Factors Affecting Qualification/Certification:

The Effect of Machine Variabilities on Mechanical Properties of LB-PBF Ti-6Al-4V Gr. 5

National Center for Additive Manufacturing Excellence (NCAME)

Joint Centers of Excellence for Advanced Materials

A Center of Excellence
AMTAS
Advanced Materials in Transport Aircraft Structures

composites and advanced materials

JAMS Technical Review
August 26, 2021

Introduction

- Project Title: Factors Affecting Qualification/Certification - The Effect of Machine Variabilities on Mechanical Properties of Additive Manufactured Materials
- Principal Investigator: Nima Shamsaei

  (See next slide for complete list of participants.)
- FAA Technical Monitor: Kevin Stonaker
- Source of matching contribution: Faculty time and use of equipment

Project team

Advisory Group

NCAME Project Team
Auburn University

PI: Nima Shamsaei (Mechanical Engr.)

PM:

Co-PIs:
Shuai Shao (Mechanical Engr.)
Masoud Mahjouri Samani (Elec. Comp. Engr.)
Hareesh Tippur (Mechanical Engr.)

Background

Effect of key process variables (KPVs) drift within the tolerances on defect content ar part performance is not very well understood

- Identified on several Roadmaps
- Challenge arises from the dependency of micro-/defect-structure and mechanical properties to multiple synergistic factors, including powder quality, laser-material interaction, inherent heat-transfer effects, geometrical factors, process parameters, etc.

Challenge

Objective & approach

Objective: To understand the effect of KPVs drift within tolerance bands on defect characteristics and mechanical properties of L-PBF Ti-6Al-4V Gr. 5

Approach: Four steps are taken,

I. Quantify the powder re-use effects to exclude their influences from the KPVs drift study. Geometry and time interval will be kept constant

II. Identify the combined effect of KPVs (laser power, laser spot size, and hatching distance) drift and location on the defect structure

III. Evaluate the impact of KPVs drift on tensile, fatigue, and high strain rate fracture behaviors using specimens fabricated with worst KPVs/location combinations

IV. Leverage machine learning and simulations wherever applicable

TASK 1: Literature Review

Collect information from literature, equipment OEM, FAA AM team, and steering committee

TASK 2: Design of Experiments

Design and refine the experiments for L-PBF Ti-6Al-4V Gr. 5 based on findings from the literature review

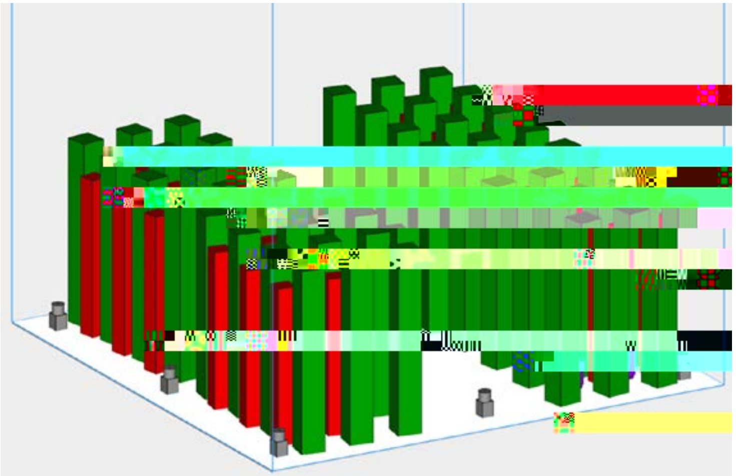
TASK 3: Powder Re-use Effects

DoE to understand the effect of powder re-use

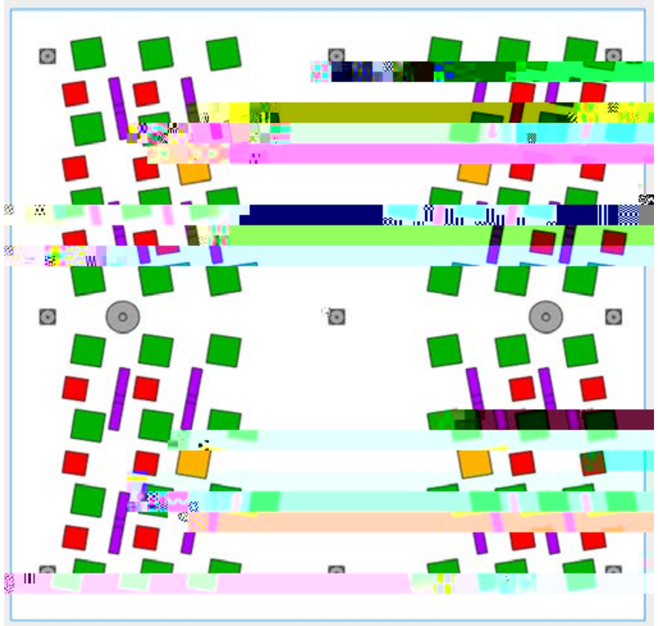
Powder re-use effect

Prints start with un-used powder and continues until powder is used several time

- 48 fatigue specimens (ASTM E466) (12 in each quadrant)
- 24 tensile specimens (ASTM E8) (6 in each quadrant)
- 16 high-strain test specimens (4 in each quadrant)
- 2 powder holders (at both ends)-Note that the powder in E and W may be sampled based on ASTM B215 instead of using the powder holders
- 4 microscopy specimens (1 in each quadrant)
- 9 XCT witness coupons

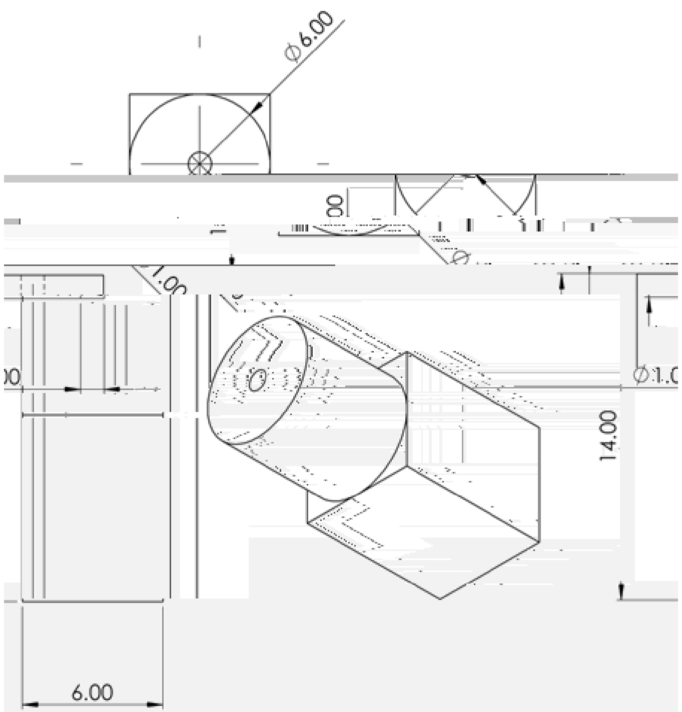


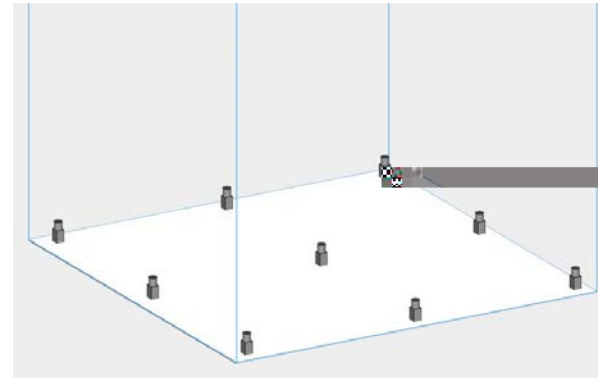
Occupied build plate density= 12%

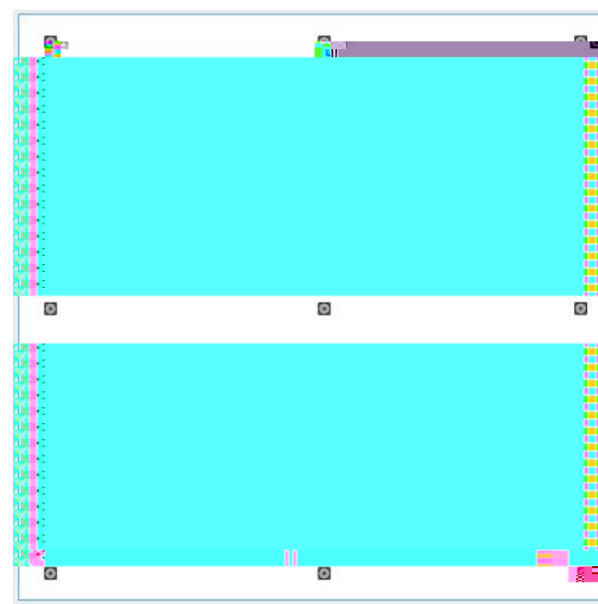


Build quality XCT coupons

XCT porosity witness coupons are always included in all prints throughout the study







DoE to identify the worst combination of KPVs/location

Identify worst KPVs combinations

Suggested KPVs and their possible deviations from nominal values:

- Laser power ±4%
- Scan speed ±0.015% (accuracy decreases for scan speeds > 3000 mm/s)
- Layer thickness ±0.1 µm
- Hatching distance ±2.4%
- Laser spot size (focal dimeter): 80 µm ± 5 µm (highly depends on material and laser powder, not monitored)

Scan speed and layer thickness are excluded from this study due to their sm drifts

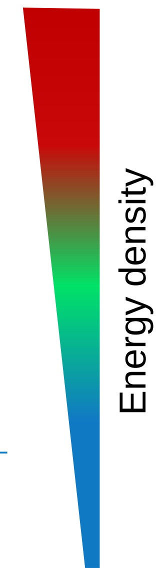
Only laser power (P), laser spot size (d) and hatching distance (h) will be included for further analyses

P, d and h will be either individually or simultaneously altered to increase or decrease the energy density (E) from the baseline

Identify worst KPVs combinations

Only overheating and underheating KPV combinations will be investigated as they can intensify the defect population

Factorial Design Parameters		Hatch spacing (h)		
Laser power (P)	Laser spot size (d)	h^{+}	h°	h^{-}
P^{+}	d^{+}	$P^{+} d^{+} h^{+}$	$P^{+} d^{+}$ h°	$P^{+} d^{+} h^{-}$
	d°	P^{+} d° h^{+}	P^{+} d° h°	P^{+} d° h^{-}
	d^{-}	$P^{+} d^{-} h^{+}$	$P^{+} d^{-}$ h°	$P^{+} d^{-} h^{-}$
P°	d^{+}	P° $d^{+} h^{+}$	P° d^{+} h°	P° $d^{+} h^{-}$
	d°	P° d° h^{+}	P° d° h°	P° d° h^{-}
	d^{h}			

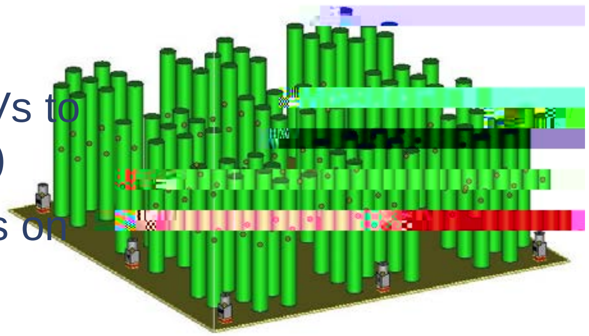


DoE to determine impact of KPVs drift on mechanical performance

Effect of KPVs drift on properties

- All specimens will be fabricated based on the worst combination of KPVs/location
- XCT coupons will be fabricated via recommended KPVs to monitor the effect of powder re-use (whenever possible)
- The tensile specimens will be machined to solely focus on the defects and microstructure of the parts
- The fabrication will be repeated at least multiple times for the tensile specimens to have 8 specimens per condition
  - 136 tensile specimens (17 sets of 8 specimens)
  - 6 specimens will be tested for each condition and kept as backup
  - 9 XCT coupons per built plate

Tensile



Occupied build plate density = 10%

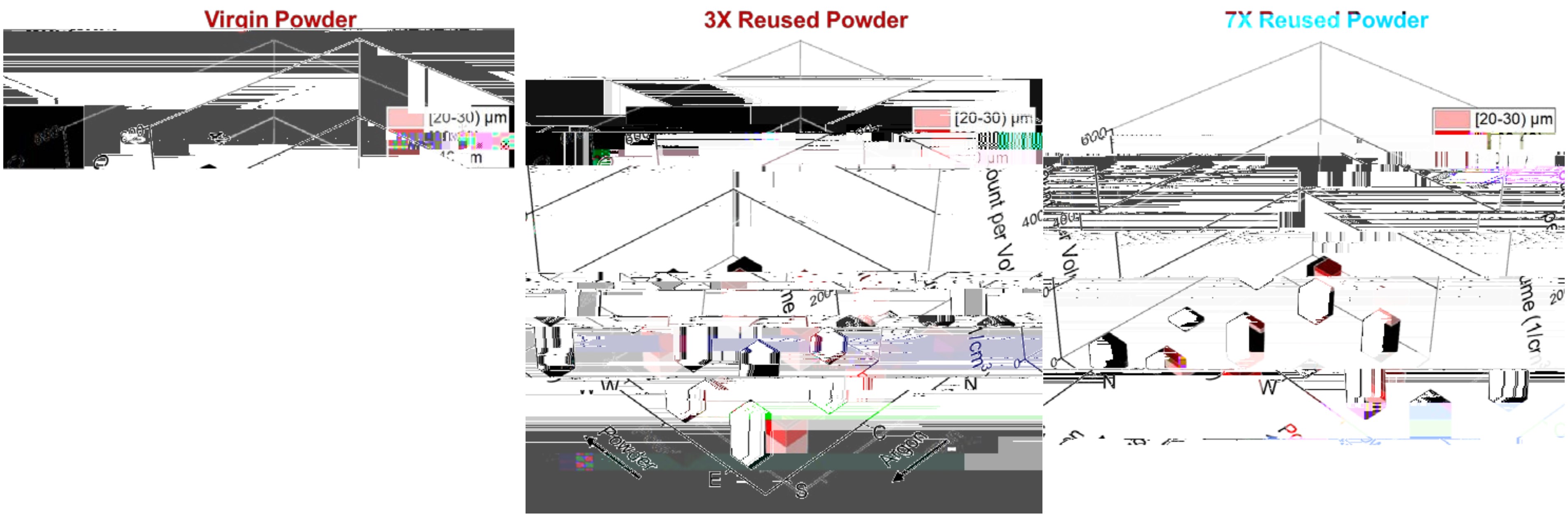
* The number of specimens may be adjusted to minimize the occupied build pl density to avoid excessive spatter, and powder layer disturbance due to inter-part interaction

Preliminary results

Powderre-use effect: defect characteristics

South locations tend to produce more defects

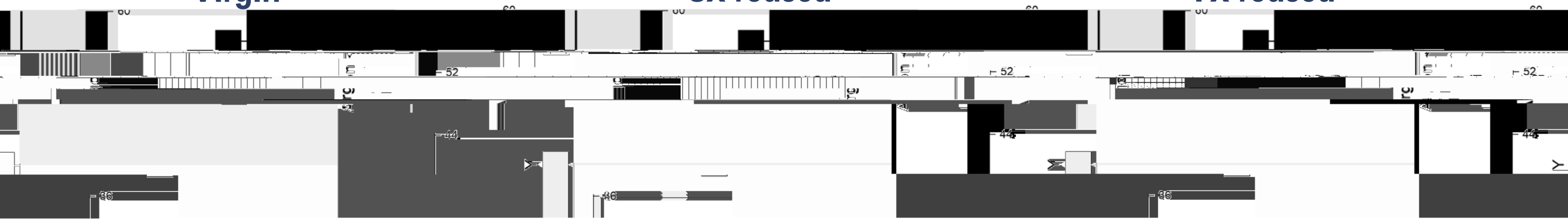
Defect population tend to decrease in re-used powder



Powderre-use effect: defect characteristics

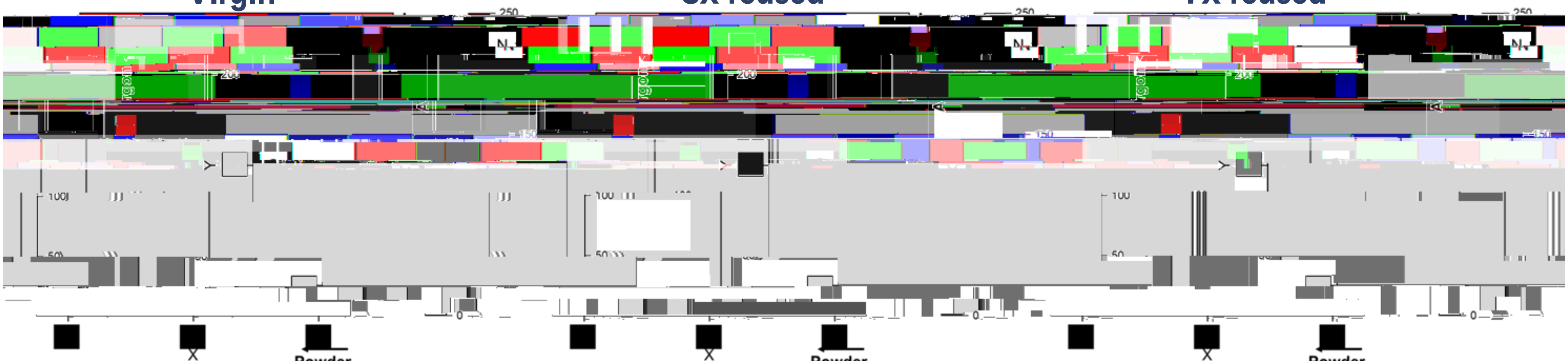
Maximum defect size

Virgin **3x reused** **7x reused**



No. of defects > 30 m

Virgin **3x reused** **7x reused**



Location dependency and KPVs drift effects

SE or SW generally performed worse for most KPVs.

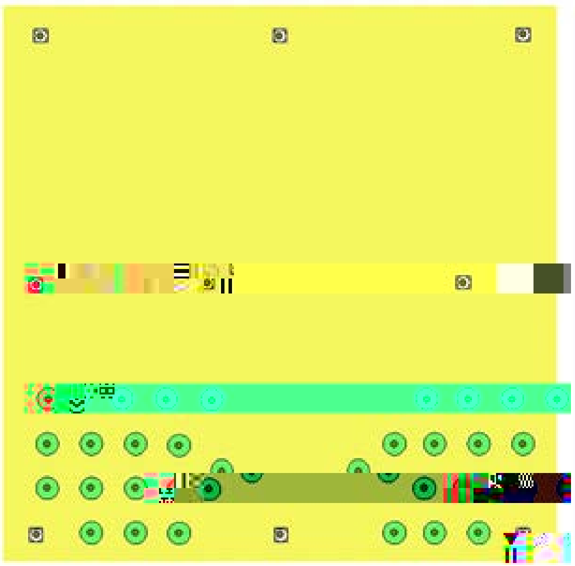
A volume of ~(5 x 5 x 5) mm^3 was considered for all specimens

Gray box indicates overestimation of defect size due to the smas cyo(z)198.0.5 (iackgro5(d)

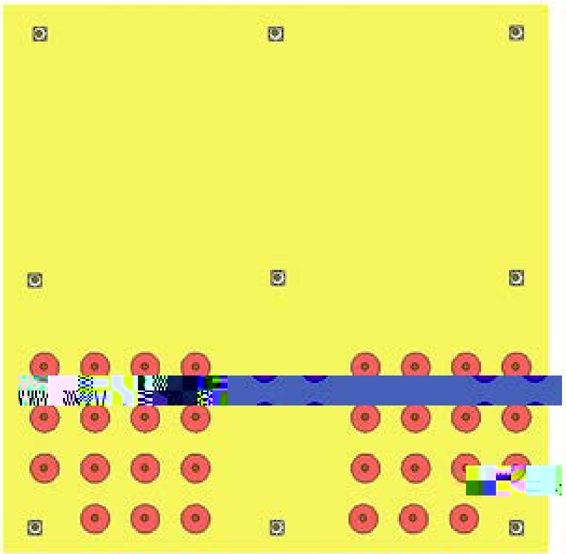
Next step

Fabrication of specimens will be limited to SW and SE locations as they were fou
to produce the worst defect conditions

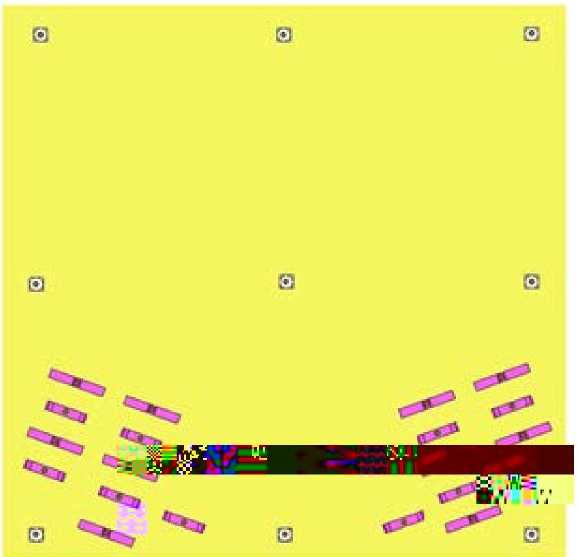
Tensile



Fatigue



High strain rate fracture



- Data on powder reuse is planned to be fully analyzed and become available by the end of 2021