Comparisons Between 316L Stainless Steel Made Using Multiple Laser Powder Bed Fusion Systems

Caroline Scheck and Bryan Kessel
Naval Surface Warfare Center Carderock Division

Acknowledgements

Funding

- Department of Navy Innovation Sustainment Group (DISG)
- NAVSEA Technology Office Cross Platform Systems Development (CPSD) Program
- Defense Logistics Agency (DLA)

Collaborators

- Naval Surface Warfare Center Indian Head Explosive Ordinance Division
- Naval Surface Warfare Center Dahlgren Division
- ARL Pennsylvania State University

Background

- Process qualification is a focus area for the Navy
  - Interested in understanding how usage of different additive manufacturing systems impacts results
  - Naval Surface Warfare Centers maintain four laser powder bed fusion systems from three different manufacturers
- Project purpose was to, when a reasonable effort was made to maintain general consistency across systems, examine:
  - Mechanical, microstructural, and corrosion variation
  - Identify issues in set-up across systems
- Scope was not intended to keep parameters consistent across systems or control variation
- Results to inform process qualification and Navy knowledge

Laser Powder Bed Fusion Systems

Machines

- System A
- System B
- System C

Processing Parameters

- Default parameter sets for 316SS were used on all systems, no attempt was made to correlate parameters between systems
  - Raster patterns, power, travel speed, etc. were unique to each system
- Argon environment

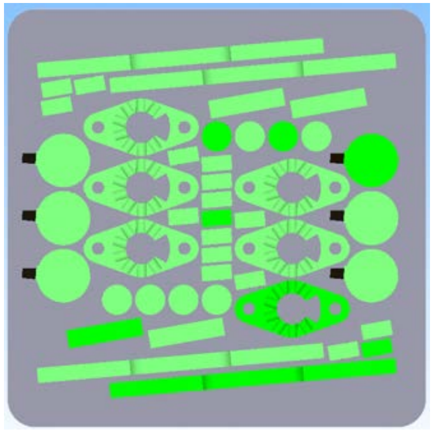
3 Powder Suppliers

- System B and System C used the recommended original equipment manufacturer (OEM) powders (powder B and powder C)
- System A used powder B and an a non-OEM alternate powder (powder X)
- 316SS argon atomized powders, sizing varied
- Powders bought in single lots, virgin powder used for all builds

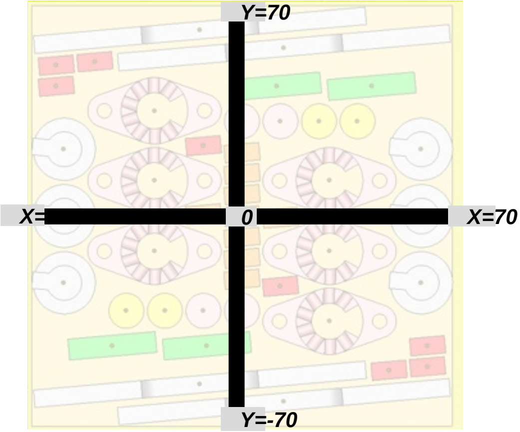
Build Design

Primary Specimens

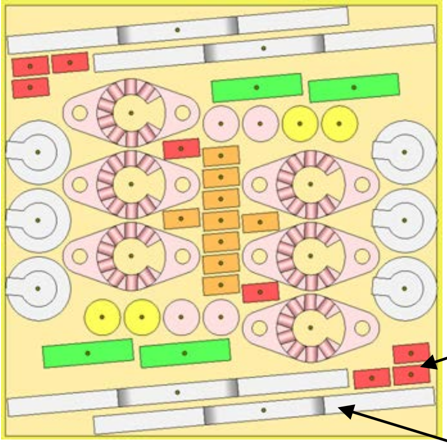
- Tensile *(to be tested machined and as-built)*
  - Round, vertical, net shape
  - Round, vertical, pre-machine
  - Flat, vertical, net shape
  - Flat, vertical, pre-machine
  - Flat, horizontal, pre-machine
- Corrosion
- Torsion

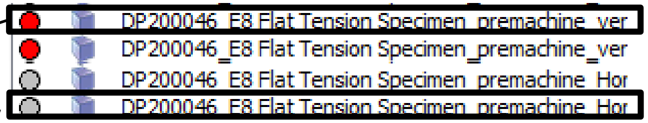


Systems A



While specimens have same dimensions, different CAD files were designed for each specimen to aid in placement

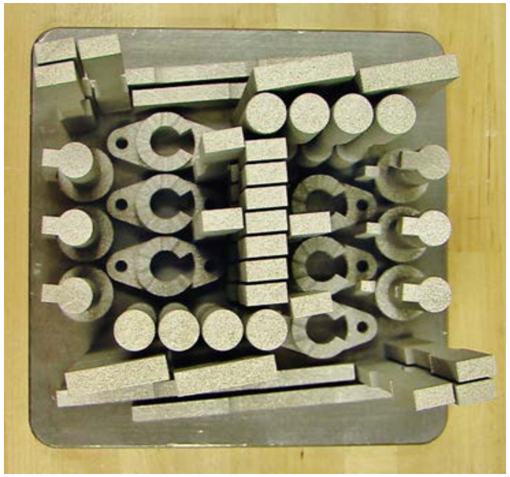




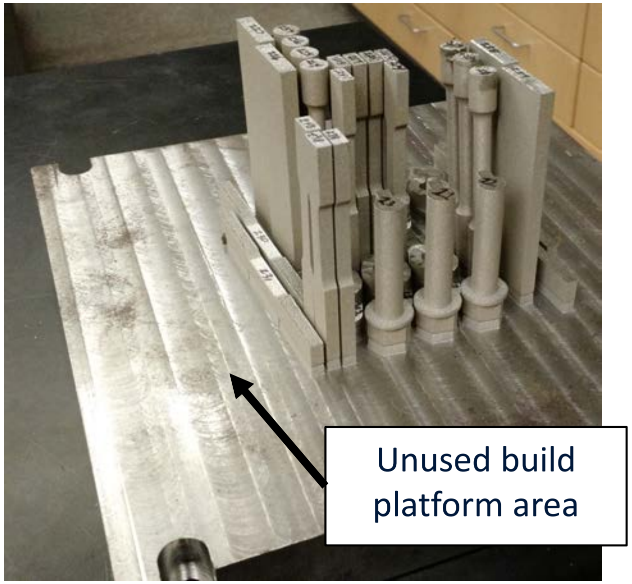
System B

Build Design

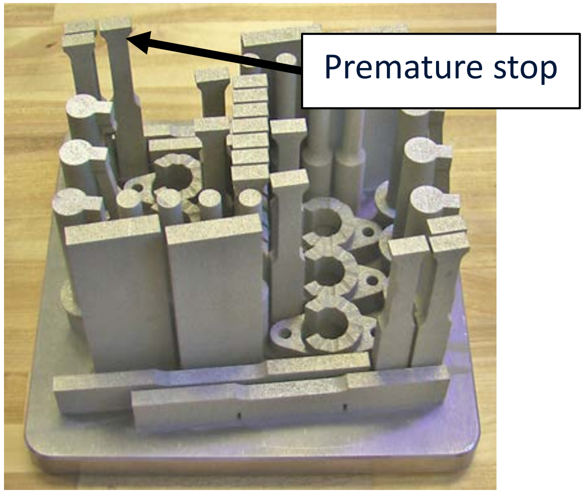
- Specimens were designed to fit on the smallest build platform (System A)
- Larger systems located specimens in center of build platforms
- Solid support structures necessary to prevent build failures
- 2 build cycles/system
- Specimen removal
    - Band saw
    - EDM



Small build platform



Large build platform



Partial build

Machined Verses As-Built (Strength)

	As-Built	
	Average 0.2% YS	Stdev
System A (powder X)	388	13
System A (powder B)	452	8
System B (powder B)	516	4
System C (powder C)	585	33

	Machined	
	Average 0.2% YS	Stdev
System A (powder X)	397	40
System A (powder B)	445	62
System B (powder B)	519	11
System C (powder C)	588	26

	Difference (As-Built to Machined)	
	Average 0.2% YS	Stdev
System A (powder X)	9	27
System A (powder B)	-7	54
System B (powder B)	3	6
System C (powder C)	4	-6

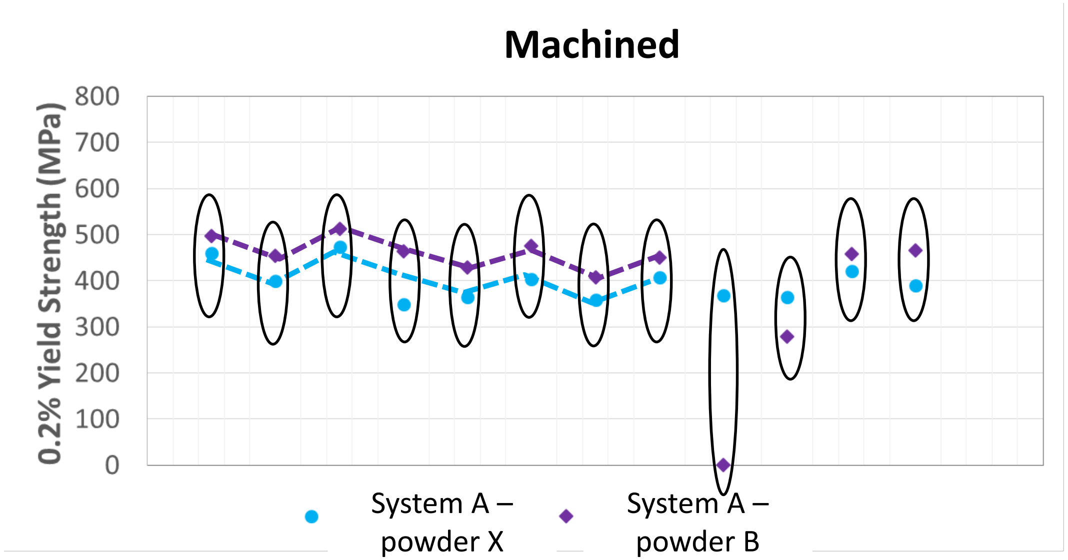
Of Note

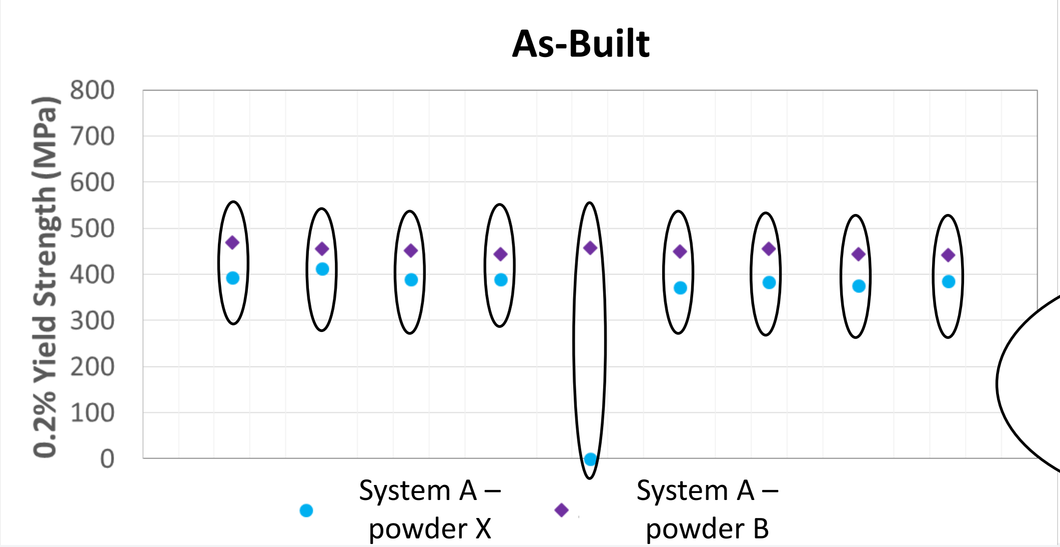
- Figures show machined and as-built properties disregarding relative location on build platform between systems and build cycles
- Machined specimens were designed with extra material to achieve same dimensions as as-built specimens post machining

Results

- System A showed more variability in machined specimens verses as-built
- System B shows consistent properties regardless of machined or as-built surface

Repeatability by Location (Strength)





Of Note

- Results are from two different build cycles on System A
- Each build cycles used identical processing parameters
- Only change was powder (powder X verses powder B)

Results

- Reduction in properties due to impact of powder variability only
- Results indicate system has repeatable processing ability based on location

Each group of specimens were made at the same build platform location

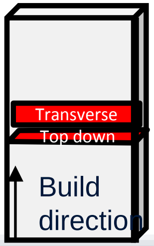
Microstructure

System A – powder B | System B | System C

Top-down

Transverse

- Significant variation in macrostructures observed across systems
- Various indications (incomplete fusion, cracks, unmelted powder, etc.) seen in System A - indicates non-optimized processing parameters

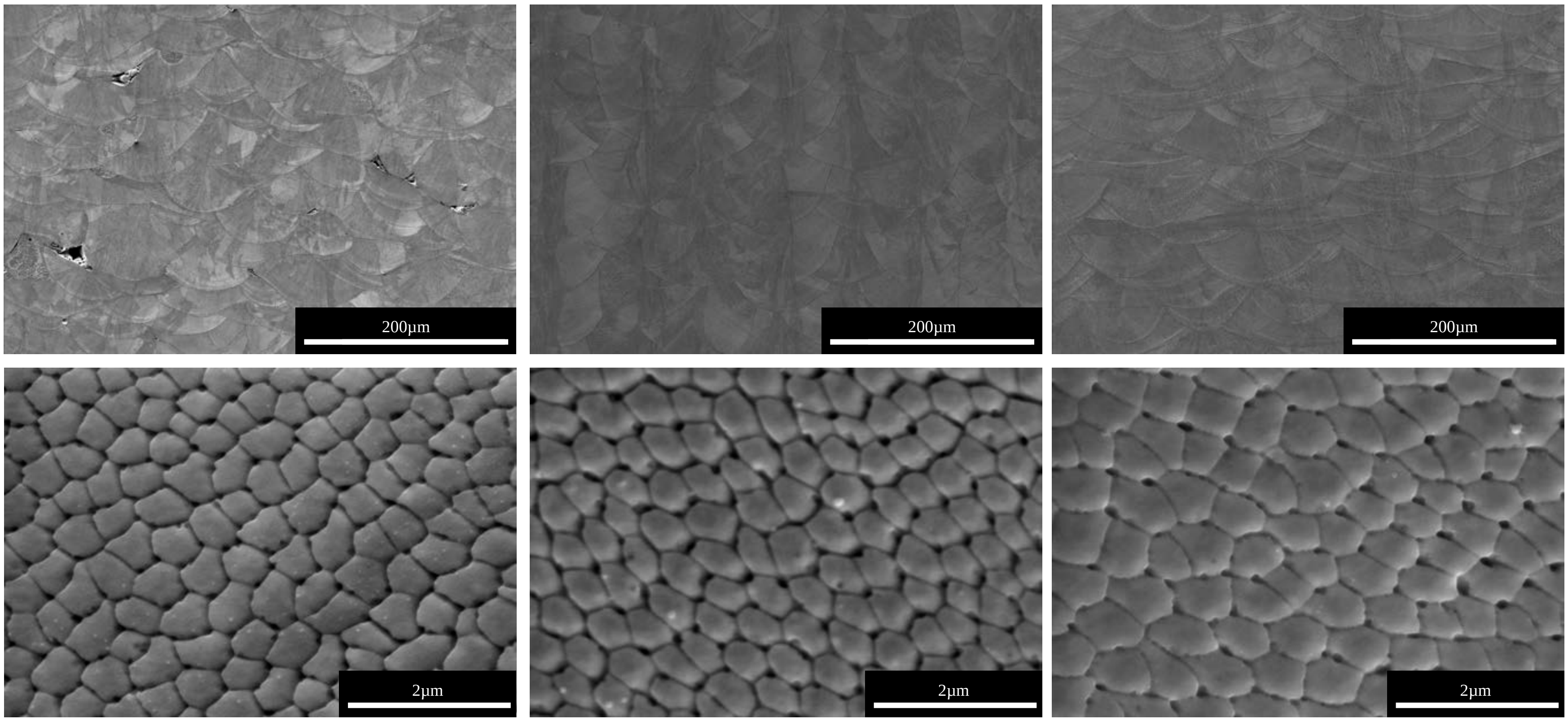


Microstructure

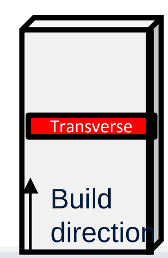
System A – powder B | System B | System C

Macro

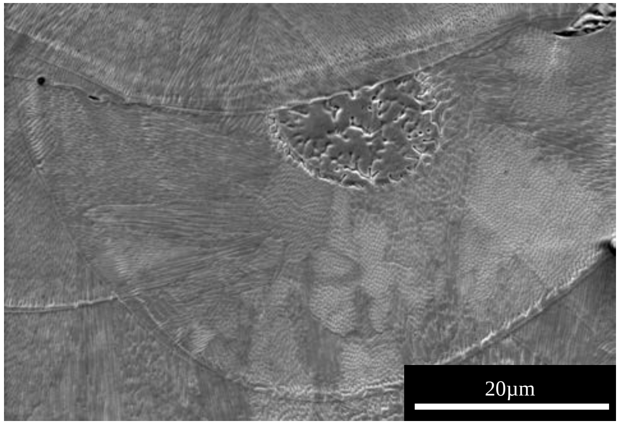
Sub structure



- Images taken from center of specimen
- Transverse orientation

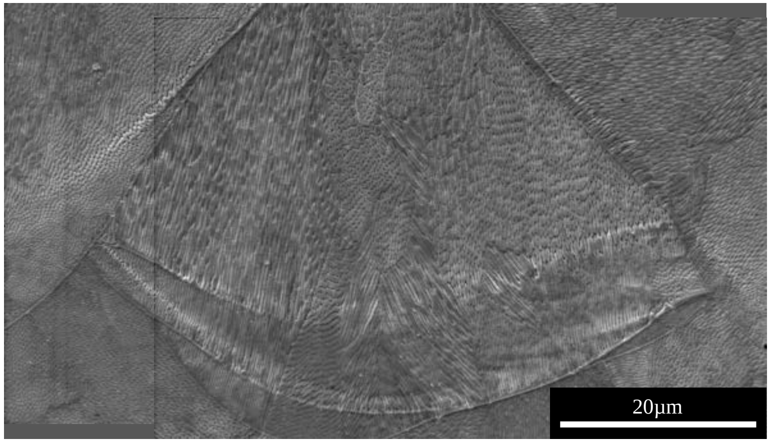


Microstructure

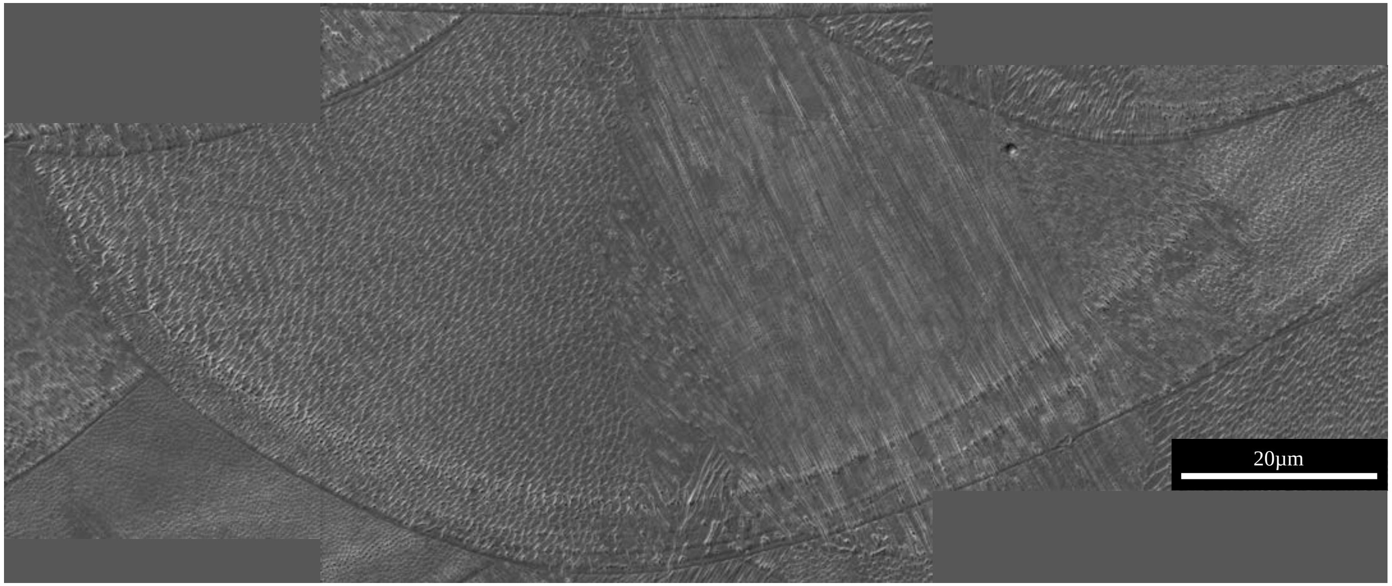


System A – unmelted powder

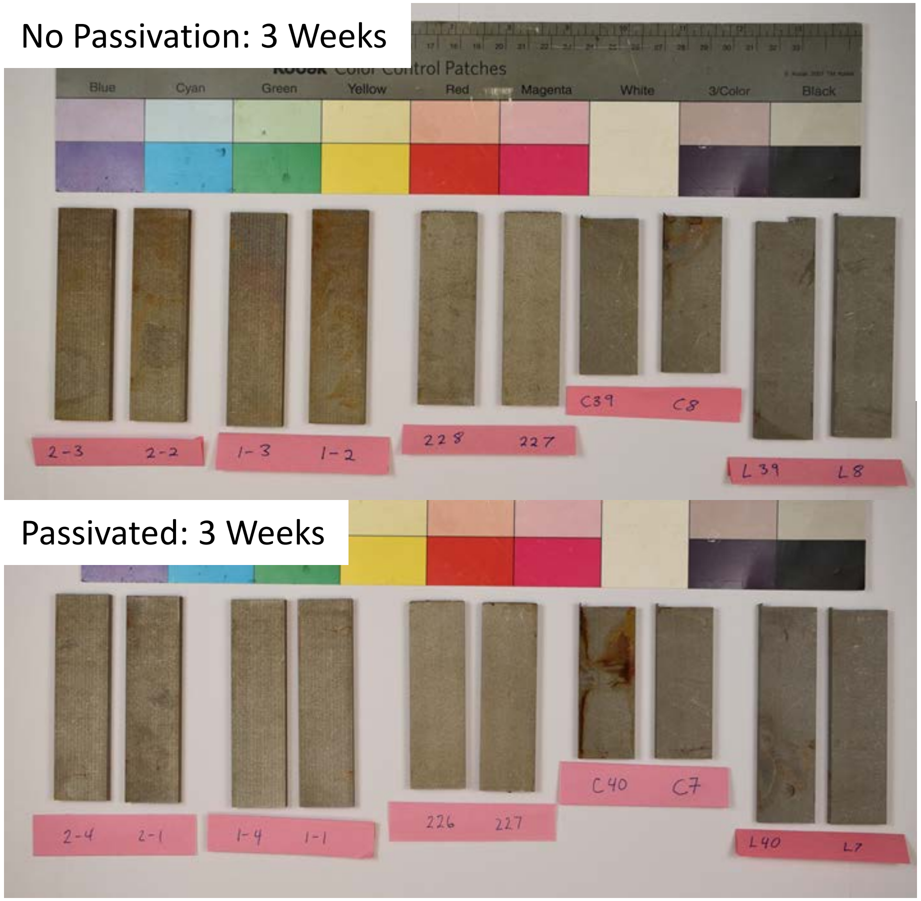
System A



System C



Corrosion – Initial Results



Salt Fog Testing

Results

- Results in-progress
- Preliminary results indicate accelerated corrosion on System A samples (non-optimized parameters)

Conclusions

- Purpose of project was to examine major differences across AM laser powder bed fusion systems when default processing parameter sets were used
  - Default system parameters may not be optimized for material properties
  - Even when not processing parameters are not optimized, tested specimens indicate general consistency over multiple build cycles

Continuing Work

- Mechanical property variation across systems
- Mechanical property variation within systems (two build cycles) by location
- Scanning electron microscopy evaluation
- Powder characterization

ABSTRACT: Abstract: Metal powder bed fusion (PBF) additive manufacturing (AM) systems fabricate material layer-by-layer using an energy source that selectively melts or sinters raw powder feedstock. There are multiple original equipment manufacturers (OEMs) for PBF systems and each OEM utilizes its own unique software, system controls, processing parameter options, etc. that can result in material and mechanical variation. This project focuses on the results from using three different OEM PBF systems to fabricate 316L austenitic stainless steel; the purpose is understanding variability when a reasonable attempt is made to maintain consistency between build files and using OEM recommended system processing parameters and raw materials. Results include powder feedstock characterization, mechanical and corrosion testing, and microstructural feature comparisons between fabricated coupons from each system.