National Center for Additive Manufacturing Excellence

Factors Affecting Qualification/Certification - Effect of Drifts in Key Process Variables within Tolerance on Mechanical Properties of Additively Manufactured Ti-6Al-4V Parts

Project sponsored by: Federal Aviation Administration (FAA)

Introduction

- **Project Title**: Factors Affecting Qualification/Certification - Effect of Drifts in Key Process Variables within Tolerance on Mechanical Properties of Additively Manufactured Ti-6Al-4V Parts
- **Principal Investigator**: Nima Shamsaei

(See next slide for complete list of participants.)

- **FAA Technical Monitor**: Kevin Stonaker
- **Source of matching contribution**: Faculty time and graduate research assistant tuition

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- Katherine Olson, US Army
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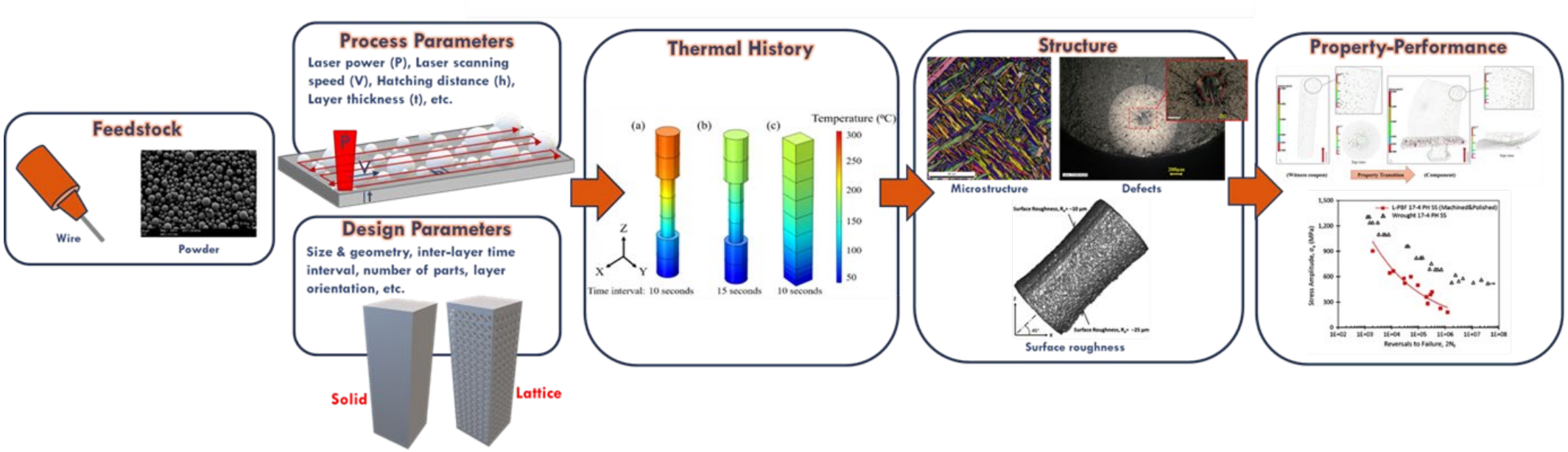
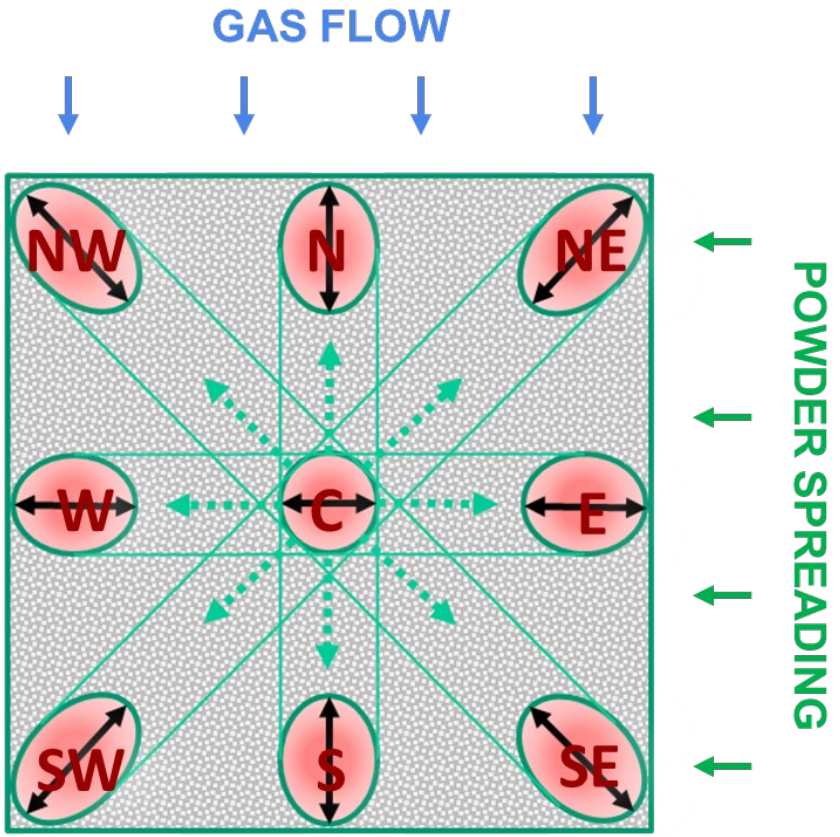
Background



- Effect of key process variables (KPVs) drift within the tolerances on defect content and part performance is not very well understood
  - Identified on several roadmaps including America Makes/ANSI AMSC, ASTM R&D
  - 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

- For a fixed set of process parameters, factors such as powder **specification, location, geometry,** and **time interval** can also affect the fabricated parts' structure and properties
- The effect of **power re-use** and **location dependency** will be investigated first so that their influence can be excluded from the KPVs drift study
- <u>Geometry and time interval will be kept constant</u>



Objective & Approach

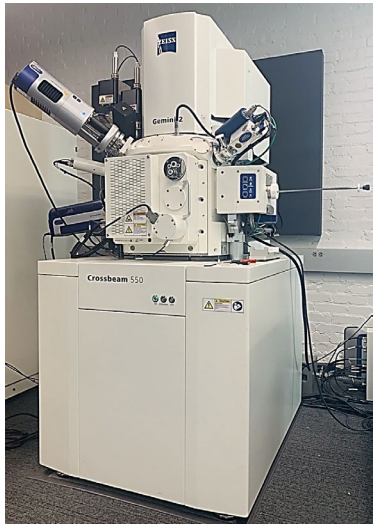
- **Objective**: To understand the effect of KPVs drift within tolerance bands on defect characteristics and mechanical properties of L-PBF Ti-6Al-4V Gr. 5
- **Approach**: Four steps are taken,
  I. Quantify the powder re-use effects. Geometry and time interval will be kept constant
  II. Identify the effect of filter clogging and location on the defect-structure, tensile and fatigue behaviors
  III. Identify the combined effect of KPVs (laser power and hatch distance) drift and location on the defect-structure
  IV. Evaluate the impact of KPVs drift on tensile, fatigue and high strain rate fracture behaviors using specimens fabricated with worst KPVs/location combinations
  V. Leverage machine learning and simulations wherever applicable

Fabrication and Testing Equipment

EOS M290 L-PBF Machine

X-ray Computed Tomography (XCT) Machine

MTS Fatigue Testing Machines



Scanning Electron Microscope

- AP&C Ti-6Al-4V Grade 5 powder (15-53 μm) was used as feedstock
- During fabrication, time homogenization, and skywriting features were enabled in the infill region
- All specimens were stress-relieved at 704 °C for 1 hour followed by furnace cooling

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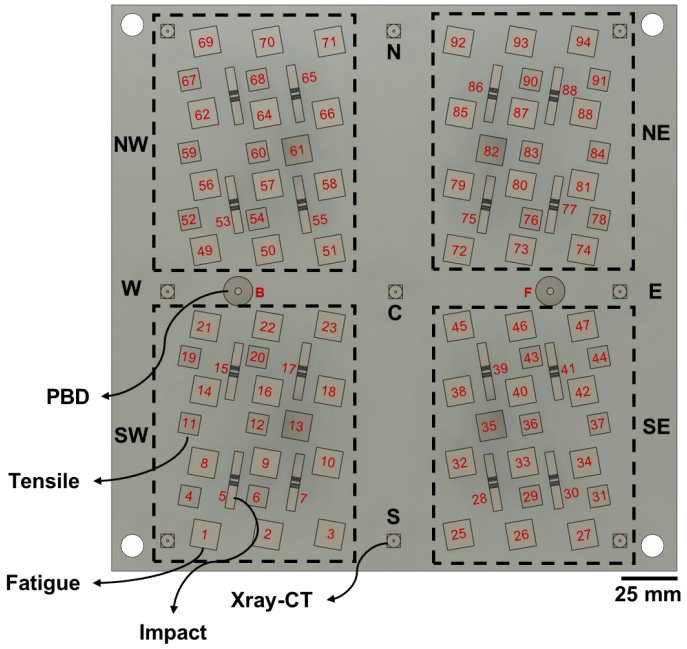
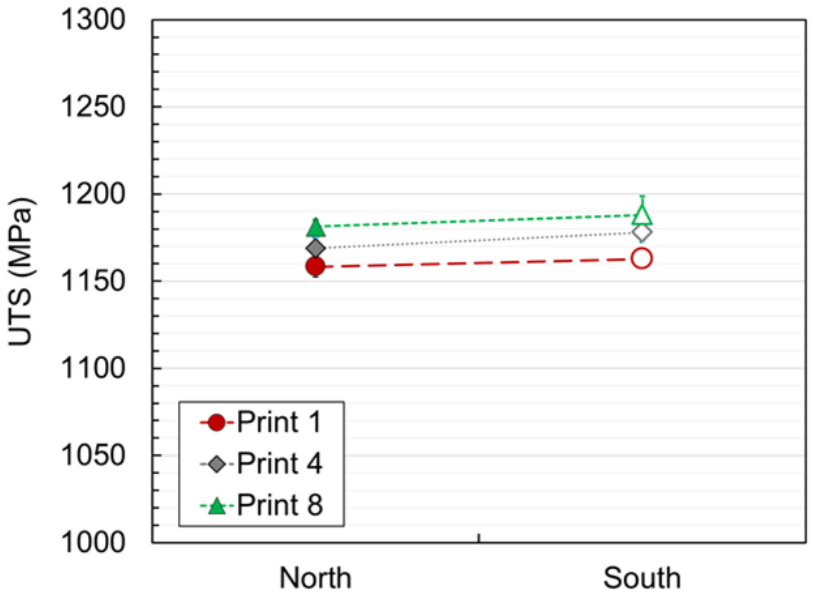
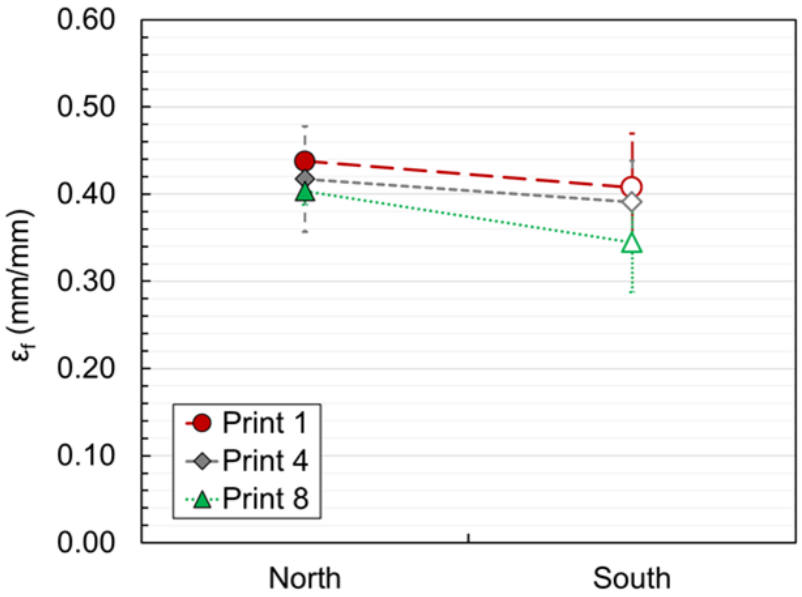
Effects of Powder Reuse on Tensile Properties



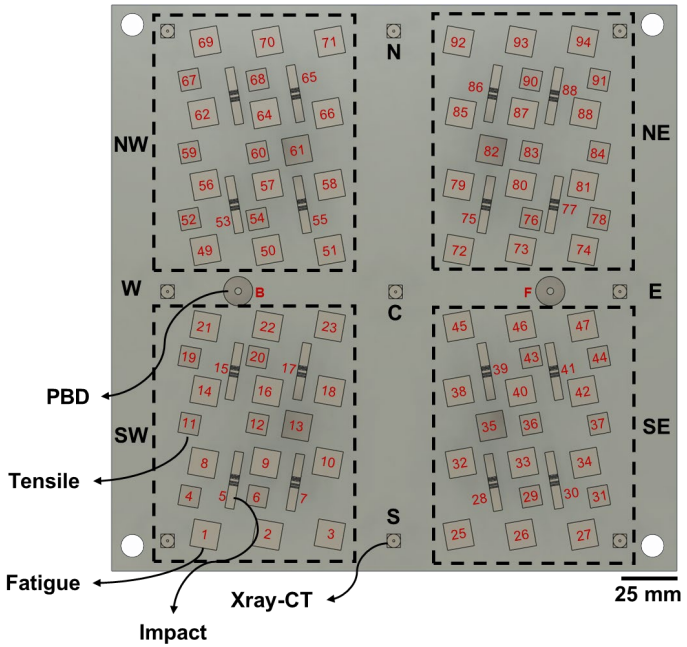




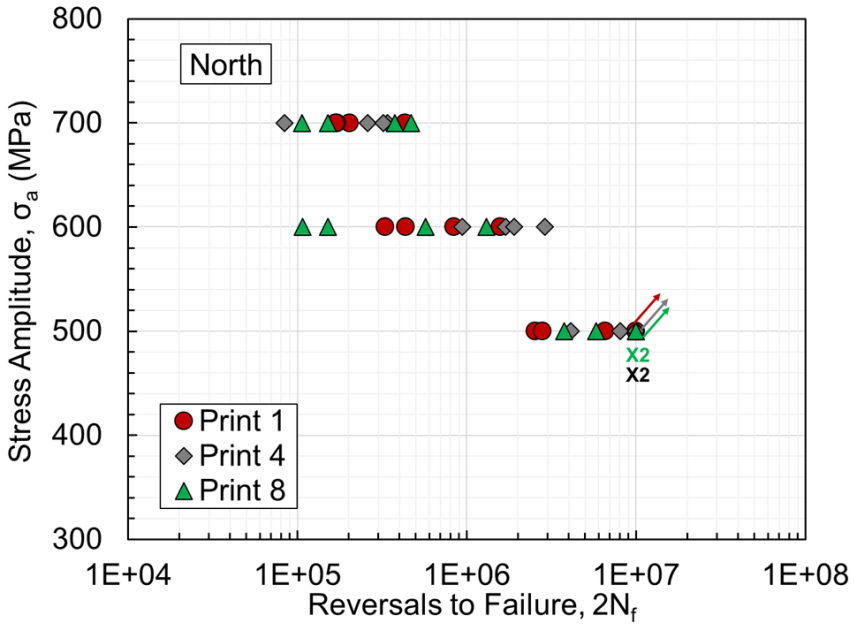
Note: Fresh powder was added for the first print and was reused for the remaining 7 prints

- Slight increase in ultimate tensile strength and decrease in ductility with powder reuse was ascribed to the increase in oxygen/nitrogen content in the reused powder
- Minor location dependency was also observed with south specimens exhibiting slightly higher strength and lower ductility

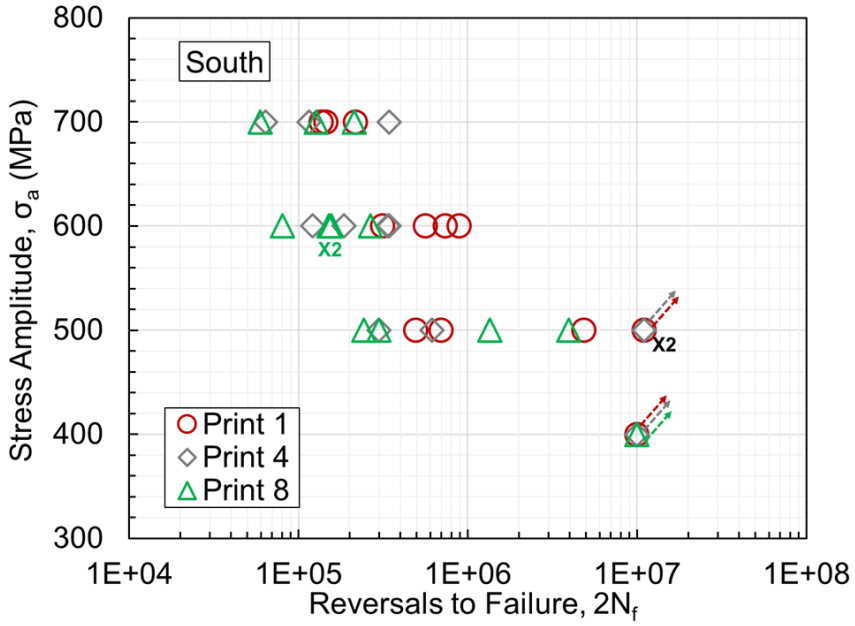
Effects of Powder Reuse on Fatigue Performance



Build Layout



Fatigue Performance (North)



Fatigue Performance (South)

- In North specimens, fewer defects in Print 4 led to slightly higher fatigue performance than other batches
- Fatigue resistance of South specimens was lower than those from the North, and it was observed that the reuse of powder resulted in degradation, possibly due to the presence of spatter-induced defects

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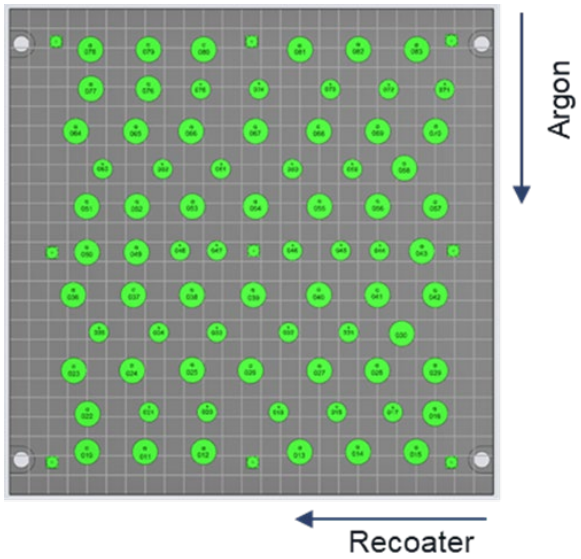
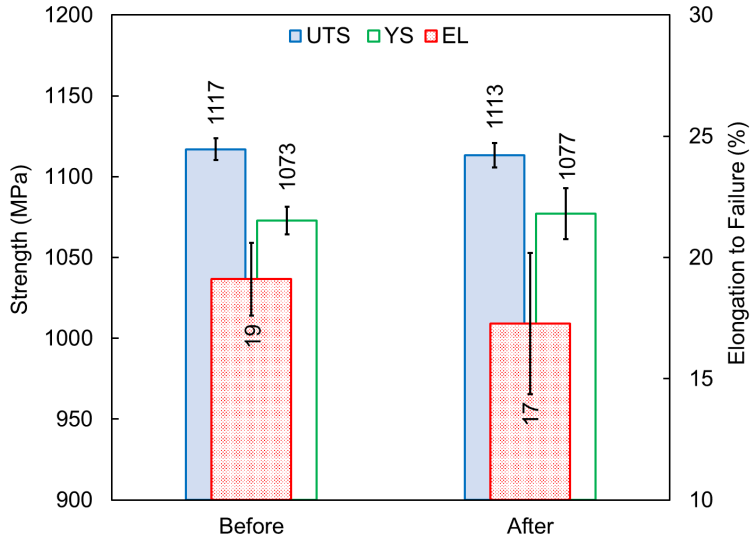
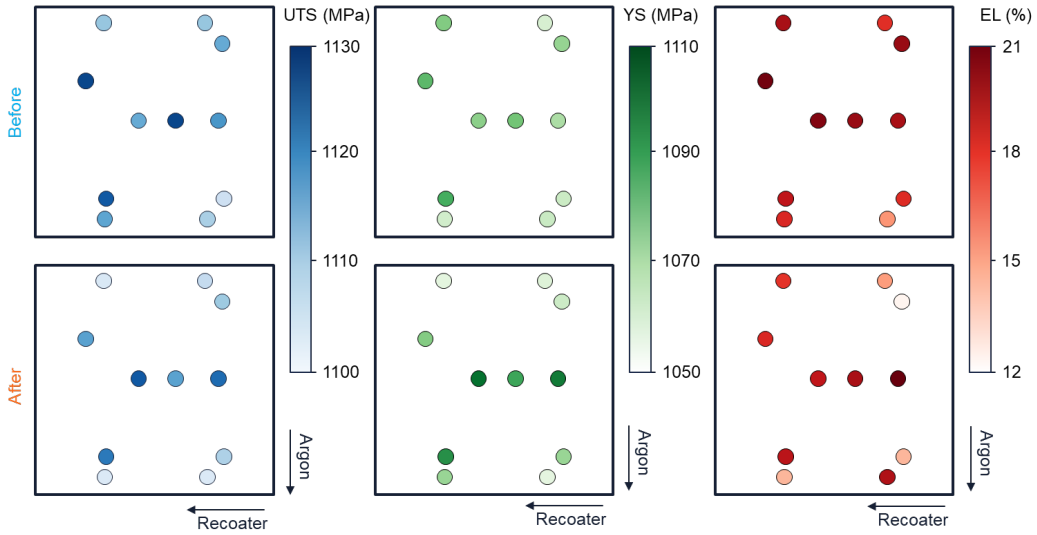
Effects of Filter Clogging on Tensile Properties



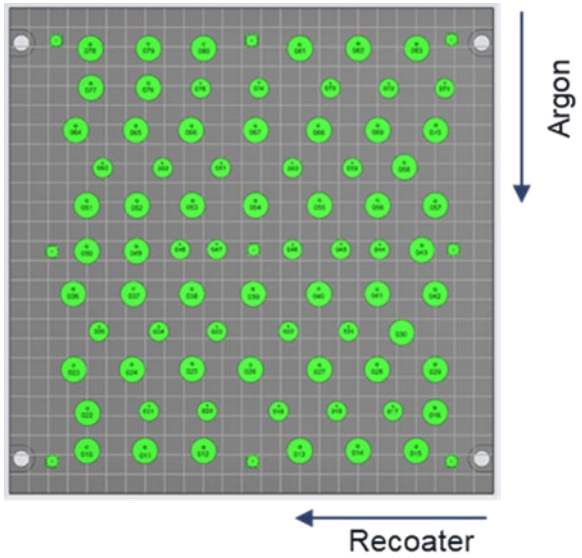


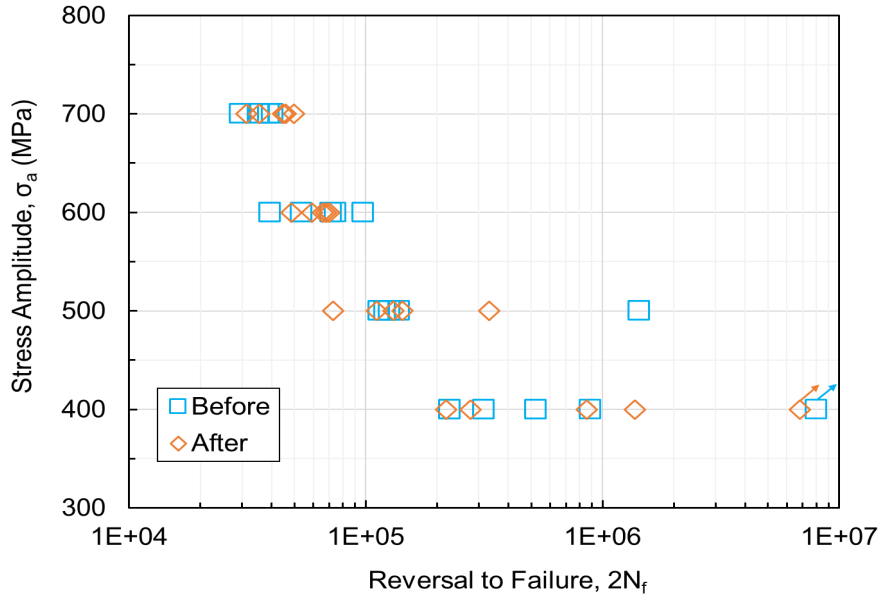


Note: 11 specimens per condition were tested from different locations of the build plate for this study

- Overall, the center specimens exhibited superior tensile properties compared to those from the North and South, both before and after the filter change

Effects of Filter Clogging on Fatigue Performance





- No significant difference in fatigue lives were found before and after the filter change

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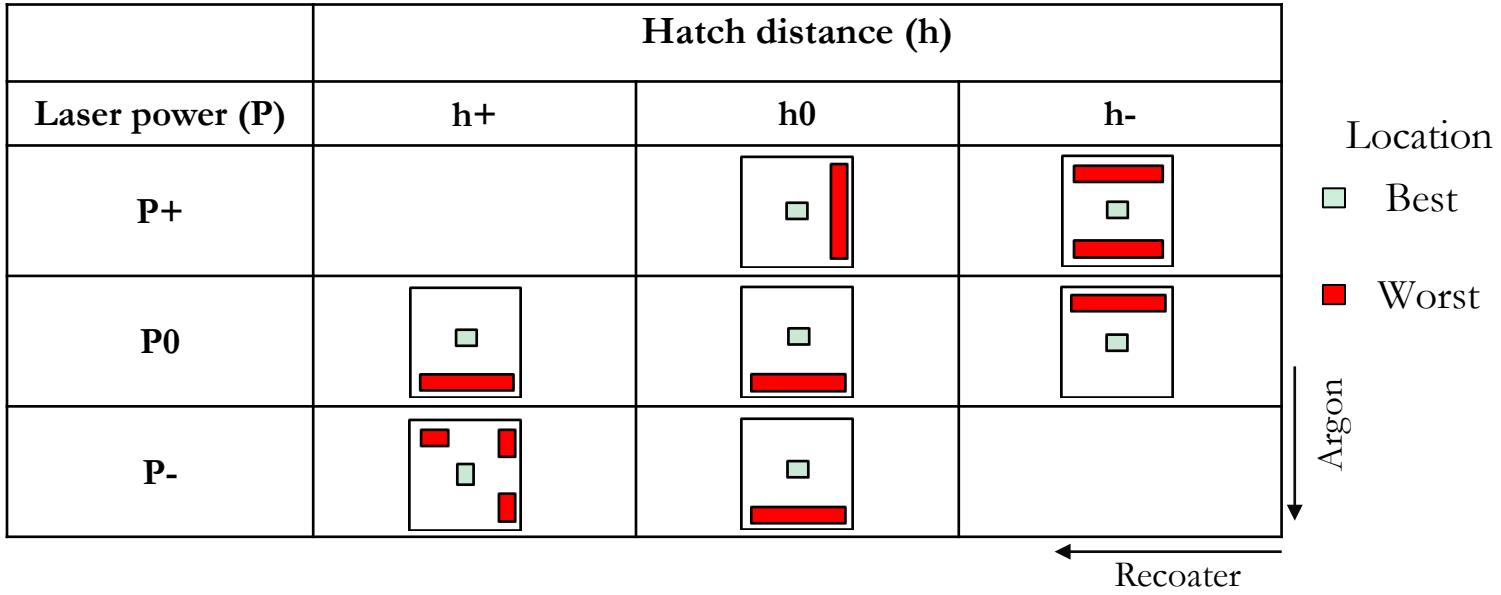
Design of Experiment for KPV Drift

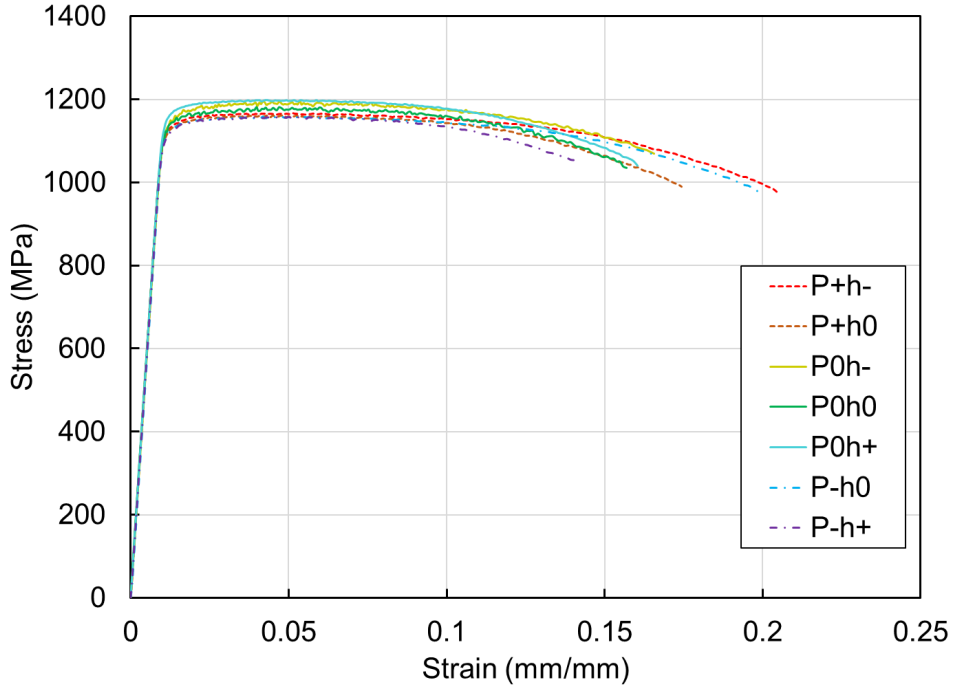
	Hatch distance (h)		
Laser power (P)	**h+**	**h0**	**h-**
P+	P+h+	P+h0	P+h-
P0	P0h+	P0h0	P0h-
P-	P-h+	P-h0	P-h-

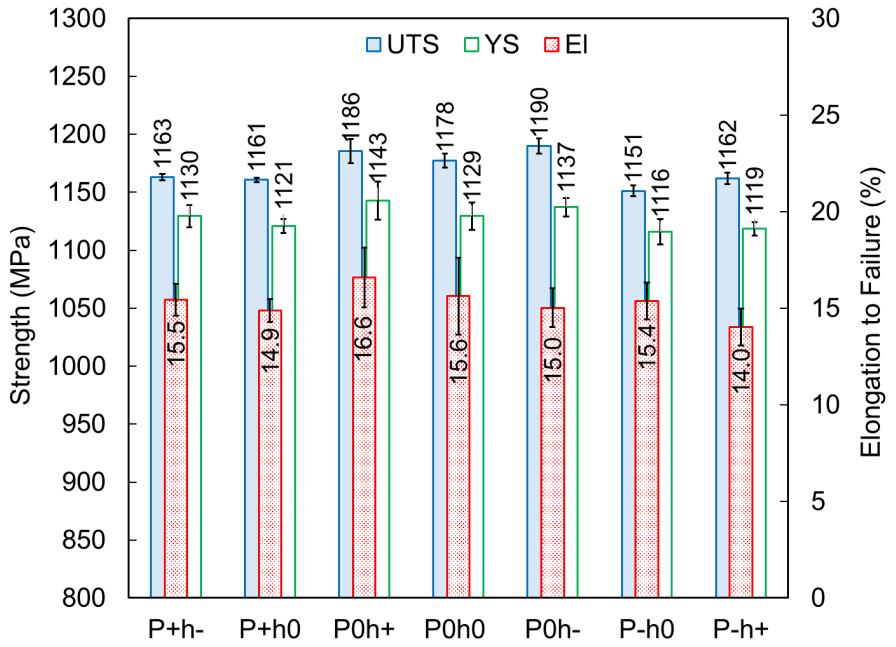
Note: The combinations in gray were not considered for this study



- KPVs and their possible deviations in EOS M290 from the nominal values are laser power (± 4%), hatch distance (± 2.4%)
- 10 builds were fabricated to be tested, 7 for fatigue/tensile, and 3 for high strain rate specimens
  - 105 fatigue (7 x 15), 42 tensile (7 x 6), and 42 high strain rate (7 x 6) specimens were fabricated
- Specimens were fabricated in their respective best and worst locations based on the XCT coupons results

Effects of KPV on Tensile Properties

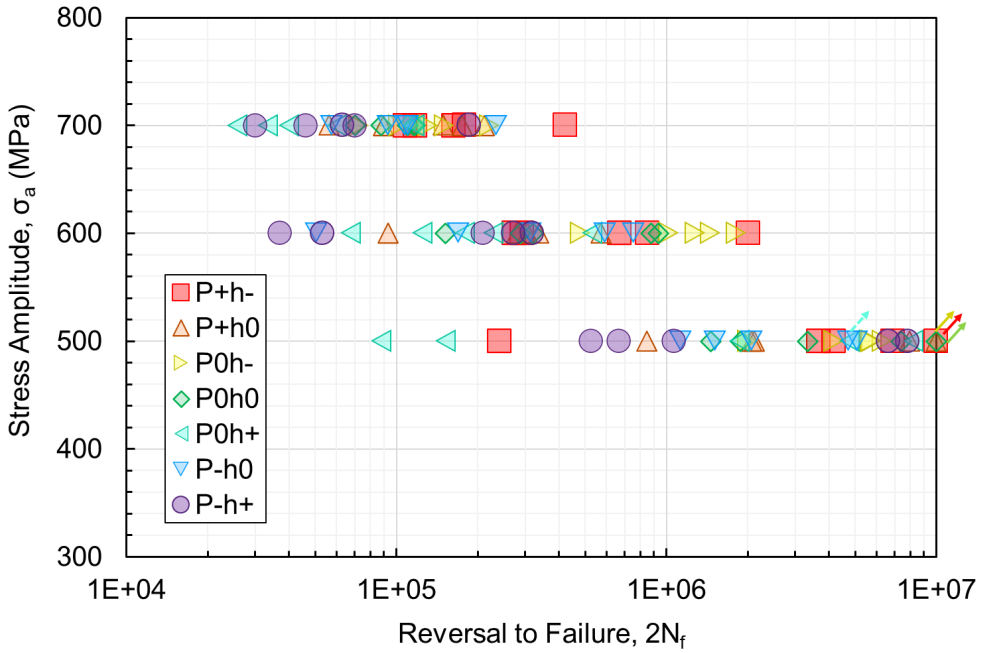




- No specific trend was noticed for elongation to failure

	Hatch distance (h)		
Laser power (P)	**h+**	**h0**	**h-**
P+	P+h+	P+h0	P+h-
P0	P0h+	P0h0	P0h-
P-	P-h+	P-h0	P-h-

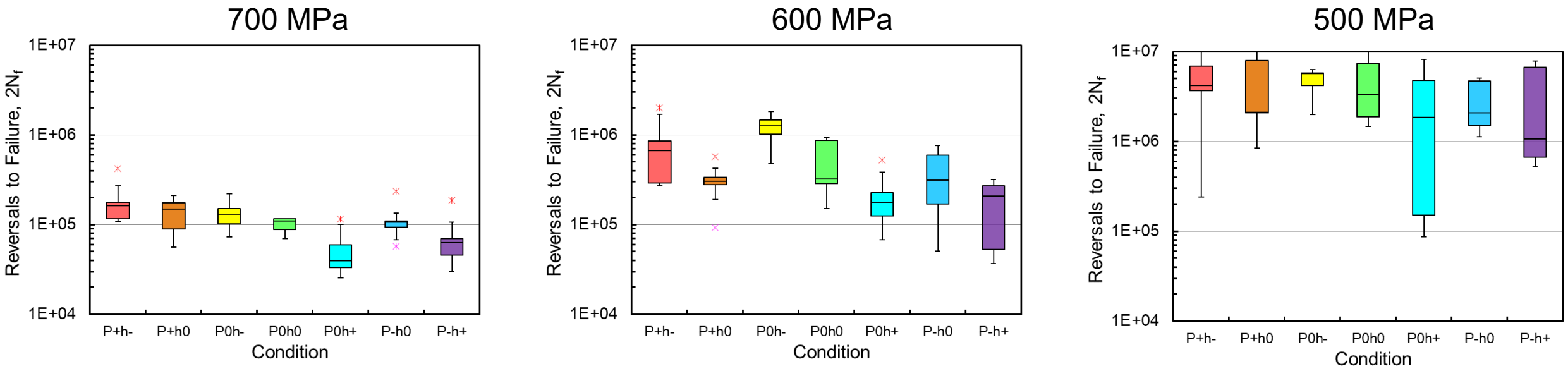
Effects of KPV on Fatigue Behavior



	Hatch distance (h)		
Laser power (P)	**h+**	**h0**	**h-**
P+	P+h+	P+h0	P+h-
P0	P0h+	P0h0	P0h-
P-	P-h+	P-h0	P-h-

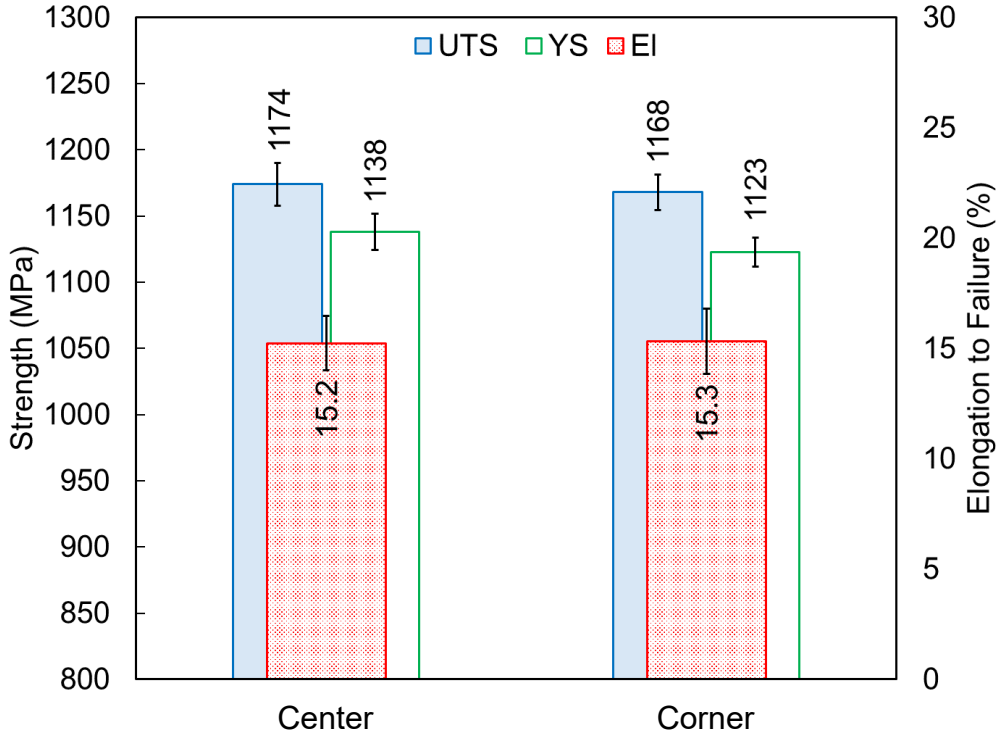
- In general, no specific trend in fatigue lives were noticed within KPV tolerance

Effects of KPV on Fatigue Behavior



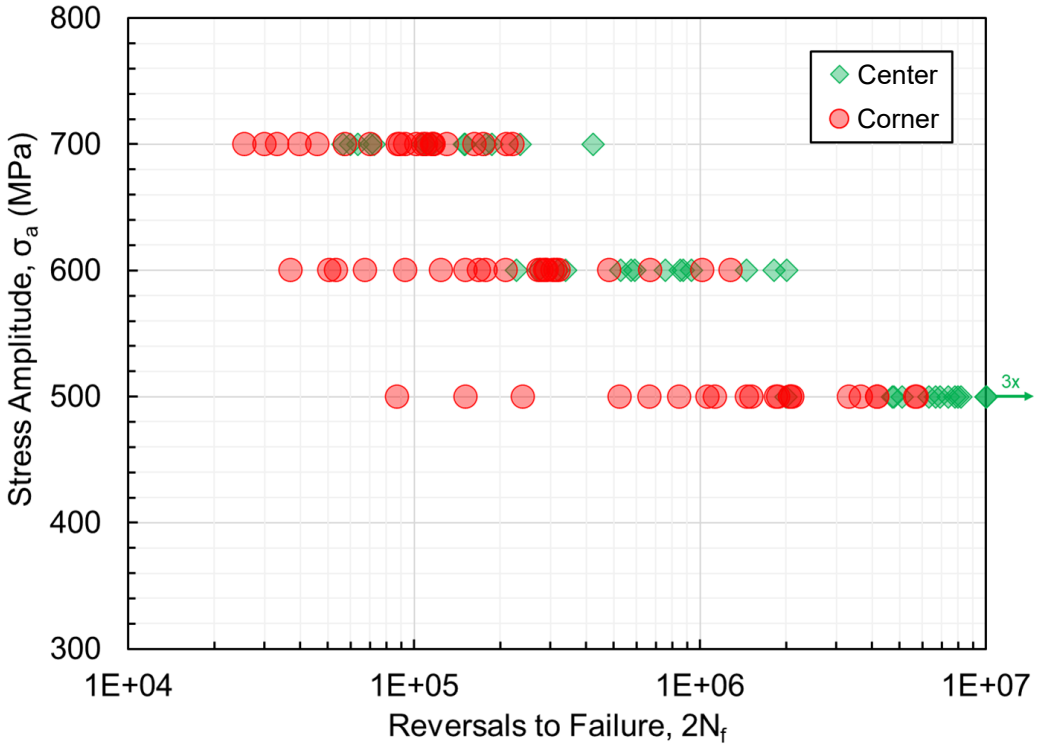
- Although scatter was significant within KPV tolerance, there was no specific trend in fatigue lives

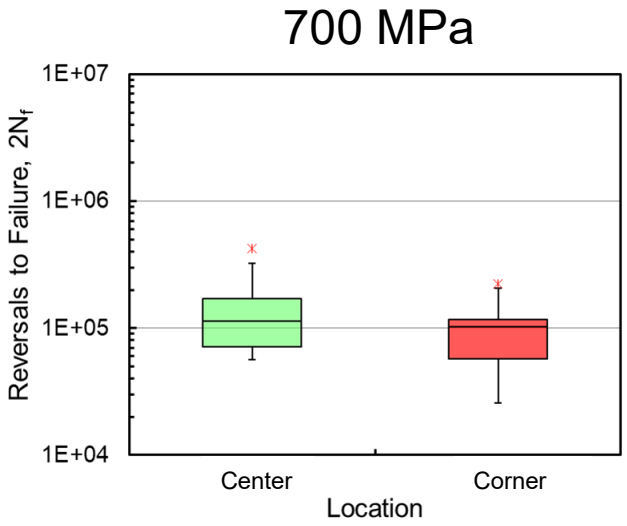
Effects of Location on Tensile Properties

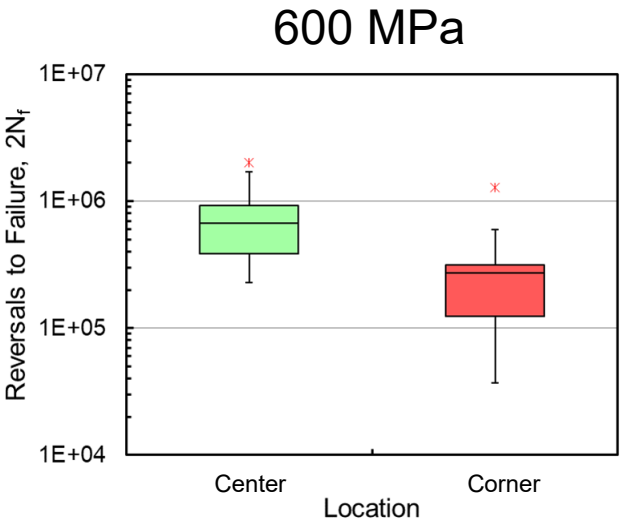


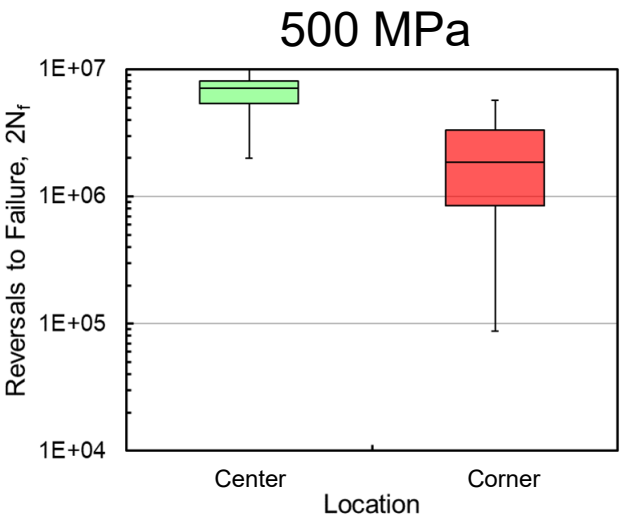
- No significant change in tensile properties was noticed across different locations

Effects of Location on Fatigue Behavior









- Effect of specimen location was more prominent at 500 MPa

Summary

- Powder reuse exhibited a slight increase in strength and decrease in ductility
- Powder reuse led to decrease in fatigue resistance
- Filter clogging did not affect tensile and fatigue behaviors
- Specimens fabricated within KPV tolerance did not show any specific trend in tensile and fatigue behaviors
- The effect of specimen location on fatigue behavior was more noticeable at lower stress amplitudes

Thank you for your attention !

- National Center for Additive Manufacturing Excellence (NCAME)