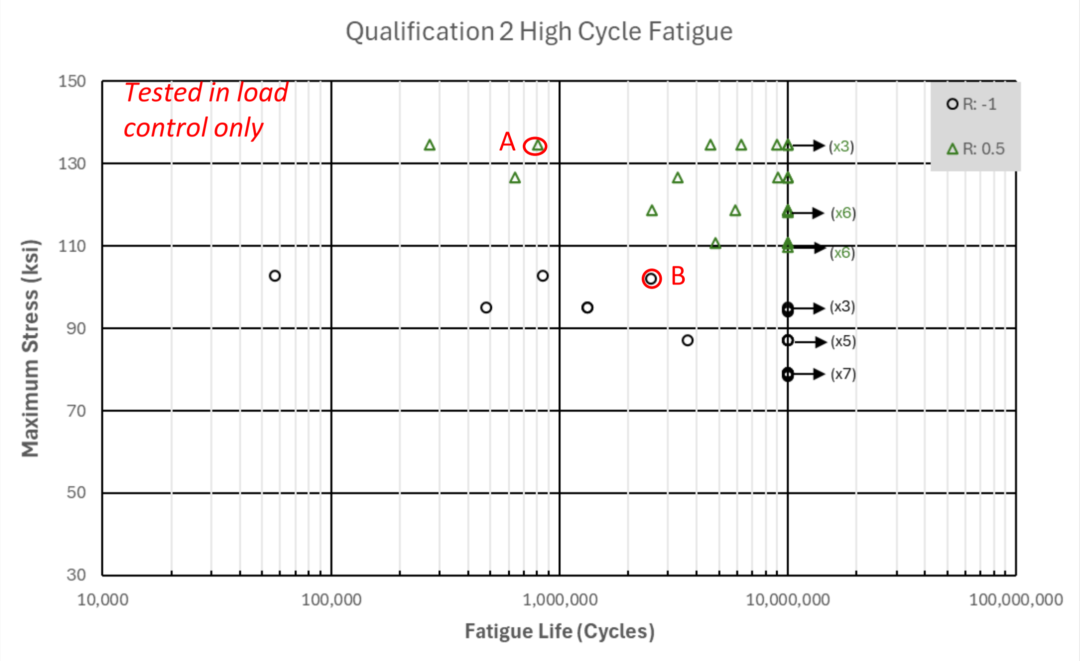


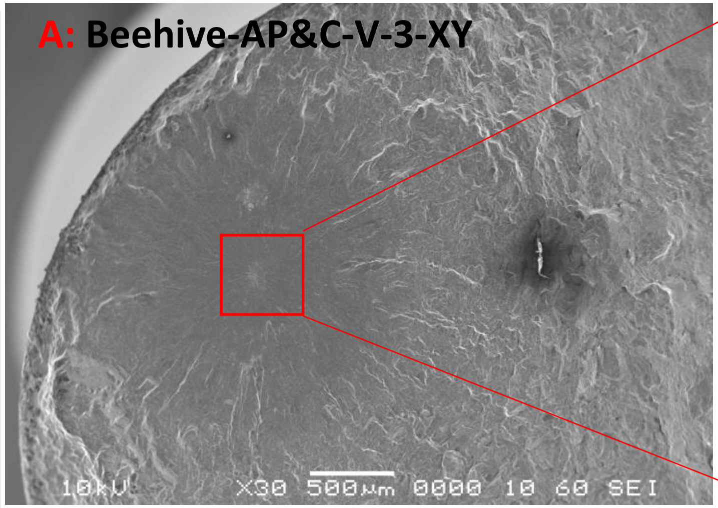
Figure 5.4.1.1.8(i). Best-fit S/N curves for unnotched Ti-6Al-4V mill annealed casting, 0.50-inch thick, 600°F.

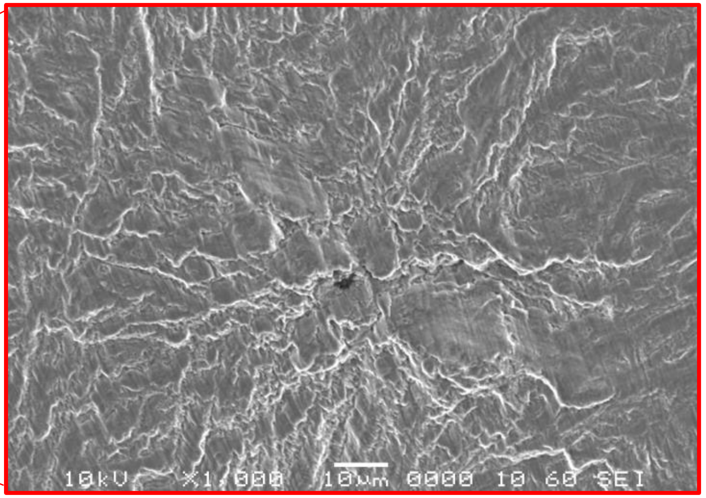
Stress level	Maximum Stress (ksi)	Min. no. of cycles (R:-1/R:0.5)
40%	63.3	(Run Out / Not tested)
45%	71.3	(26,727 / Not tested)
50%	79.2	(14,674 / Not tested)
60%	95.0	(1,713 / Run Out)
70%	110.8	(Not tested / Run Out)
72%	114.0	(Not tested / 104,453)

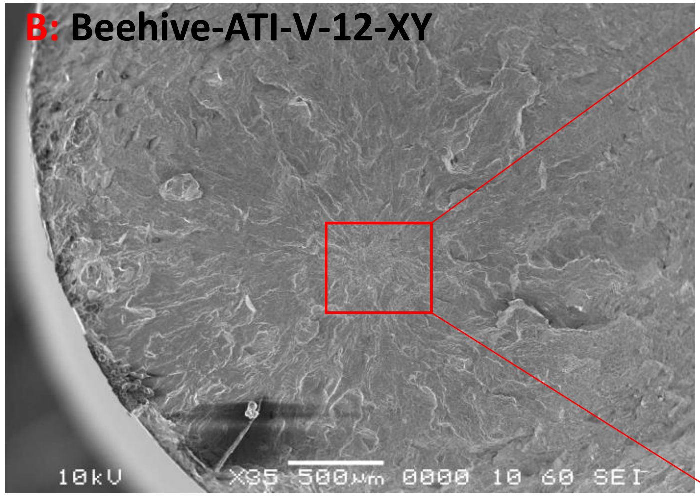
High cycle fatigue data (Run out 10 million)

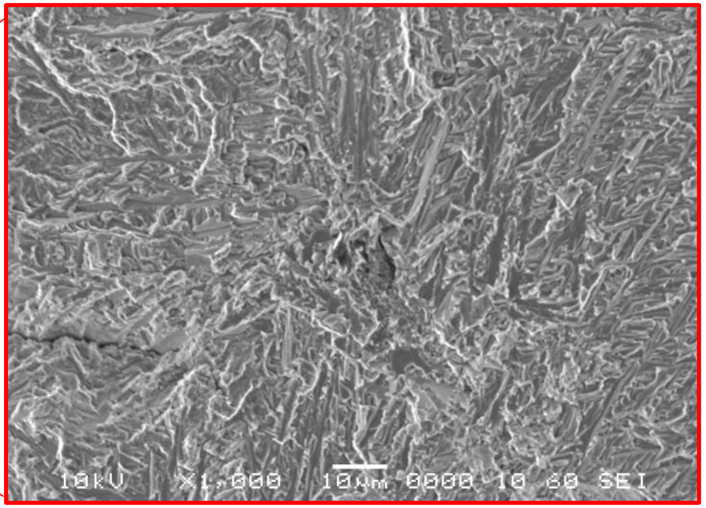


Stress level	Maximum Stress (ksi)	Min. no. of cycles (R:-1/R:0.5)
50%	78.78	(Run out / not testing)
55%	87.09	(Run out / not testing)
60%	95.01	(478,773 / not testing)
65%	102.93	(56,925 / not testing)
70%	109.86	(not testing / Run out)
75%	118.76	(not testing / Run out)
85%	134.60	(not testing / 271,317)





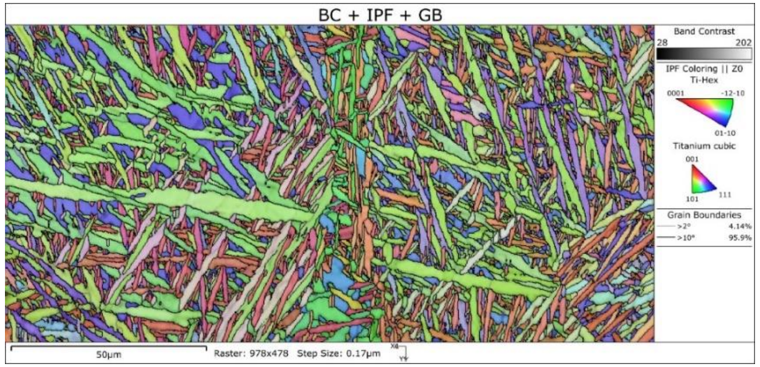




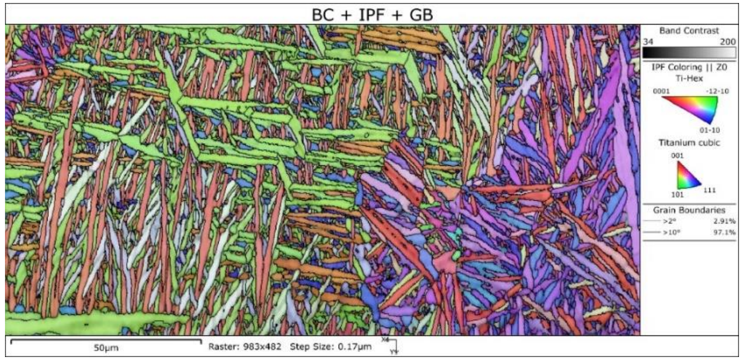
LCF @ 600°F testing to follow

JMADD Microstructure Results

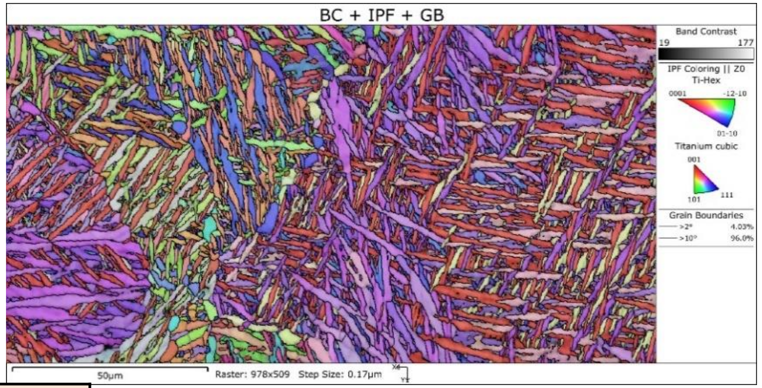
NIAR-Tekna-2 (N16)



Boeing-Tekna-1 (B1)



Beehive-ATI-6 (A8)

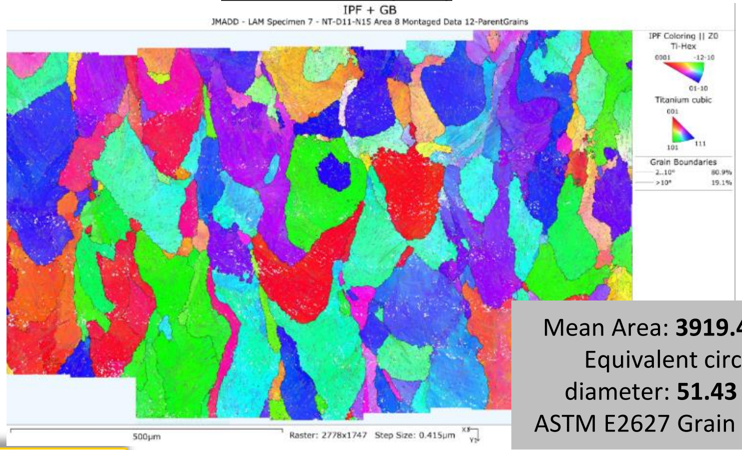


Print Direction

- All Images shown were taken on the **ZX plane**.
- Parent grains below were reconstructed with AZTEC ICE software.

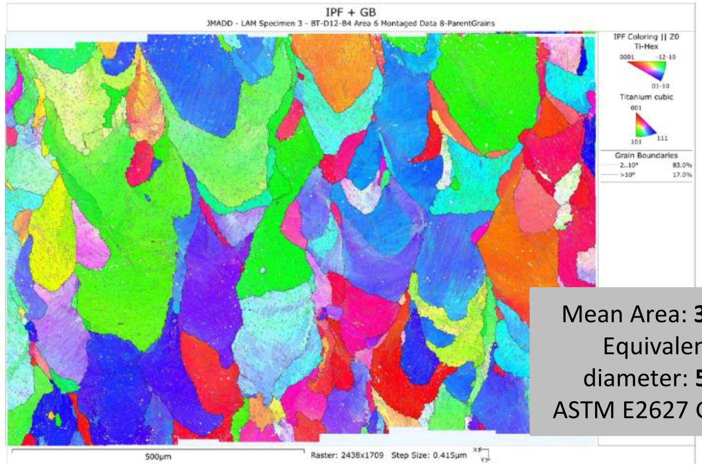
	NIAR (across 18 builds)		Boeing (across 6 builds)		Beehive (across 10 builds)	
Measurement	**Average**	**CoV (%)**	**Average**	**CoV (%)**	**Average**	**CoV (%)**
α Width (μm)	2.33	11.67	2.19	7.20	2.69	11.90
α Length (μm)	8.72	18.07	8.31	4.88	9.54	13.32

NIAR-Tekna-2 (N15)



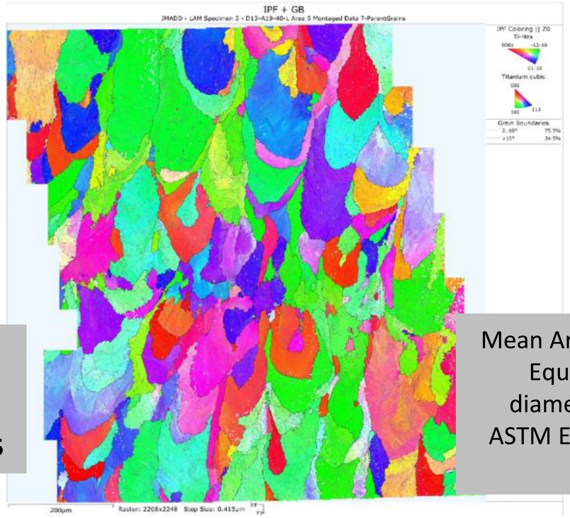
Mean Area: **3919.4 μm²**
Equivalent circle diameter: **51.43 μm**
ASTM E2627 Grain Size: **5**

Boeing-Tekna-1 (B4)



Mean Area: **3903.8 μm²**
Equivalent circle diameter: **50.86 μm**
ASTM E2627 Grain Size: **5**

Beehive-AP&C-2 (A19)



Mean Area: **2307.88 μm²**
Equivalent circle diameter: **40.64 μm**
ASTM E2627 Grain Size: **6.1**

Chemistry of Bulk Printed Material

- According to AMS2249K check limits for Ti64, the oxygen and Nitrogen content for highlighted values are within acceptable variation.

Check Analysis limits (AMS2249K)

Element	Limits or Maximum of Specified Range %	Variation Under Min or Over Max
Nitrogen	Up to 0.10 (1000 ppm), incl	0.02 (200 ppm)
Oxygen	Up to 0.20 (2000 ppm), incl	0.02 (200 ppm)
	Over 0.20 (2000 ppm)	0.03 (300 ppm)

Per AMS2249 section 2.3.1:
In the analysis of finished parts, these values do not apply to elements whose percentage can be varied by fabricating techniques employed (for example, oxygen, nitrogen, hydrogen) unless the sample is sufficiently large to produce a reliable result.

			CHEMICAL COMPOSITION (wt. %) - Ti BALANCE									
Supplier	Lot #	Powder state	Al	V	Fe	Y	C	O^2	N	H^2	OTHERS EACH	OTHERS TOTAL
AP&C	Lot 1	Virgin	6.41	4.03	0.22	< 0.001	0.010	0.14	0.0100	0.0020	< 0.10	< 0.40
		Bulk Mat.	6.38	3.96	0.22	< 0.001	0.016	0.16	0.0270	0.0026	<0.05	<0.1
	Lot 2	Virgin	6.31	3.96	0.2	< 0.001	0.01	0.14	0.01	0.002	< 0.1	< 0.4
		Bulk Mat.	6.28	4.04	0.2	<0.001	0.014	0.16	0.033	0.0027	<0.05	<0.1
Tekna	Lot 1	Virgin	6.13	4.05	0.17	< 0.005	0.009	0.12	0.0070	0.0020	< 0.05	< 0.05
		Bulk Mat.	6.42	4.33	0.18	<0.001	0.011	0.15	0.0160	0.0097	<0.05	<0.1
	Lot 2	Virgin	6.39	4.23	0.18	< 0.005	0.010	0.13	0.0070	0.0020	< 0.05	< 0.05
		Bulk Mat.	6.4	4.25	0.18	<0.001	0.010	0.15	0.0260	0.0025	<0.05	<0.1
	Lot 4	Virgin	6.18	4.06	0.16	< 0.001	< 0.005	0.12	0.0090	0.0040	< 0.02	< 0.05
		Bulk Mat.	6.34	3.95	0.17	<0.001	<0.005	0.15	0.0390	0.0086	<0.05	<0.1
ATI	Lot 1	Virgin	6.03	4.02	0.21	< 0.0009	0.006	0.149	0.013	0.0009		
		Bulk Mat.	6.1	4.05	0.2	<0.001	0.007	0.18	0.033	0.0012	<0.05	<0.1
	Lot 2	Virgin	6.12	4.06	0.22	< 0.0009	0.007	0.142	0.012	0.0006		
		Bulk Mat.	6.06	4.12	0.2	<0.001	0.12	0.17	0.028	0.0024	<0.05	<0.1
	Lot 3	Virgin	6.01	4.12	0.21	< 0.0009	0.008	0.145	0.014	0.0010		
		Bulk Mat.	6.41	4.2	0.21	<0.001	0.008	0.17	0.032	0.0015	<0.05	<0.1
	Lot 4	Virgin	6.3	4.01	0.21	< 0.0009	0.006	0.16	0.006	0.0009		
		Bulk Mat.	6.2	4.06	0.19	<0.001	0.02	0.18	0.026	0.0029	<0.05	<0.1
	Lot 5	Virgin	6.31	3.94	0.15	< 0.0009	0.029	0.178	0.030	0.0010		
		Bulk Mat.	6.14	4.07	0.16	<0.001	0.032	0.2	0.044	0.0017	<0.05	<0.1
	Lot 6	Virgin	6.22	3.86	0.15	< 0.0009	0.04	0.188	0.036	0.0009		
		Bulk Mat.	6.26	3.96	0.14	<0.001	0.041	0.21	0.047	0.0023	<0.05	<0.001
	Lot 7	Virgin	6.16	3.86	0.14	<0.0009	0.039	0.185	0.036	0.001		
		Bulk Mat.	6.39	4.32	0.14	<0.001	0.041	0.21	0.051	0.0016	<0.05	<0.1
AMS 7015 (Class A)			5.50 - 6.75	3.50 - 4.50	≤ 0.30	≤ 0.005	≤ 0.08	0.11 - 0.20	≤ 0.05	≤ 0.015	≤ 0.10	≤ 0.40
ASTM F2924								≤ 0.20				

Chemistry of Bulk Printed Material– Qualification 2

Powder Supplier	Powder Lot	Material state	CHEMICAL COMPOSITION (wt. %) - Ti BALANCE								
			Aluminum	Vanadium	Iron	Yttrium	Carbon	Oxygen	Nitrogen	Hydrogen	Titanium
ATI	R-1	Powder	6.13	4.05	0.20	< 0.0010	0.01	0.160	0.01	0.00	Balance
		Bulk Mat.	6.13	4.13	0.19	< 0.001	0.010	0.160	0.021	0.0012	Balance
	R-2	Powder	6.26	4.13	0.19	< 0.001	0.008	0.140	0.010	0.0010	Balance
		Bulk Mat.	6.13	4.14	0.20	<0.001	0.008	0.150	0.020	0.0010	Balance
	R-3	Powder	6.16	4.14	0.20	< 0.0010	0.010	0.160	0.012	0.0010	Balance
		Bulk Mat.	6.11	4.14	0.20	< 0.001	0.008	0.160	0.021	0.0013	Balance
	R-4	Powder	6.43	4.06	0.18	< 0.001	0.01	0.170	0.01	0.00	Balance
		Bulk Mat.	6.26	4.02	0.16	<0.001	0.020	0.180	0.027	0.0015	Balance
	R-5	Powder	6.35	3.96	0.15	< 0.0010	0.031	0.190	0.023	0.0011	Balance
		Bulk Mat.	6.30	3.98	0.14	< 0.001	0.032	0.180	0.026	0.0014	Balance
	R-6	Powder	6.49	3.99	0.13	< 0.001	0.038	0.200	0.030	0.0011	Balance
		Bulk Mat.	6.54	4.00	0.13	< 0.001	0.037	0.190	0.042	0.0014	Balance
	V-7	Powder	6.16	3.86	0.14	< 0.0009	0.039	0.190	0.036	0.0010	Balance
		Bulk Mat.	6.46	3.97	0.13	<0.001	0.038	0.190	0.015	0.0027	Balance
	V-8	Powder	6.27	3.96	0.15	< 0.0009	0.038	0.190	0.039	0.0011	Balance
		Bulk Mat.	6.50	3.97	0.13	<0.001	0.038	0.190	0.065	0.0024	Balance
	V-9 Beehive	Powder	6.28	3.90	0.15	< 0.0009	0.044	0.195	0.035	0.0008	Balance
		Bulk Mat.	6.40	3.90	0.14	<0.001	0.039	0.180	0.045	0.0021	Balance
	V-9 NIAR	Powder	6.25	3.91	0.15	< 0.0009	0.038	0.193	0.035	0.0010	Balance
		Bulk Mat.	6.44	3.89	0.14	<0.001	0.039	0.200	0.060	0..0028	Balance
	v-10 Beehive	powder	6.15	3.91	0.15	< 0.0009	0.039	0.190	0.034	0.0014	Balance
		Bulk Mat.	6.48	4.03	0.13	<0.001	0.039	0.200	0.043	0.0020	Balance
	v-10 NIAR	powder	6.24	3.89	0.15	< 0.0009	0.041	0.193	0.034	0.0010	Balance
		Bulk Mat.	6.20	3.89	0.13	<0.001	0.042	0.190	0.026	0.0013	Balance
	v-11	powder	5.73	3.54	0.16	< 0.0009	0.022	0.150	0.023	0.0015	Balance
		Bulk Mat.	6.29	3.85	0.15	<0.001	0.034	0.160	0.021	0.0026	Balance
	v-12 Beehive	Powder	6.21	3.72	0.20	< 0.0009	0.006	0.097	0.012	0.0013	Balance
		Bulk Mat.	6.37	3.80	0.17	<0.001	0.006	0.099	0.032	0.0022	Balance
	v-12 NIAR	Powder	6.01	3.66	0.20	< 0.0009	0.008	0.090	0.010	0.0013	Balance
		Bulk Mat.	6.25	3.69	0.18	<0.001	0.006	0.096	0.042	0.0029	Balance

Powder Supplier	Powder Lot	Material	CHEMICAL COMPOSITION (wt. %) - Ti BALANCE								
			Aluminum	Vanadium	Iron	Yttrium	Carbon	Oxygen	Nitrogen	Hydrogen	Titanium
AP&C	R-1	Powder	6.48	4.04	0.22	< 0.001	0.016	0.15	0.009	0.0017	Balance
		Bulk Mat.	6.56	4.15	0.19	<0.001	0.017	0.17	0.036	0.0020	Balance
	R-2	Powder	6.41	4.01	0.19	< 0.001	0.014	0.14	0.013	0.0016	Balance
		Bulk Mat.	6.39	4.02	0.19	<0.001	0.014	0.16	0.033	0.0020	Balance
	V-3	Powder	6.35	4.12	0.22	< 0.001	0.020	0.15	0.020	0.0020	Balance
		Bulk Mat.	6.44	4.21	0.20	<0.001	0.018	0.19	0.037	0.0023	Balance
TEKNA	R-1	Powder	6.32	4.26	0.19	<0.001	0.010	0.14	0.005	0.0029	Balance
		Bulk Mat.	6.23	4.25	0.17	<0.001	0.009	0.12	0.016	0.0016	Balance
	R-2	Powder	6.37	4.17	0.19	< 0.001	0.010	0.16	0.007	0.0022	
		Bulk Mat.	6.31	4.19	0.17	<0.001	0.013	0.12	0.023	0.0022	Balance
	V-3	Powder	6.44	4.37	0.17	<0.005	0.009	0.13	0.009	0.0020	Balance
		Bulk Mat.	6.35	4.23	0.15	<0.001	0.024	0.14	0.017	0.0026	Balance
	R-4	Powder	6.32	4.07	0.17	< 0.001	0.006	0.14	0.010	0.0037	
		Bulk Mat.	6.22	4.05	0.15	< 0.001	0.006	0.14	0.021	0.0033	Balance
AMS 7015			5.50 - 6.75	3.50 - 4.50	≤ 0.30	≤ 0.005	≤ 0.08	0.11 - 0.20	≤ 0.05	≤ 0.015	Balance
ASTM F2924								≤ 0.20			

Check Analysis limits (SAE AMS2249K)

Element	Limits or Maximum of Specified Range %	Variation Under Min or Over Max
Nitrogen	Up to 0.10 (1000 ppm), incl	0.02 (200 ppm)
Oxygen	Up to 0.20 (2000 ppm), incl	0.02 (200 ppm)
	Over 0.20 (2000 ppm)	0.03 (300 ppm)

All powder lots, except for ATI Lot 12, meet the AMS 7015 specifications.

JMADD Lessons Learned

- **Room Temperature Mechanical Properties**: The room temperature static mechanical properties across different fabricators show strong consistency, with coefficients of variation (CoV) ≤ 6%. The observed scatter trends align closely with those seen in Ti-6Al-4V wrought products as reported in MMPDS.

- **Impact of Powder Lot Composition on Strength**: It was found that powder lots with higher interstitial elements, particularly oxygen and nitrogen, resulted in increased strength properties seen in both **Qual 1** and **Qual 2**. This suggests that controlling powder composition can influence the strength characteristics of the final printed parts (see slide 8).

- **Strength-Ductility Trade-Off**: Specimens with higher strength properties exhibited a lower reduction in gauge section area during tensile testing, coupled with a decrease in fracture toughness. This finding supports the well-known strength-ductility trade-off, where increasing material strength can lead to reduced ductility and toughness.

- **Elevated Temperature Performance**: Elevated temperature test results for L-PBF Ti-6Al-4V showed similar performance to the percent knockdown data reported by MMPDS, further validating the material's high-temperature behavior and reinforcing the consistency of Ti-6Al-4V properties across different manufacturing methods and conditions.

- **Elemental Composition Changes After Powder Blending**: After blending reuse with virgin powder, changes were observed in the elemental composition, particularly in oxygen and iron contents. This highlights the importance of closely monitoring and controlling elemental composition when reusing or mixing powder lots to ensure material consistency.

- **Physical Properties Consistency**: The physical properties, such as density and hardness, exhibited comparable results between different powder lots and fabricators, suggesting that the variability in physical properties is minimal and within acceptable ranges.

- **Variability Across Builds and Machines**: Build-to-build variability was observed across the three fabricators (see slide 7) when powder lot was kept constant. However, it was observed that there were no significant difference between machine-to-machine comparisons when powder lots with similar chemistry were used.

JMADD Next Steps & Summary

Next Steps:

- NIAR to complete all remaining Qualification 1 and Qualification 2 fatigue testing and EBSD analysis.
- NIAR to collaborate with OSU on fractography and EBSD analysis data.
- Distribute NCAMP Material Property Data Report (MPDR) to steering committee for review.
- Continue work on statistical analysis to compare CMH-17 and MMPDS methodologies for allowables. (Final NCAMP statistical analysis methodology to be decided by Government Steering Committee before publishing NCAMP allowable.)
- NIAR to continue analyzing fatigue data (fractography and S-N curves)

Benefit to Aviation:

- Standardized qualification framework which can be applied to new metal AM material.
- Publicly available material allowables for L-PBF Ti-6Al-4V grade 5 material.

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FAA JAMS – Metal AM | Program Overview

M-JMADD	**JMADD** **Joint Metal Additive Database Definition**	Baseline qualification program for Ti-6-4/EOS M290 *Jointly funded with America Makes*
M-JMADX	**JMADD Expansion**	• Generate data on 4th JMADD machine for dataset inclusion. • Development of fatigue curves for various post processing conditions.
M-MASFI	**Surface Inspection**	Investigate as-printed surface design values and bulk material inspection methods on fatigue sensitive LPBF components.
M-NANPQ	**New Alloy/Process Qualification**	Qualification of new alloy/process of interest to the FAA and related industry.
M-BBFLP	**Building Block**	Investigate feature-level performance debits for AM test articles via static test characterization.

Project M-JMADX: JMADD Expansion

WICHITA STATE UNIVERSITY

Project Overview

Research Objectives

- **Task 1:** Utilize NIAR's GE M2 Series 5 machine to fabricate specimens for static mechanical and fatigue testing as the 4th machine to be combined to the JMADD dataset.
- **Task 2:** Generate fatigue curves for the as-fabricated and additional alternate post-processing conditions for comparison back to JMADD fatigue performance (EOS M290).

Project Deliverables

Research Outcomes

- A deliverables report documenting the lessons learned and results, including statistical comparison (combinability) between the Concept Laser M2 data and the baseline JMADD EOS M290 qualification.
- An FAA technical report documenting the design value fatigue curves with as printed and alternative heat treatment debits.

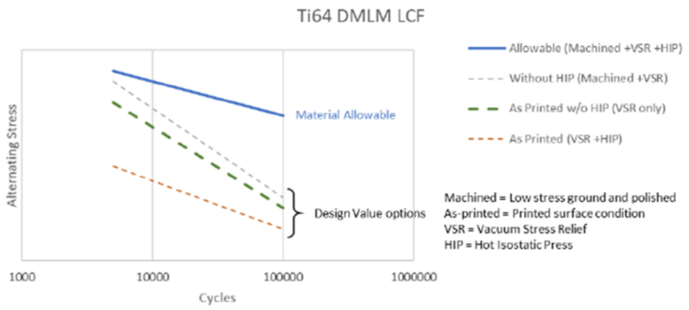
Project Timeline – Outline of Deliverables

Main Task	Subtasks	Percent Complete	CY2024						CY2025												CY2026					
			Q3			Q4			Q1			Q2			Q3			Q4			Q1			Q2		
			M7	M8	M9	M10	M11	M12	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M1	M2	M3	M4	M5	M6
1	Coordination	100%	✓																							
1.1	*Establishment of Industry Steering Committee*																									
2	Material Selection and Processing Method Downselect	100%					✓																			
2.1	*JMADD 4th Machine*																									
2.2	*Alternative Post-Processing*																									
3	Speicmen Fabrication, Post-Processing, and Testing	15%																								
3.1	*Pre-Qualification Testing*																									
3.2	*Qualification Fabrication*																									
3.3	*Specimen Post-processing*																									
3.3	*Specimen Testing*																									
4	Material and Process Specifications	15%																								
5	Fatigue Curve Study	15%																								
6	Statistical Guidelines	0%																								

JMADD (3 machines)

4th Machine

Fatigue Curves



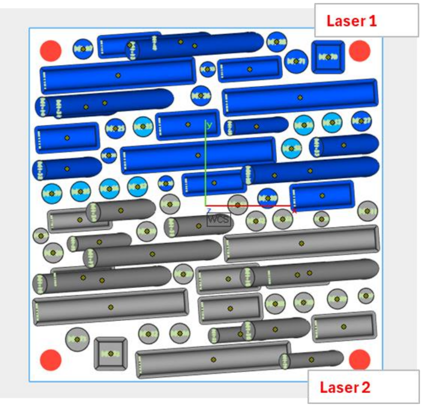
Project M-JMADX: Task 1 (JMADD 4th Machine)

Pre-Qualification:

- Compare build quality and test results to baseline JMADD qualification data following the defined JMADD process chain.
- Confirm acceptable quality of fabrication and material performance to support qual effort.

Approach:

- Pre-qualification fabrication will leverage test matrix and build design from JMADD pre-qualification site comparison study.
- Internal GE M2 Series 5 stock parameter for Ti64 material (60 um layer height) will be utilized to fabricate build NIAR to post-process and test specimens.
- Specimen post-processing will follow process defined JMADD (SR, HIP, & machine)
- After receiving pre-qualification test results, NIAR to run equivalency analysis using CMH-17 and MMPDS (OSAT) methods for comparisons to baseline JMADD data.



GE M2 Fabricated pre-qualification build

Task 1 test matrix

DMP Flex 350			RTA	ETA 700°F
Test Type	Specimen	Property	No. of Coupons	No. of Coupons
Tension	E8/E21/E111 XY	Strength and modulus	3	3
	E8/E21/E111 ZX	Strength and modulus	3	3
	E8/E21/E111 ZX-45	Strength and modulus	3	3
Compression	E9/E209/E111 XY	Compressive strength, yield, and modulus	3	3
	E9/E209/E111 ZX	Compressive strength, yield, and modulus	3	3
	E9/E209/E111 ZX-45	Compressive strength, yield, and modulus	3	3
Shear	B769 XY	Ultimate shear strength	3	3
	B769 ZX	Ultimate shear strength	3	3
	B769 ZX-45	Ultimate shear strength	3	3

Fatigue specimens will be available for testing if required.

Pre-Qualification in progress

4th JMADD machine Qualification approach:

- Will utilize one **Ti64 Grade 5** powder lot from **Tekna** (total 565kg) and JMADD build designs.
- **Two dataset** will be generated: First larger dataset will use virgin powder and second smaller dataset will use (50/50) reuse blend powder.
- **17 builds total** (10 virgin builds, 7 reuse builds). Number of builds proposed is similar to the Boeing site fabrication.
- After first ten virgin builds are completed, recaptured powder feedstock will be sieved and blended (ratio of 50/50) by **ELCAN industries** for reuse build fabrication (similar to JMADD).
- **Both lasers will be utilized** on the GE M2 Series 5. (Build plate areas will be split into six areas to evaluate location-location variability)
- **There will be no stitching during fabrication.**
- Test conditions: RTA, ETA (300, 500, 700, 900°F).
- NCAMP will develop separate NCAMP PCD for the GE M2 machine.

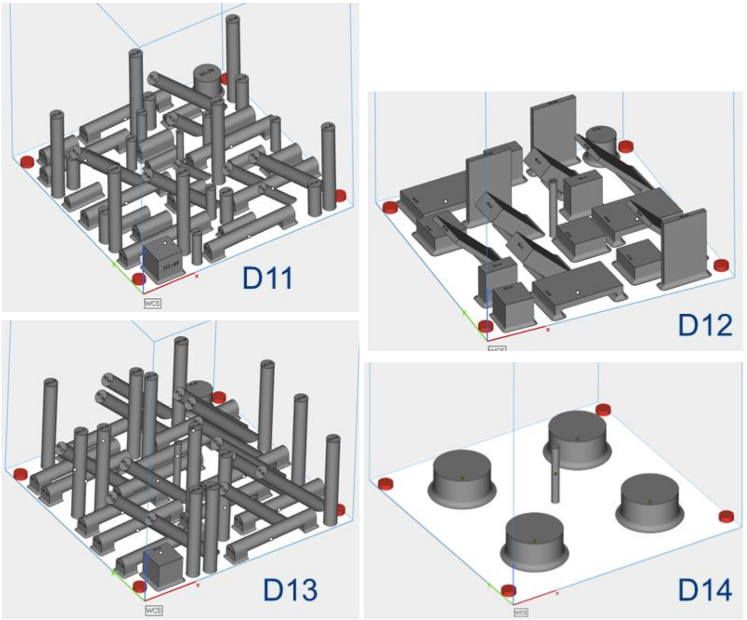
Virgin powder builds

Site	Powder	Lot	Build Design	Build ID
NIAR	Tekna	1 lot	D11	M2
				M3
				M4
			D12	M5
				M6
				M7
			D13	M8
				M9
				M10
			D14	M11

Reuse (50/50 blend) powder builds

Site	Powder	Lot	Build Design	Build ID
NIAR	Tekna	1 lot	D11	M12
			D12	M13
			D13	M14
			D11	M15
			D12	M16
			D13	M17
			D14	M18

TEKNA



JMADD Build Designs

Static test matrix

Virgin Static Test Matrix							(50/50) Reuse blend Static Test Matrix		
Build Orientation	Test Type	ASTM Standard	Property	Number of Lots x Runs per Machine x Number of Specimens per build — Test Temperature		Coupons Tested	Number of Lots x Runs per Machine x Number of Specimens per build — Test Temperature		Coupons Tested
				RTA	ETA (300, 500, 700, 900°F)		RTA	ETA (300, 500, 700, 900°F)	
XY	Tension	ASTM E8, E21, E111	UTS, Yield, Modulus, and Elongation	1x2x3	1x2x8	22	1x2x3	1x2x8	22
ZX	Tension	ASTM E8, E21, E111	UTS, Yield, Modulus, and Elongation	1x2x3	1x2x8	22	1x2x3	1x2x8	22
Z45	Tension	ASTM E8, E21, E111	UTS, Yield, Modulus, and Elongation	1x2x3	1x2x8	22	1x2x3	1x2x8	22
XY	Compression	ASTM E9, E209, E111	Compressive Strength, Yield, and Modulus	1x1x3	1x1x8	11	1x1x3	1x1x8	11
ZX	Compression	ASTM E9, E209, E111	Compressive Strength, Yield, and Modulus	1x1x3	1x1x8	11	1x1x3	1x1x8	11
Z45	Compression	ASTM E9, E209, E111	Compressive Strength, Yield, and Modulus	1x1x3	1x1x8	11	1x1x3	1x1x8	11
XY	Shear	ASTM B769	Ultimate Shear Strength	1x1x3	1x1x8	11	1x1x3	1x1x8	11
ZX	Shear	ASTM B769	Ultimate Shear Strength	1x1x3	1x1x8	11	1x1x3	1x1x8	11
Z45	Shear	ASTM B769	Ultimate Shear Strength	1x1x3	1x1x8	11	1x1x3	1x1x8	11
XY	Bearing (e/D=1.5 & 2.0)	ASTM E238	Bearing Strength and Yield	1x3x5		15	1x2x5		10
ZX	Bearing (e/D=1.5 & 2.0)	ASTM E238	Bearing Strength and Yield	1x3x5		15	1x2x5		10
Z45	Bearing (e/D=1.5 & 2.0)	ASTM E238	Bearing Strength and Yield	1x3x5		15	1x2x5		10
XY	Frac. Tough.	ASTM E399	Plain Strain Fracture Toughness	1x2x3		6	1x2x3		6
ZX	Frac. Tough.	ASTM E399	Plain Strain Fracture Toughness	1x2x3		6	1x2x3		6
Z45	Frac. Tough.	ASTM E399	Plain Strain Fracture Toughness	1x2x3		6	1x2x3		6

Project M-JMADX: Task 1 (JMADD 4th Machine)

Fatigue test matrix

Virgin Static Test Matrix									(50/50) Reuse blend Static Test Matrix		
Build Orientation	Test Type	ASTM Standard	R-value	Stress Levels	Property	Number of Lots x Runs per Machine x Number of Specimens per build		Coupons Tested	Number of Lots x Runs per Machine x Number of Specimens per build		Coupons Tested
						Test Temperature			Test Temperature		
						RTA	ETA (700°F)		RTA	ETA (700°F)	
XY	LCF (1 million runout)	ASTM E606	0.5 and -1	3 stress levels	Fatigue Strength, Residual	1x3x3	1x3x3	18	1x2x3	1x2x3	12
ZX	LCF (1 million runout)	ASTM E606	0.5 and -1	3 stress levels	Fatigue Strength, Residual	1x3x3	1x3x3	18	1x2x3	1x2x3	12
Z45	LCF (1 million runout)	ASTM E606	0.5 and -1	3 stress levels	Fatigue Strength, Residual	1x3x3	1x3x3	18	1x2x3	1x2x3	12
XY	HCF (10 million run out)	ASTM E466	0.5 and -1	3 stress levels	Fatigue Strength, Residual	1x3x3		9	1x2x3		6
ZX	HCF (10 million run out)	ASTM E466	0.5 and -1	3 stress levels	Fatigue Strength, Residual	1x3x3		9	1x2x3		6
Z45	HCF (10 million run out)	ASTM E466	0.5 and -1	3 stress levels	Fatigue Strength, Residual	1x3x3		9	1x2x3		6

Physical properties test matrix

Test Type	Test Standard	Coupons Tested
Density	ASTM B311	6
Hardness, Rockwell	ASTM E18	6
Microstructure & EBSD	ASTM E112	6
X-ray CT	ASTM E1441	12 from each test type
Coefficient of Thermal Expansion	ASTM E831	6
Thermal Conductivity	ASTM E1530	6
Thermal Diffusivity	ASTM E1461	6
Specific Heat Capacity	ASTM E1269	6

All specimens will be tested in the stress relieved, HIP'ed, and machined condition.

Project M-JMADX: Task 1 (JMADD 4th Machine)

Current Status:

- Powder feedstock for the proposed fabrication plan have been purchased and inventoried.
- Pre-qualification build specimens have been fabricated.
- NIAR working on developing process control document (PCD) for GE M2 series 5 machine.

Next Steps

- Post-process fabricated pre-qualification specimens and prepare for specimen testing.
- Begin qualification fabrication.

Benefit to Aviation:

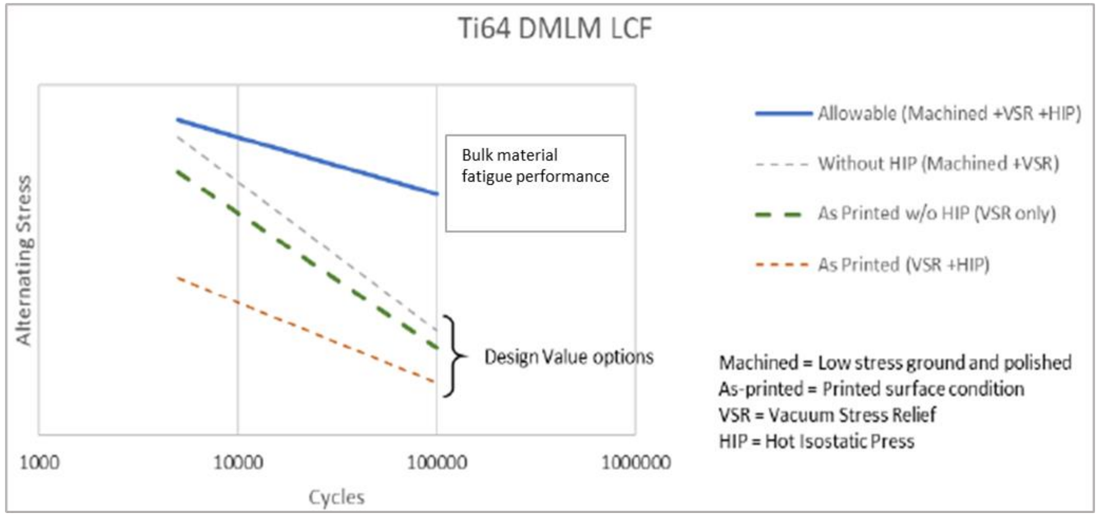
- Expansion of established framework to additional AM machine types.
- The Ti-6Al-4V dataset from a fourth AM machine contributes toward satisfying MMPDS C/D-basis requirements for multi-machine statistical validation.

Project M-JMADX: Task 2 (Fatigue Design Curves)

WICHITA STATE UNIVERSITY

Approach:

- After bulk material average fatigue curves have been generated (JMADD), fatigue curves must be created to enable design of parts based off of differing surface finish and post-processing, such as stress relief and HIP. Additional curves may be generated in industry to provide characterization of knock-downs for other part features.
- Knock-downs and behavior associated with each iteration will be generated.
- JMADD test plan and specifications will be leveraged to ensure resulting data aligns with methodology used in the original JMADD qualification Program.



Notional Graphic of Material Allowable and Design Value Fatigue Curves

	Group	SR	200 MPa HIP	100 MPa HIP	Machined	Notes	Purpose
	JMADD	X	X		X	*Baseline*	-
Alternate Processes	A	X			X	No HIP	Cost reduction
Alternate Processes	B	X		X	X	Alternate HIP	Alignment with GAMAT & castings
Alternate Processes	C	X				VSR only, As-fab	Potential As-fab best case
Alternate Processes	D	X		X		Alternate HIP, As-fab	Comparison to C, As-fab
Alternate Processes	E	X	X			Baseline, As-fab	α case consideration
Alternate Processes	F		X			Straight to HIP, As-fab	Comparison to G, As-fab
Alternate Processes	G		X		X	Straight to HIP	Alignment with industry process

JMADD baseline and alternate condition comparison

Notes:

1) Industry partners have discussed that fatigue performance may be negatively impacted in the HIP-ed state if parts are not machined, due to surface α-case formation.

Alternate process definitions E and C are included to generate data to characterize this performance difference.

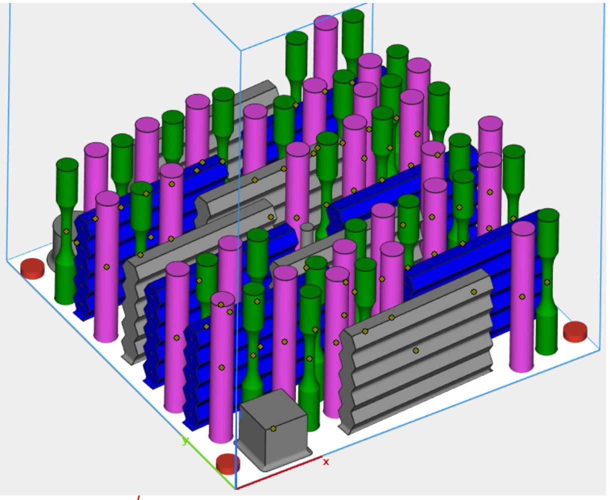
2) GAMAT P-DED static allowables project heat treatment investigation

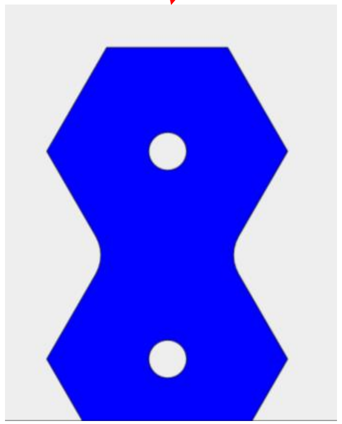
Project M-JMADX: Task 2 (Alternate Post Processing Fatigue Matrix)

Approach (continued):

- Create common mixed-orientation build design for fabrication and performance comparison across builds.
- Fabricate specimens from one common material lot and vendor.
- Post-process and machine per test matrix definition.
- Generate fatigue curves for comparison to JMADD baseline.
- Include E8 static tensile lot release, density, thermal, and microstructure specimens on each build.
- Stress levels/Strain levels utilized will be identical across all conditions.
- XY As-Fab surface condition specimen geometry determined with trial prints (0.1” hole diameter to start – teardrop geometry).

Fatigue	R-ratio	Stress levels	Finish	Heat Treat (Group)	Orientation	Number of stress levels x Specimens per stress level RTA (70°F)	Specimens tested
LCF	-1	55% 60% 65% 70% 75%	Machined	VSR (A)	XY	5 x 3	15
					ZX	5 x 3	15
				VSR+100HIP (B)	ZX	5 x 3	15
					XY	5 x 3	15
				Straight to HIP (G)	XY	5 x 3	15
					ZX	5 x 3	15
			As Fab	VSR (C)	XY	5 x 3	15
					ZX	5 x 3	15
				VSR+100HIP (D)	ZX	5 x 3	15
					XY	5 x 3	15
				Straight to HIP (F)	XY	5 x 3	15
					ZX	5 x 3	15
				VSR + 200 MPa HIP (E)	XY	5 x 3	15
					ZX	5 x 3	15
						Total	210





As-fab XY (with 0.1 inch through Hole)

Machined ZX
Machined XY
As-fab ZX
As-fab XY

Project M-JMADX: Task 2 (Fatigue Design Curves)

Project Status:

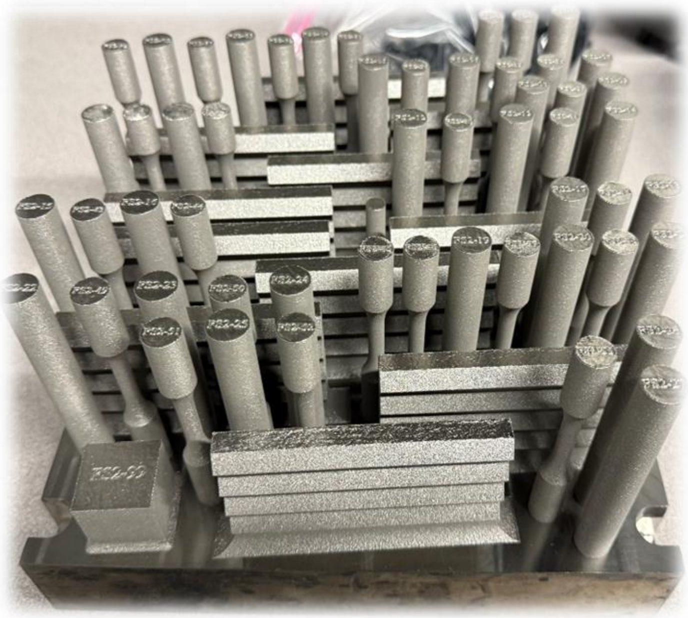
- Fatigue design curve test and fabrication plan has been proposed and presented to the FAA.
- Powder feedstock for the proposed fabrication plan have been purchased and inventoried.
- Specimen fabrication in progress.

Next Steps:

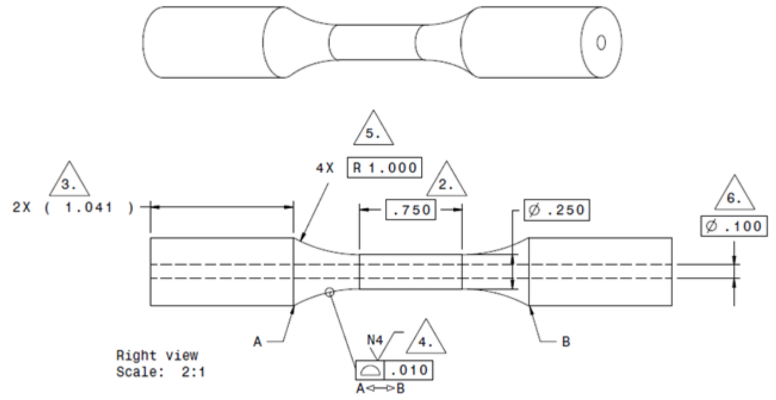
- NIAR to complete fabrication for required specimens
- Carry out heat treatment according to proposed test plan and run fatigue tests.

Benefit to Aviation:

- Understanding the effects of common industry post-processing methods on the fatigue performance of L-PBF Ti-6Al-4V.



0.1-inch As-printed hole



	Group	SR	200 MPa HIP	100 MPa HIP	Machined	Notes	Purpose
	JMADD	X	X		X	*Baseline*	-
Alternate Processes	A	X			X	No HIP	Cost reduction
	B	X		X	X	Alternate HIP	Alignment with GAMAT & castings
	C	X				VSR only, As-fab	Potential As-fab best case
	D	X		X		Alternate HIP, As-fab	Comparison to C, As-fab
	E	X	X			Baseline, As-fab	α case consideration
	F		X			Straight to HIP, As-fab	Comparison to G, As-fab
	G		X		X	Straight to HIP	Alignment with industry process

Questions?

- **Contact:**
  - Neville Tay – neville.tay@idp.wichita.edu
  - Royal Lovingfoss - royal.lovingfoss@idp.wichita.edu
  - Rachael Andrulonis – rachael.andrulonis@idp.wichita.edu

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Following are backup slides

JMADD Fifth Machine (America Makes sponsored)

NIAR
WICHITA STATE UNIVERSITY

Objective:

- To generate L-PBF fabricated Ti-6Al-4V (grade 5) data to enable the creation of a C/D-basis material allowable for MMPDS and an A/B-basis NCAMP material specification.

Test Type	**Number of specimens tested** ***(across orientations and test temperatures)***					***Five machine total specimen count***	***MMPDS*** ***C- and D-Basis Requirements and Recommendations***
	JMADD NIAR (EOS M290)	**JMADD** Beehive (EOS M290)	**JMADD** Boeing (EOS M290)	**JMADX** (GE M2)	**JMADD Fifth Machine Phase 1**		
E8 – Tension	369	292	104	132	132	**1029**	**300** **Across 5 machines, 10 heats**
E9 – Compression	175	143	51	66	66	**501**	**300 Across 5 machines, 10 heats**
B769 – Shear	174	148	54	66	66	**508**	**300 Across 5 machines, 10 heats**
E238 – Bearing (E/D = 1.5 & 2.0)	146	134	45	144	144	**613**	**600 Across 5 machines, 10 heats**
E399 – Fracture Toughness	154	130	39	36	36	**395**	**30 Across 3 machines, 3 heats**
E606 & E466 – Fatigue	143	113	48	108	-	**412**	***Recommended*** • Load control: 6 test per stress ratio (R), 3 stress ratios, no minimum heat or lot requirements • Strain control: 10 tests for Rg = -1.0, 6 tests other strain ratios

3D Systems DMP Flex 350

MMPDS requires 100 specimens in each orientations for direct analysis method. JMADD is investigating three orientations, hence 300 specimens is required

America Makes

IME INDUSTRIAL MODERNIZATION OF MATERIALS & MANUFACTURING

5th JMADD Machine Pre-Qualification

Objective:

- Compare build quality and test results to baseline JMADD qualification data following the defined JMADD process chain. Confirm acceptable quality of fabrication and material performance to support qual effort.

Approach:

- Pre-qualification fabrication will leverage test matrix and build design from JMADD pre-qualification site comparison study.
- 3DS will utilize internal stock parameter for Ti64 material to fabricate build (see table below).
- Tekna virgin powder (with Oxygen = 0.12 wt%) was utilized
- NIAR to post-process and test specimens.

Machine	3DS DMP Flex 350	EOS M290
Parameter	**Standard Part LT60**	**Ti64_SpeedM291 1.10**
Laser Power (W)	245	340
Speed (mm/s)	1250	1250
Hatch Spacing (um)	82	120
Layer Thickness (um)	60	60
Volumetric Energy Density (J/mm	**39.84**	**37.78**

3DS fabricated build

Pre-qualification test matrix

DMP Flex 350			RTA	ETA 700°F
Test Type	Specimen	Property	No. of Coupons	No. of Coupons
Tension	E8/E21/E111 XY	Strength and modulus	3	3
	E8/E21/E111 ZX	Strength and modulus	3	3
	E8/E21/E111 ZX-45	Strength and modulus	3	3
Compression	E9/E209/E111 XY	Compressive strength, yield, and modulus	3	3
	E9/E209/E111 ZX	Compressive strength, yield, and modulus	3	3
	E9/E209/E111 ZX-45	Compressive strength, yield, and modulus	3	3
Shear	B769 XY	Ultimate shear strength	3	3
	B769 ZX	Ultimate shear strength	3	3
	B769 ZX-45	Ultimate shear strength	3	3

Fatigue specimens will be available for testing if required.

Pre-qualification work in process

JMADD Fifth Machine Qualification Fabrication Plan

Qualification fabrication to begin after verifying fabricability and material performance from Pre-qualification build.

Qualification Approach:

- 17 builds total (10 virgin builds, 7 reuse builds). Number of builds proposed is similar to the Boeing site fabrication.
- Will utilize 1 Ti64 Grade 5 powder lot from AP&C (total 565kg) and JMADD build designs.
- After first ten virgin builds are completed, recaptured powder feedstock will be sieved and blended by ELCAN industries for reuse build fabrication (similar to JMADD).
- Fatigue specimens will be available for testing if required.
- NCAMP and 3DS will develop separate NCAMP PCD for the DMP Flex 350.

Task 2

Virgin powder builds				
Site	**Powder**	**Lot**	**Build Design**	**Build ID**
NIAR	Tekna	1 lot	D11	C1
				C2
				C3
			D12	C4
				C5
				C6
			D13	C7
				C8
				C9
			D14	C10

Task 3

Reuse (50/50 blend) powder builds				
Site	**Powder**	**Lot**	**Build Design**	**Build ID**
NIAR	Tekna	1 lot	D11	C11
			D12	C12
			D13	C13
			D11	C14
			D12	C15
			D13	C16
			D14	C17

JMADD Fifth Machine - Next Steps & Summary

Pre-Qualification updates:

- All fabricated tensile, shear, compression and fatigue specimens have been machined and are in queue for testing.
- Draft PCD for the DMP Flex 350 is in process.
- PO for powder was submitted to AP&C and powder will ship by beginning of May.

Next Steps:

- NIAR to perform quality control on machined specimen and subsequent testing.
- NIAR and 3DS to continue developing NCAMP PCD for the DMP Flex 350.
- After receiving pre-qualification test results, NIAR to run equivalency analysis using CMH-17 and MMPDS (OSAT) methods for comparisons to baseline JMADD data.

Benefit to Aviation:

- Broad dissemination across the aerospace industry will inform design allowable value generation.

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