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CENTER FOR MATERIAL CHARACTERIZATION

Effect of Plasma Spheroidization on the Corrosion Performance of Additively Manufactured 316L Stainless Steel

Department of Mechanical Engineering

Unites States Naval Academy

Annapolis, MD

Prof R.J. Santucci, Prof Elizabeth Getto, Prof Michelle Koul

CAPT Brad Baker, CDR Jon Gibbs, Prof Rick Link,

Midn 1/C Andrew Shumway, Midn 1/C Jordan McLaughlin

Motivation

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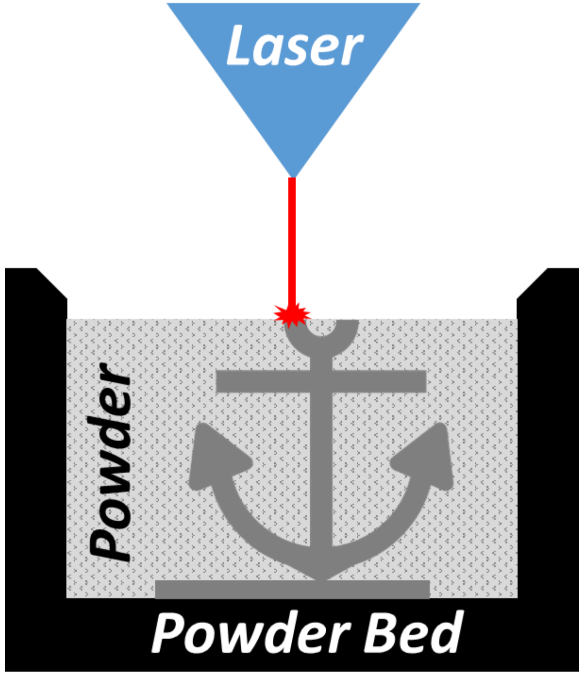
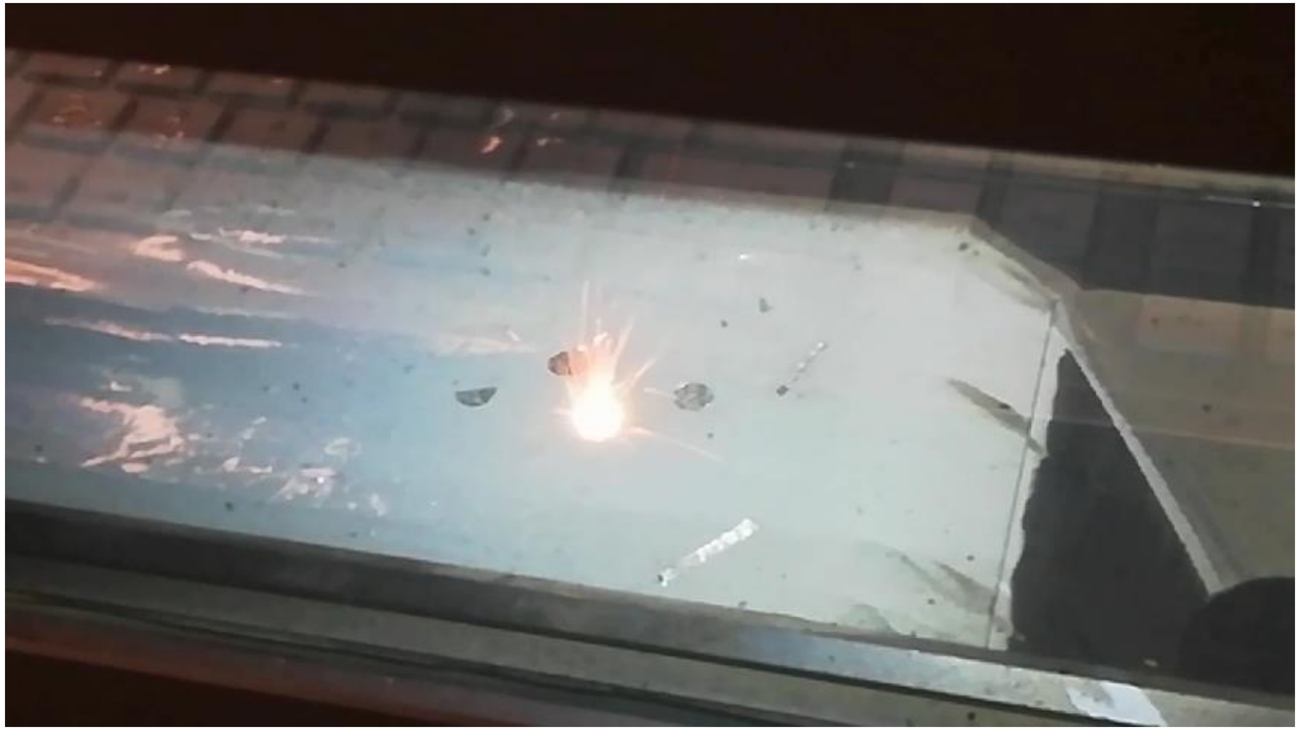
- 316L stainless steel is essential to U.S. Naval applications from ship parts to weapon systems.
- Additive manufacturing (AM), the stepwise construction of a part layer by layer, is used extensively with 316L and shows promise for use in the Navy.





Additive Manufacturing (AM) Process

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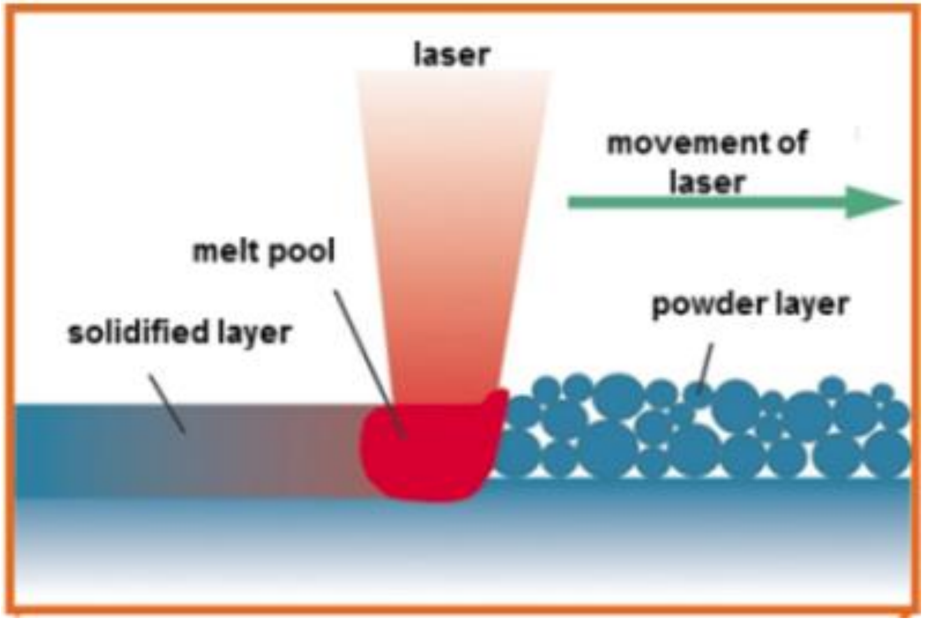
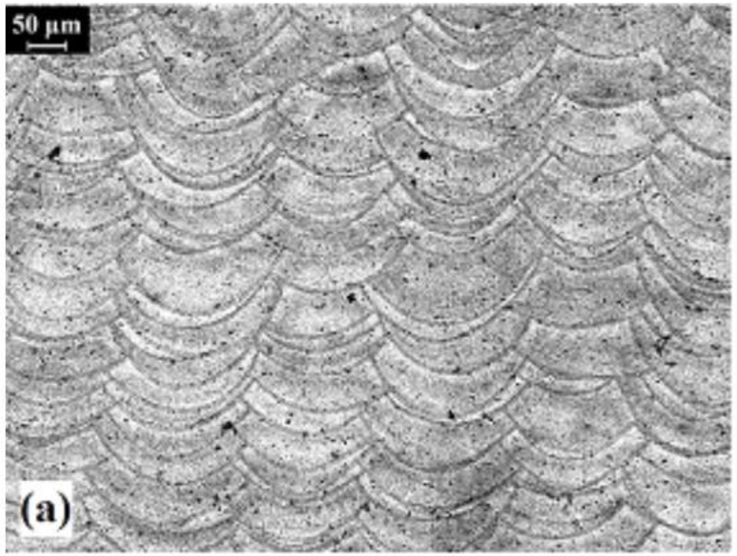
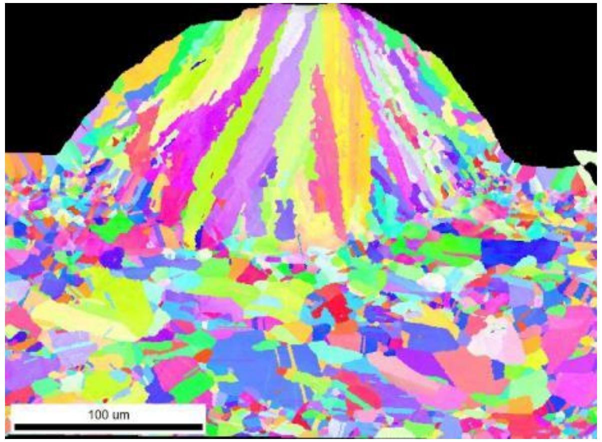


*SLM: Fraunhofer Institute for Machine Tools and Forming Technology



AM AlSi10Mg specimen, etched cross section, M. Krishnan, PhD Thesis, Politecnico di Torino; 2014

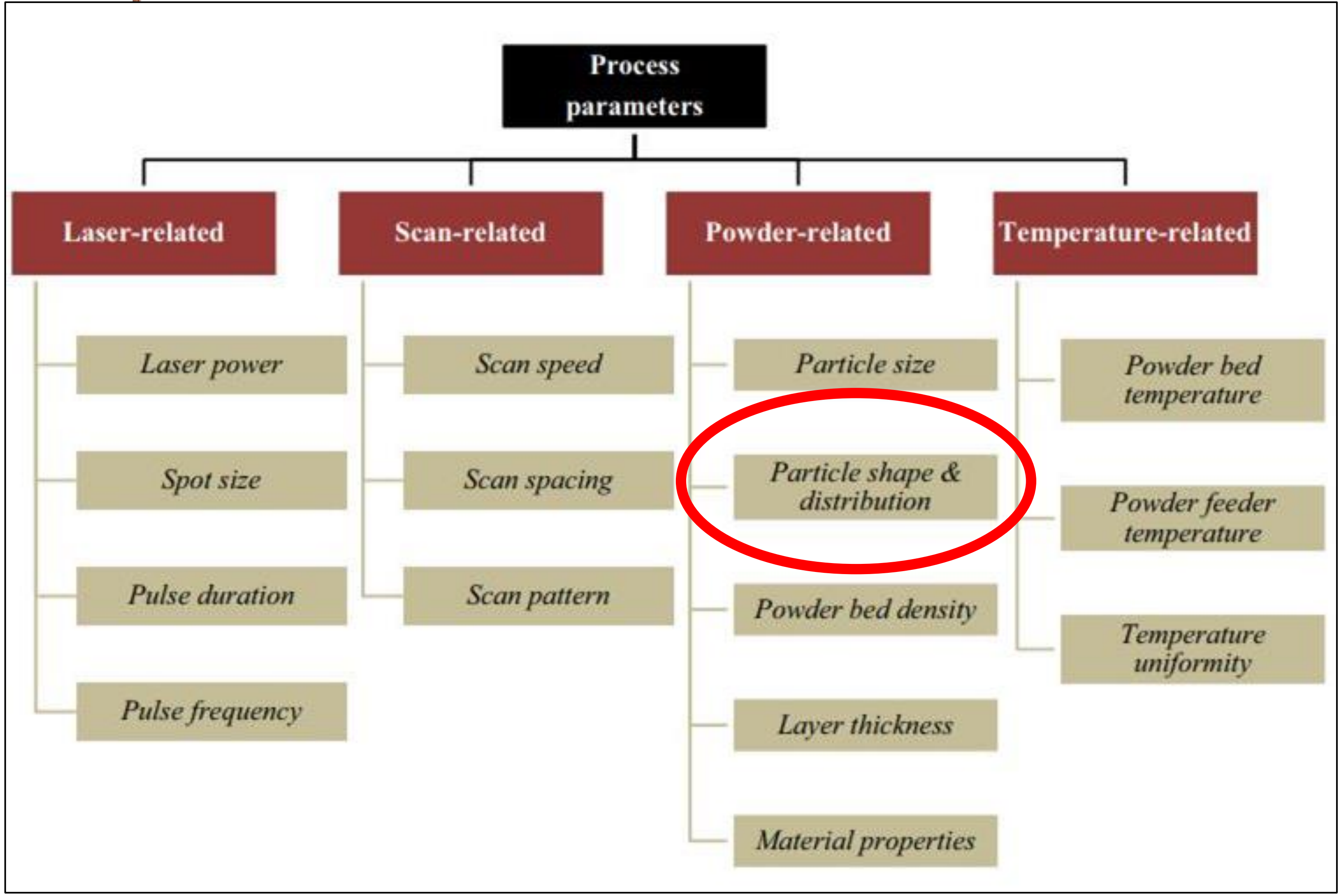


Inconel 600 specimen, EBSD of single track, Nicolas D. Hart, CAPT Brad W. Baker, US Naval Academy

Non-equilibrium solidification can result in microstructures that differ significantly from wrought materials

The same is true for the unique processing strategy employed with AM

Additive Manufacturing (AM)



From: Aboulkhair et. al., Additive Manufacturing 1–4 (2014) 77–86

AM Processing:

With so many degrees of freedom in selecting processing variables, it is important to gain a mechanistic understanding of each variable

Motivation

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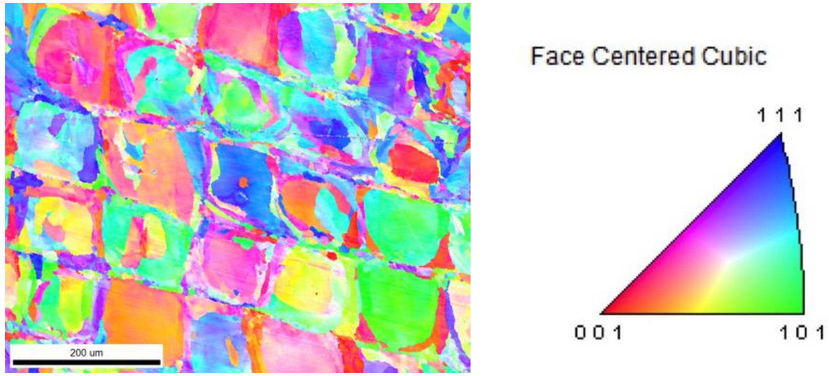
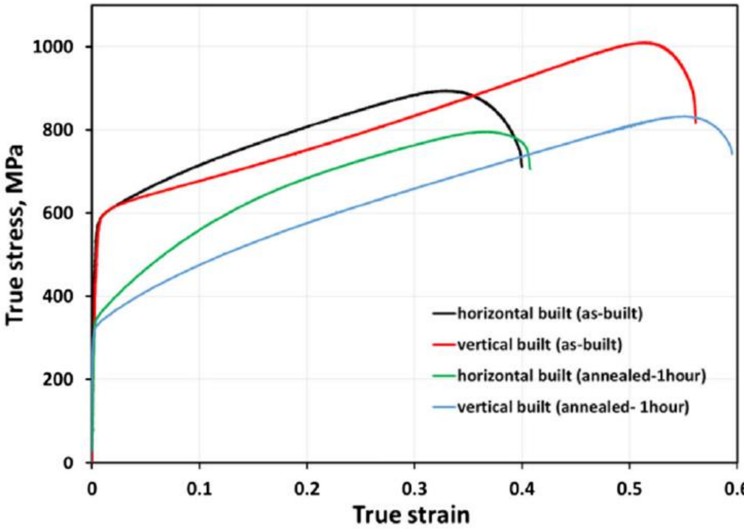
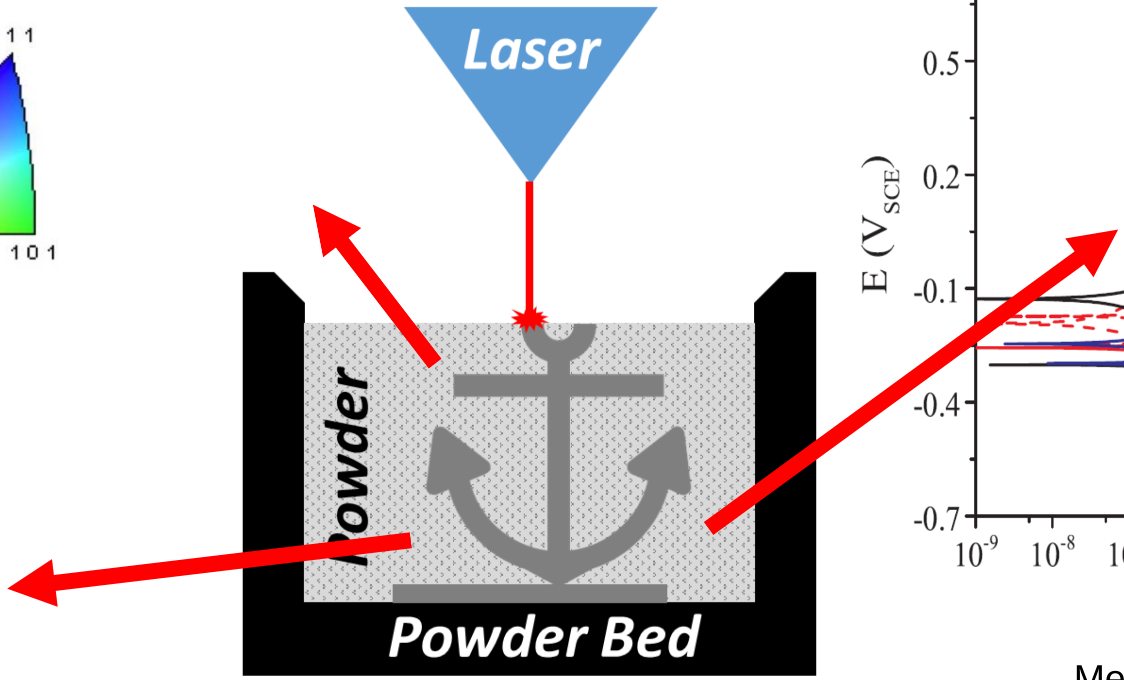
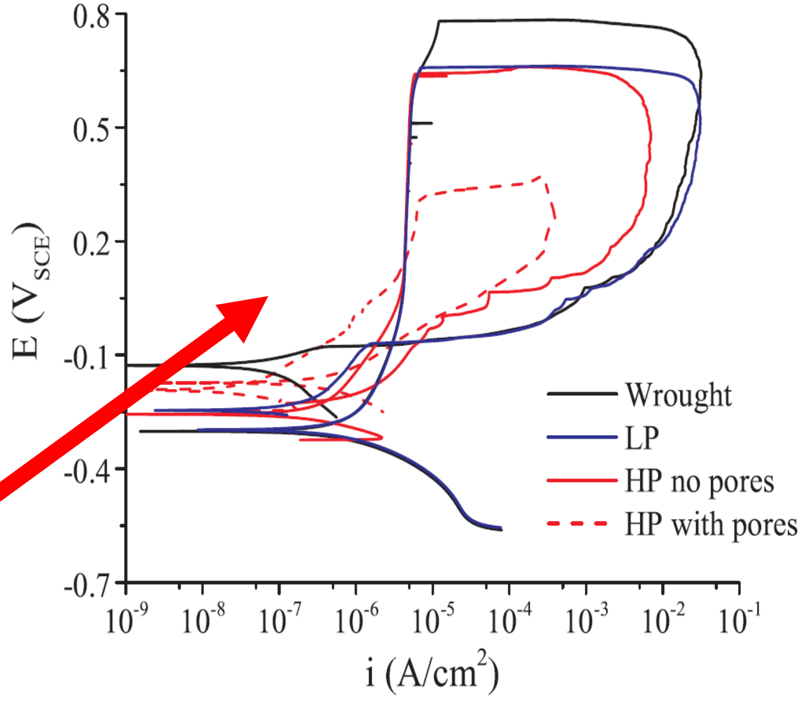
It is critical to determine the effects of AM on the properties of stainless steel parts: Microstructure, Strength, and Corrosion Resistance.





Shamsujjoha, *Met. And Mat. Trans. A*, 2018





Melia, *Corrosion Science*, 2019

Motivation

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NSWC Corona has provided two separate 316L base powders to compare, one normal and one spheroidized, to make the particles more regular

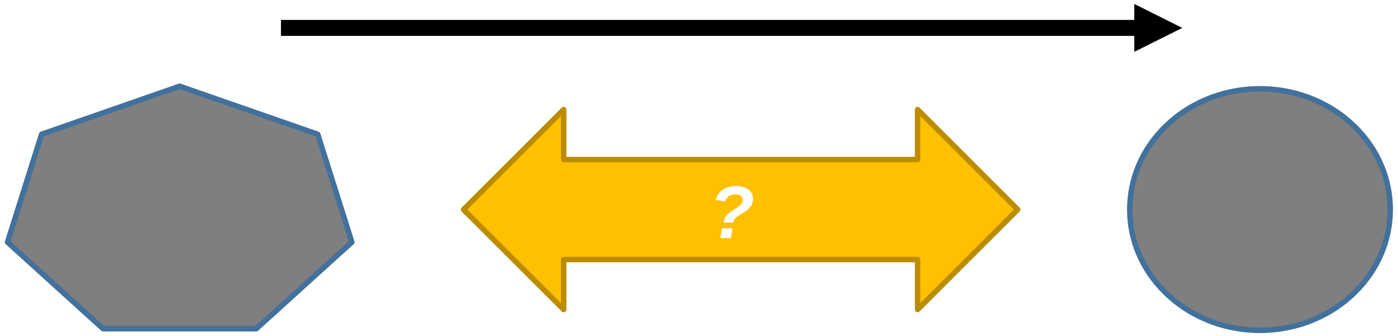
Untreated

“Normal”

Plasma Treated
or
Plasma Spheroidized

“Spheroidized”

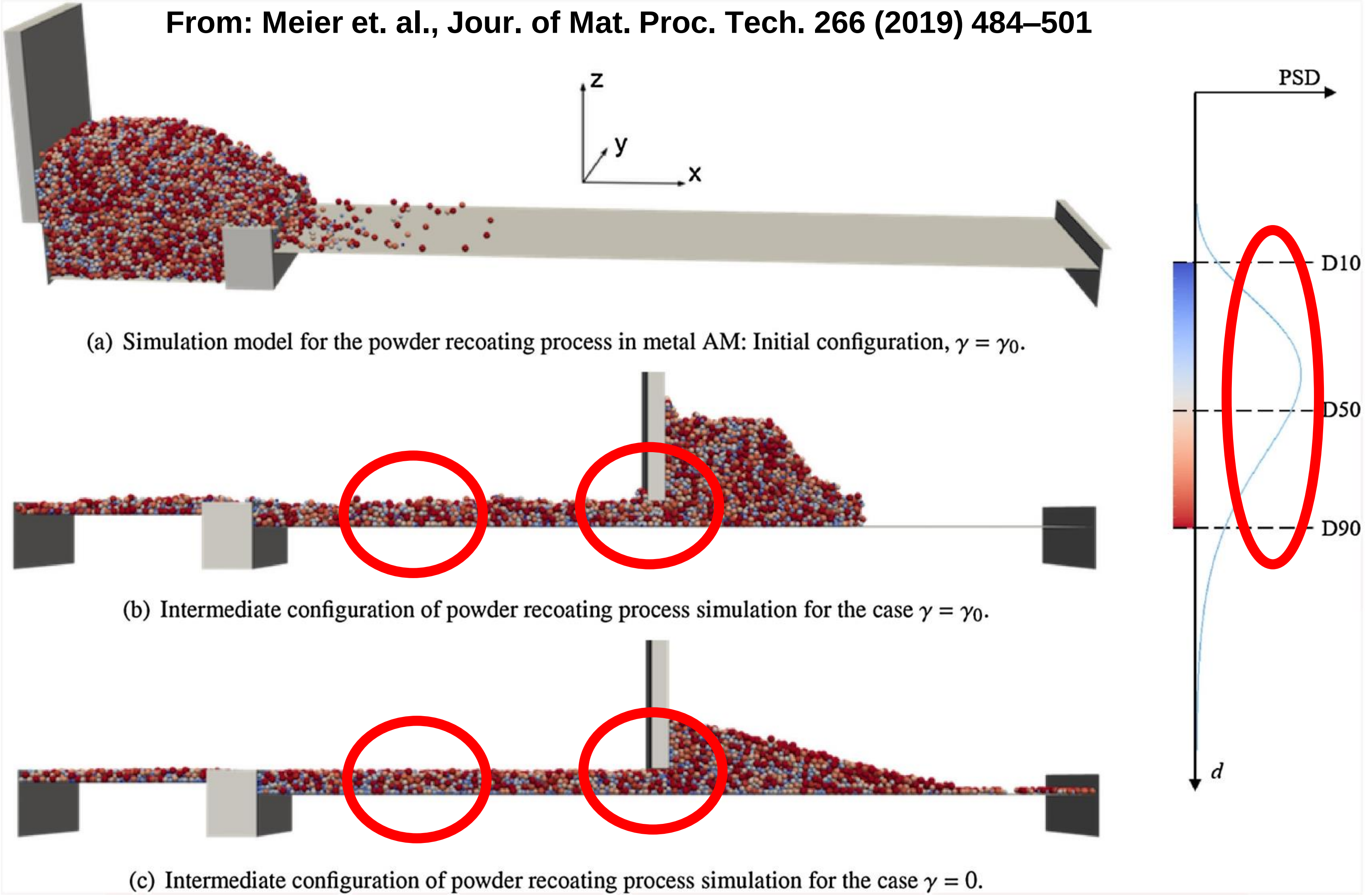
Corona Spheroidization Treatment



Specifically, what is the role of powder morphology?

Additive Manufacturing (AM)

From: Meier et. al., Jour. of Mat. Proc. Tech. 266 (2019) 484–501



(a) Simulation model for the powder recoating process in metal AM: Initial configuration, $\gamma = \gamma_0$.

(b) Intermediate configuration of powder recoating process simulation for the case $\gamma = \gamma_0$.

(c) Intermediate configuration of powder recoating process simulation for the case $\gamma = 0$.

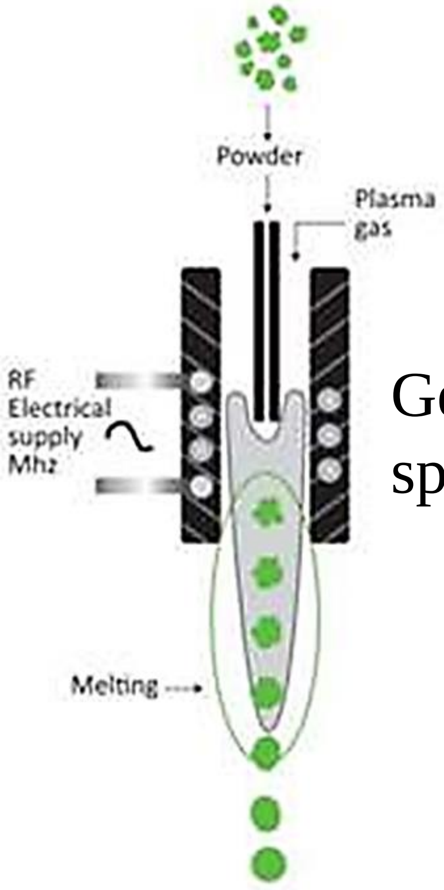
Hypothesis:

If the treatment increases the spheroidicity and tightens the size distribution of the powder, then

- Layer recoating will improve
- Powder packing will improve
- Final Properties will improve

Plasma Spheroidization Process

http://www.tekna.com/spheroidization-systems



General process used to spheroidize the powder

- Normal and Spheroidized 316L powder provided by NSWC Corona
- Powder morphology changes?
- Chemical composition for 316L is retained after treatment?

Powder Morphology Characterization

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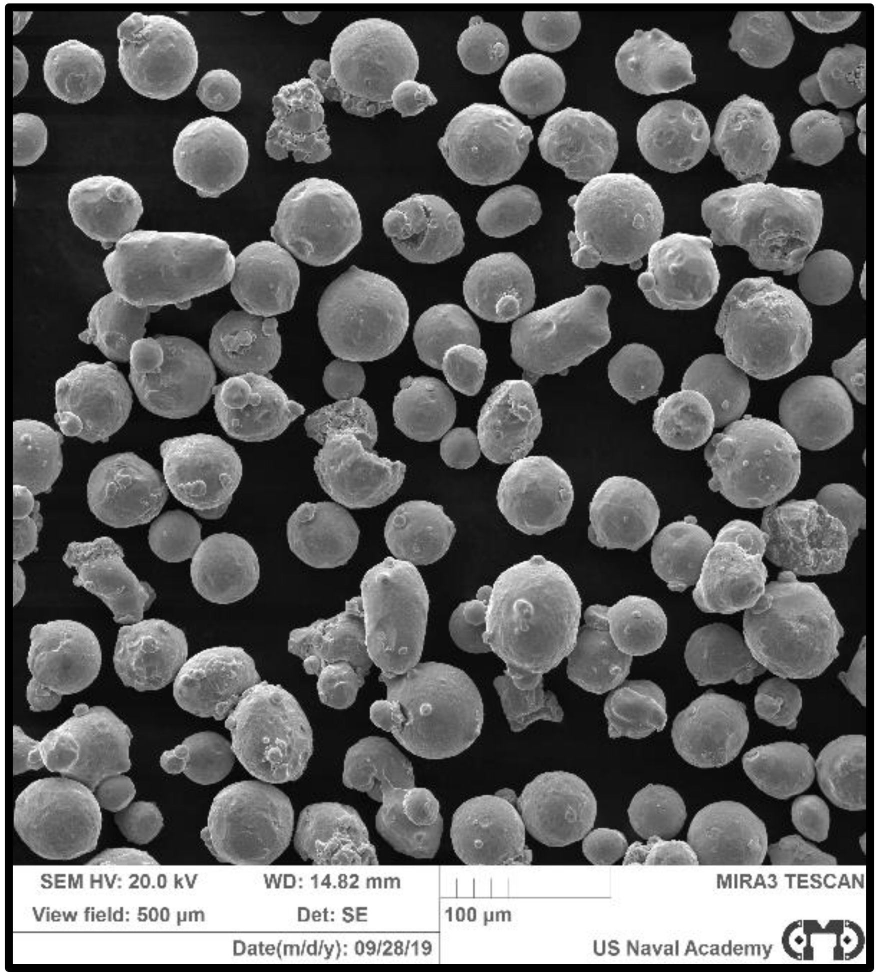
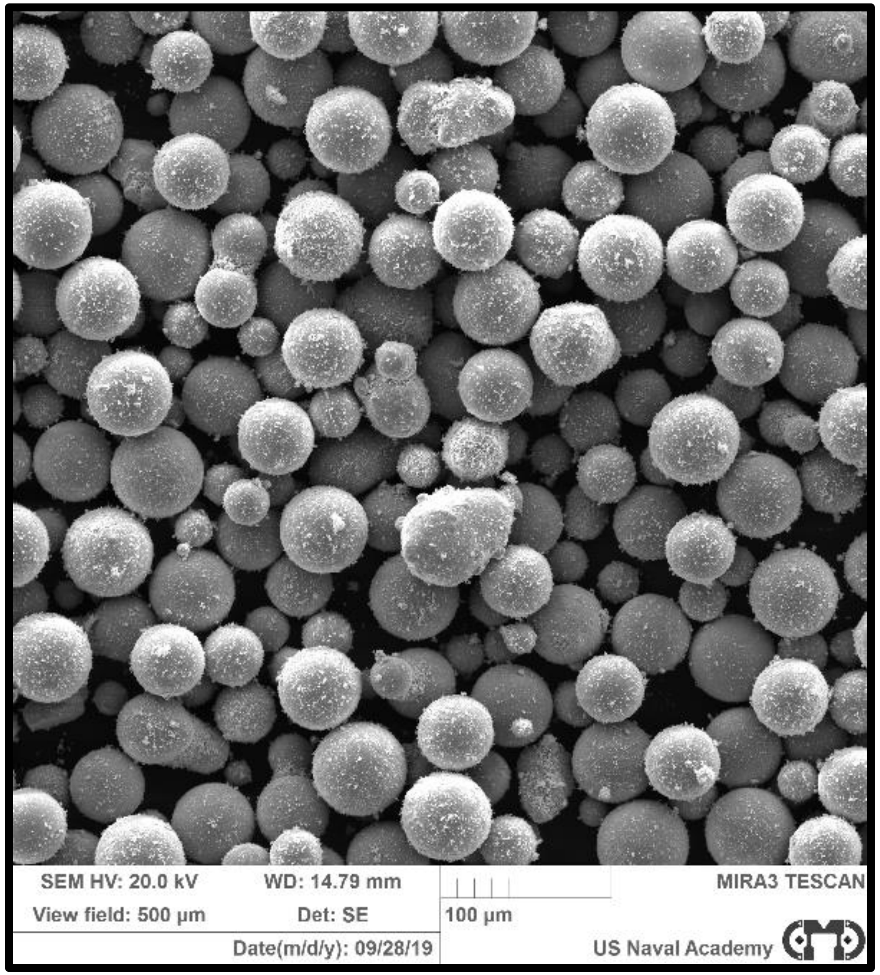


Virgin Normal



Virgin Spher.

100 µm

Powder becomes more spherical after treatment

Size distribution largely invariant

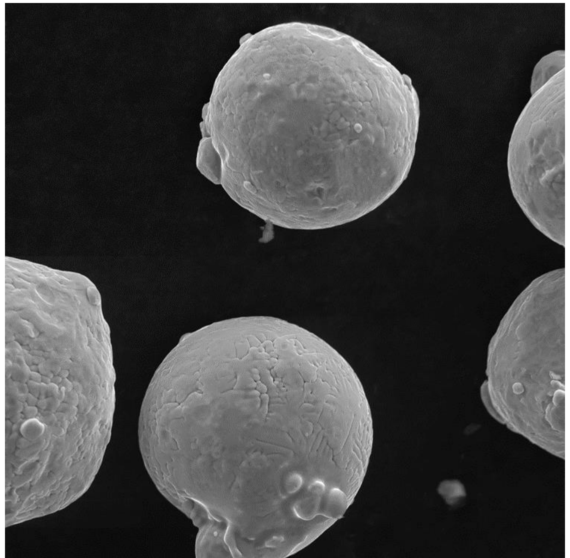
Spheroidized powder exhibits satellite artifacts on surface

Powder Elemental Characterization

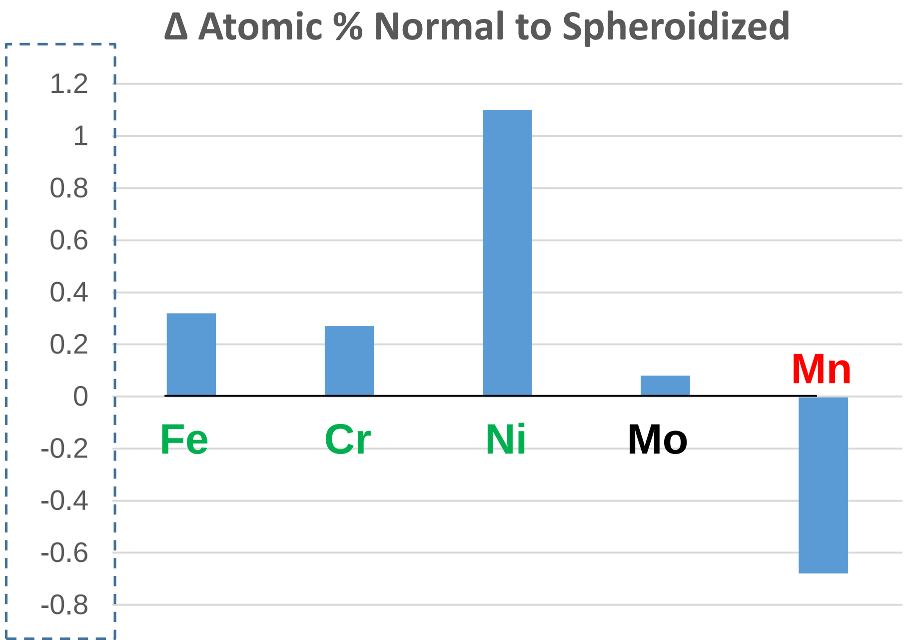
Bulk composition is relatively unchanged – still SS316L

	Weight Percent					
Powder	**Mo**	**Cr**	**Mn**	**Fe**	**Co**	**Ni**
Normal	1.91	18.39	2.46	62.99	1.15	13.10
Spheroidized	2.04	18.63	1.79	63.29	0.00	14.25

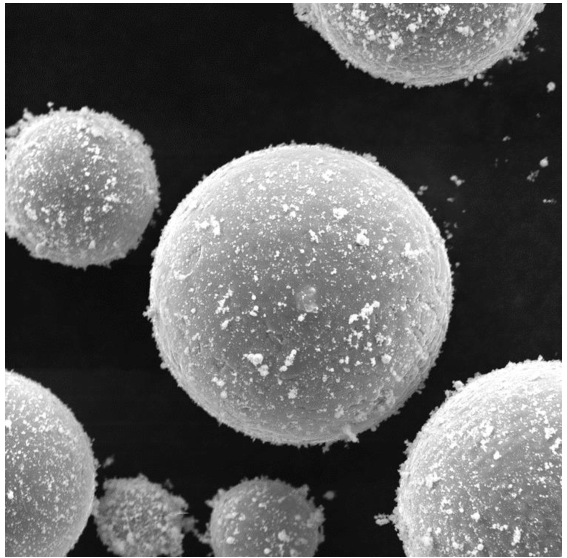
Normal



Virgin Normal



Treated



20 µm

Virgin Spher.

Print Microstructure Characterization

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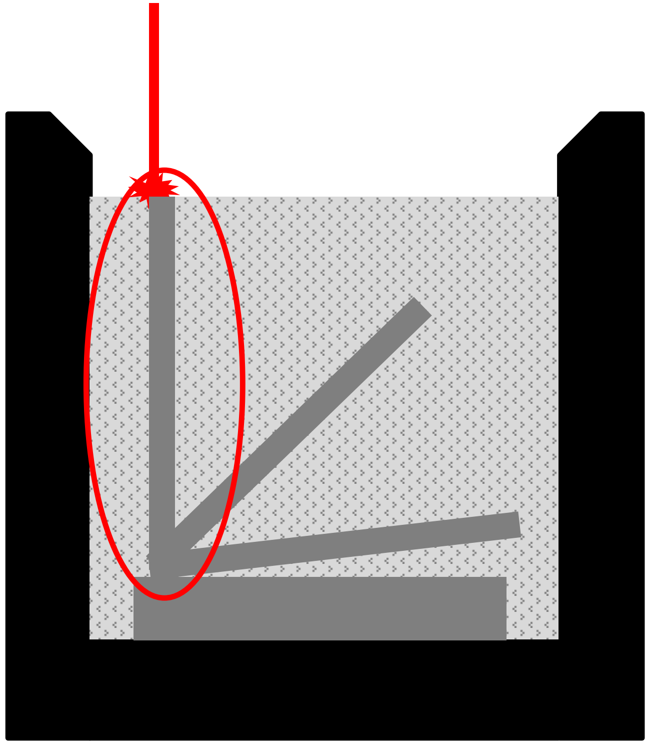
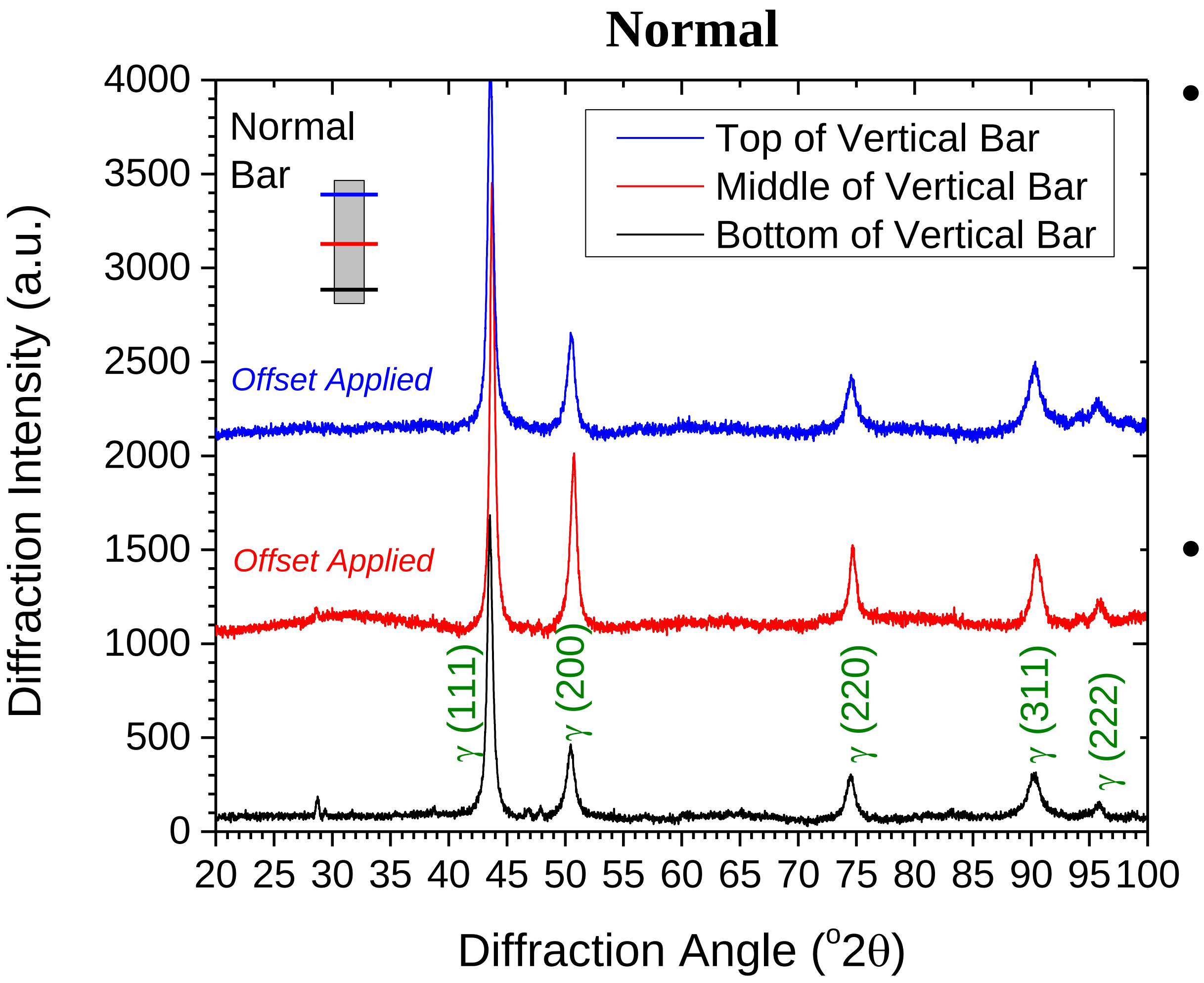
Print Orientations
- **Vertical**
- Tilted
- (Near) Horizontal



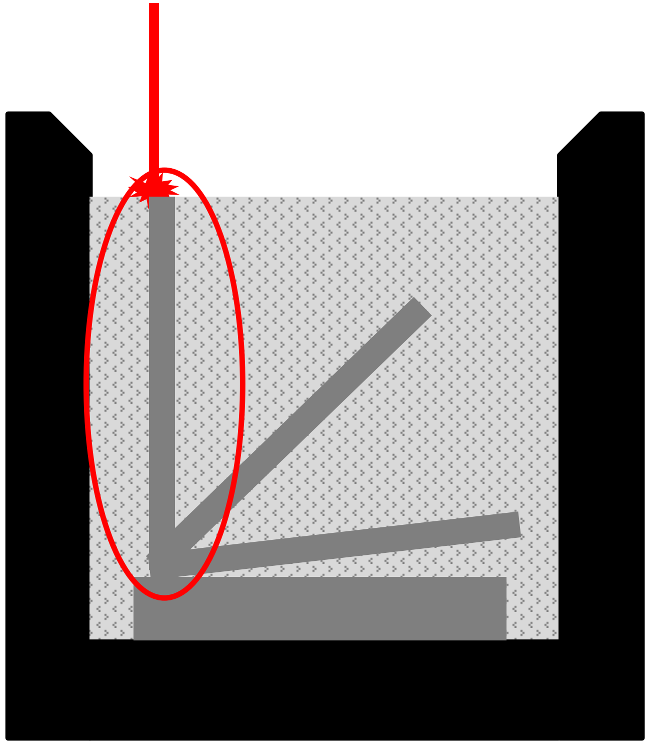


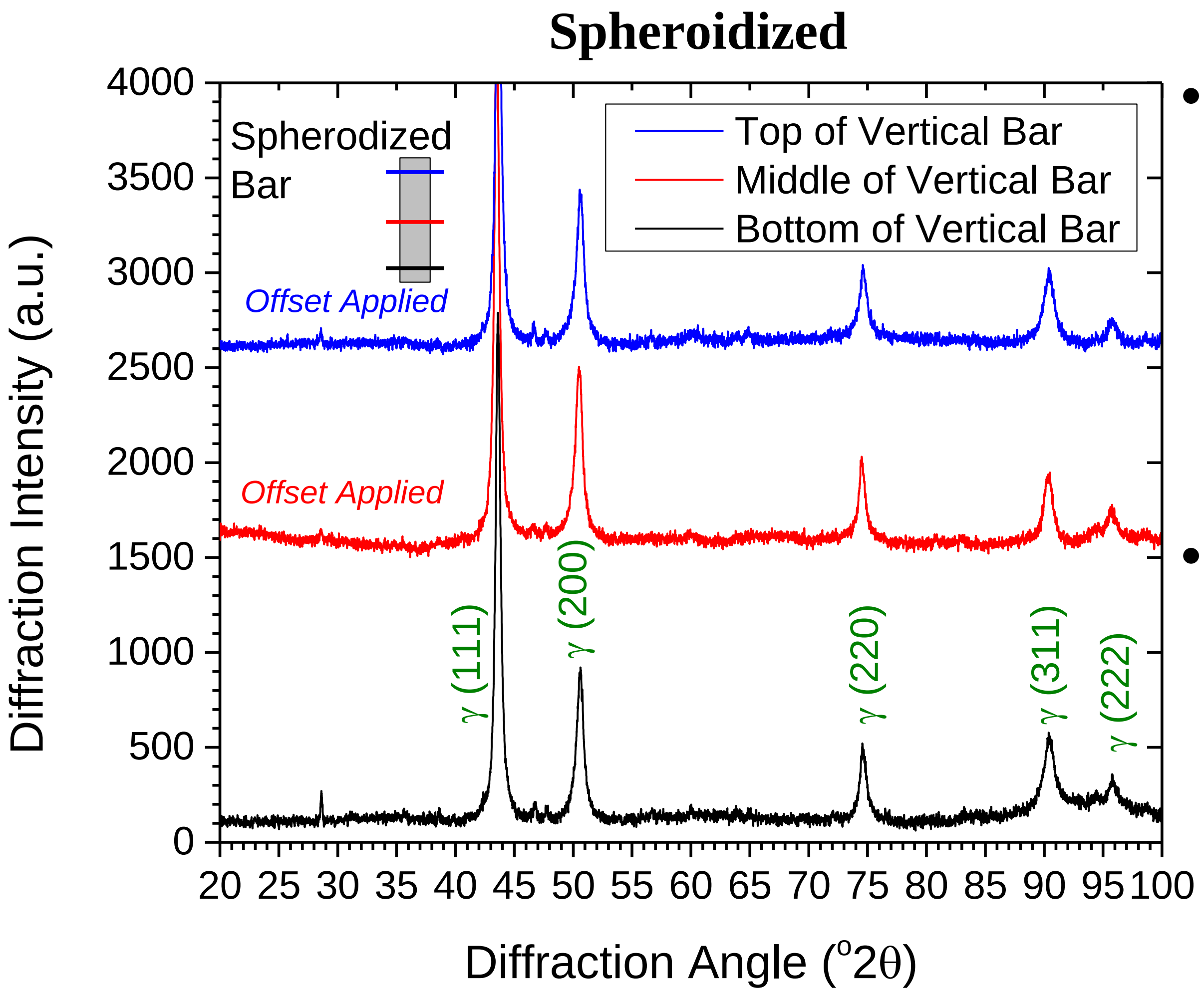
- Phase identification relatively homogenous throughout the bar (for this print direction, XY face)
- Printing does not introduce detectable ferrite

Print Microstructure Characterization

United States Naval Academy
Center for Material Characterization

Print Orientations
- **Vertical**
- Tilted
- (Near) Horizontal





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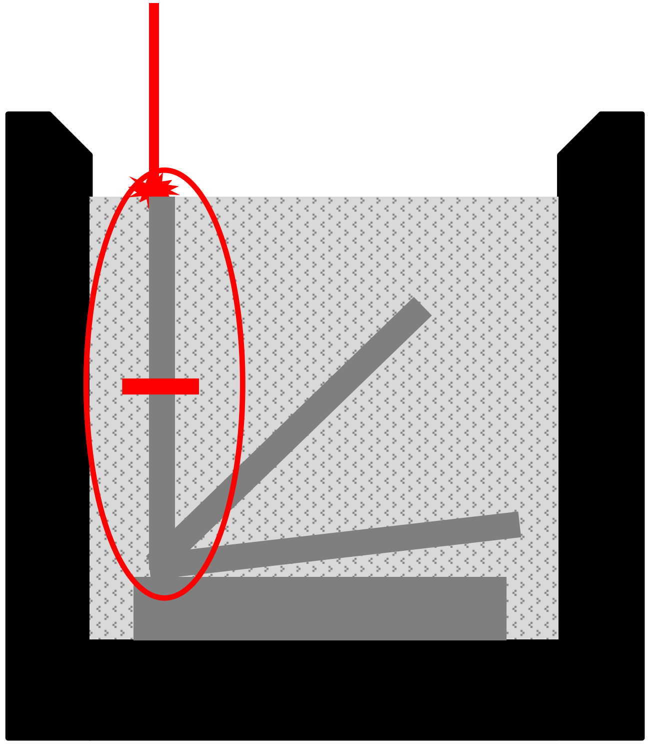
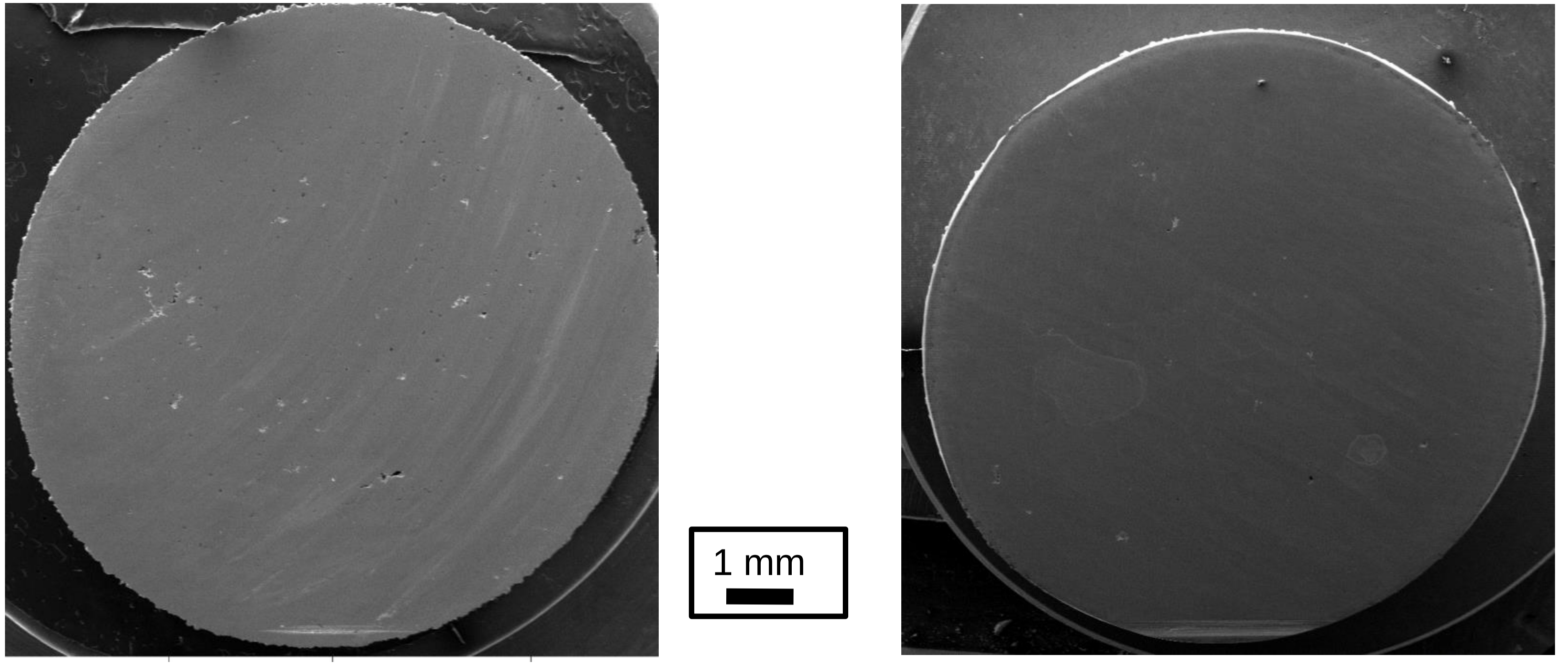


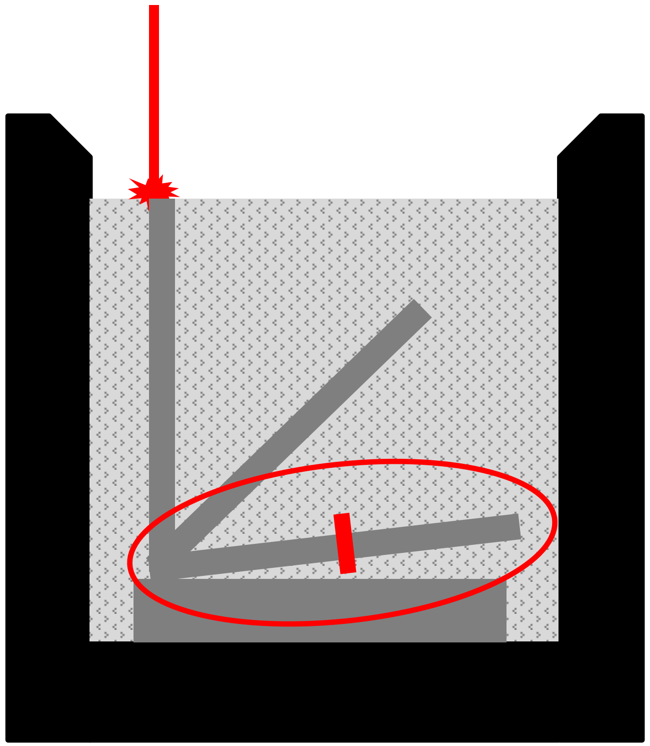
Normal **Spheroidized**



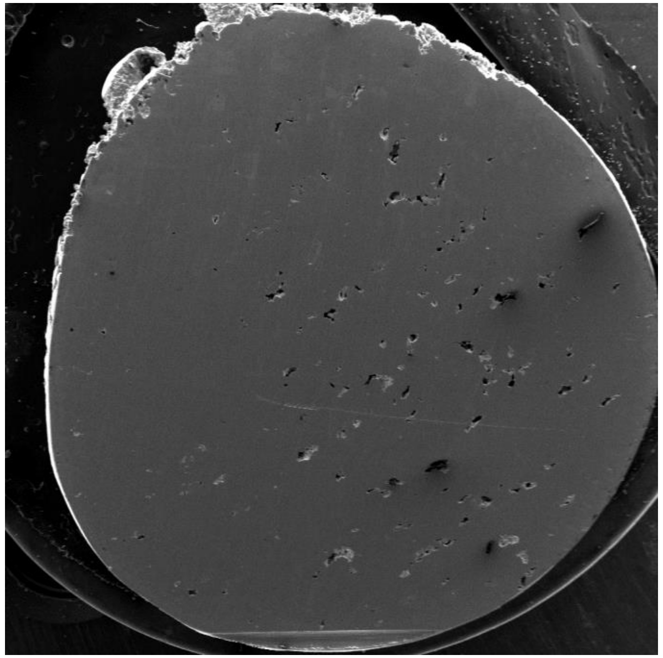
- Few macro pores overall for vertical print orientation
- Normal powder qualitatively has fewer defects or pores

Print Microstructure Characterization

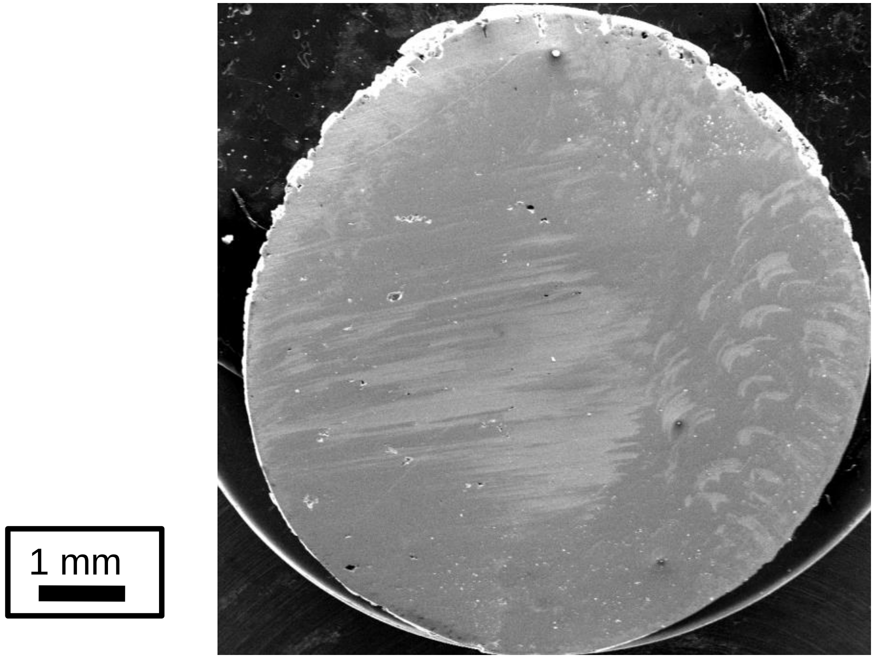
Print Orientations
- Vertical
- Tilted
- **(Near) Horizontal**



Normal



Spheroidized

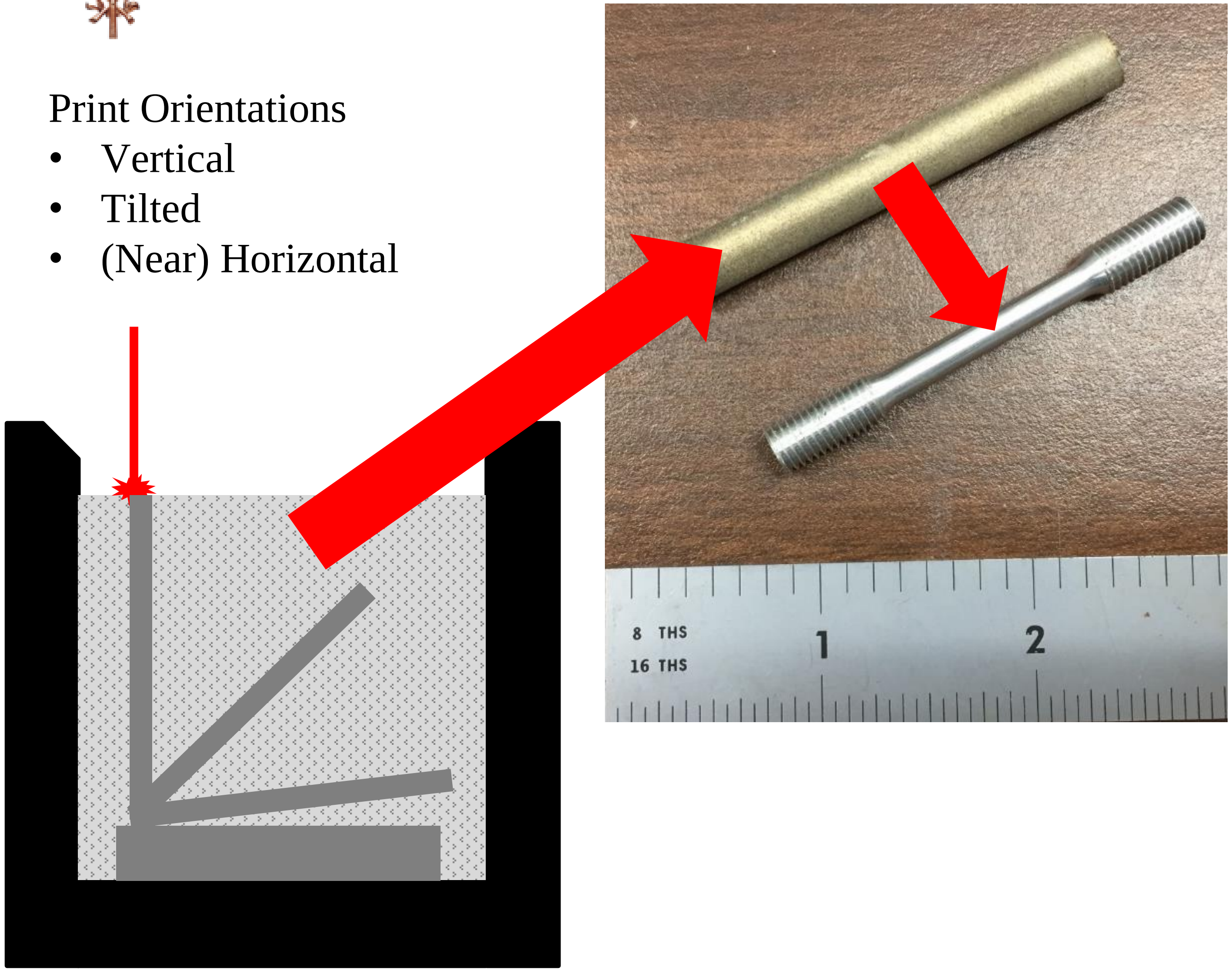


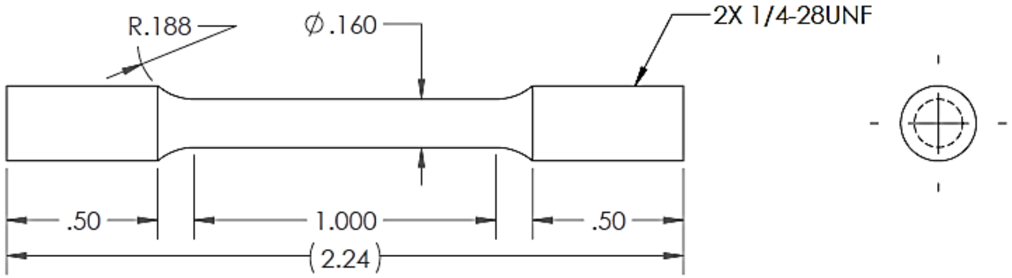
- Many more large pores and defects with normal powder
- Difference much more obvious than for Vertical build

Print Tensile Properties

Print Orientations

- Vertical
- Tilted
- (Near) Horizontal



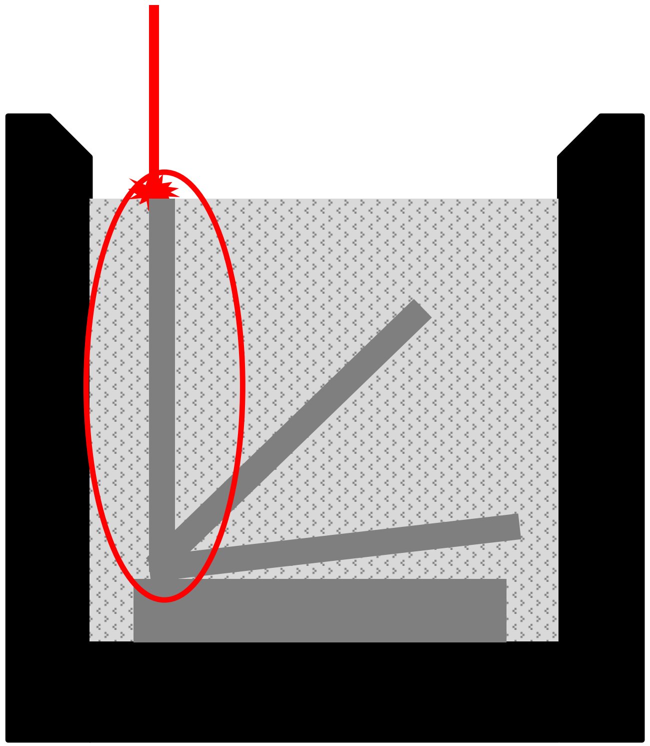


All dimensions in inches

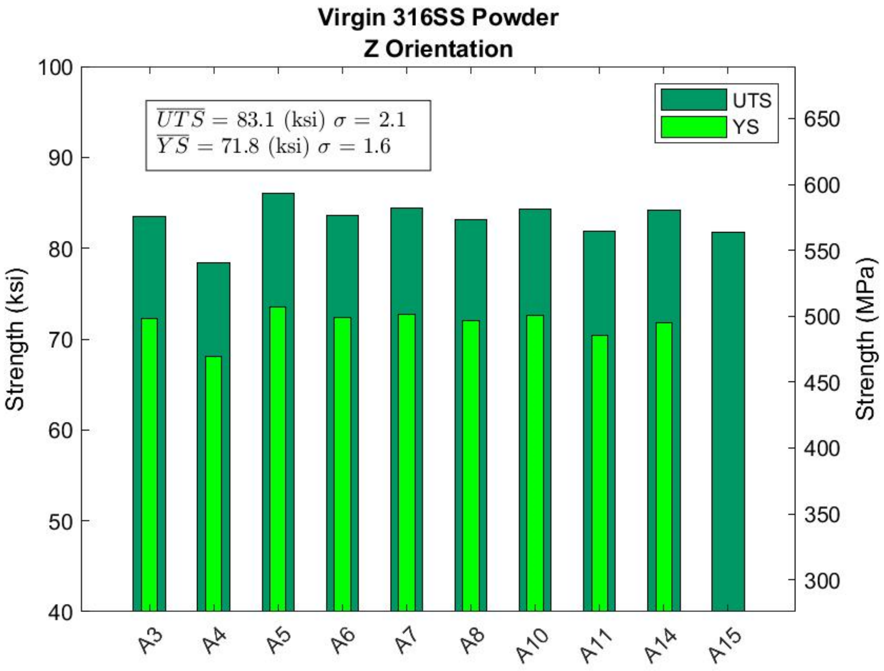
- ASTM E8 – Standard Test Methods for Tension Testing of Metallic Materials
- Elastic Strain Rate of 3 x 10^{-5} /s - displacement control
- Elongation at fracture taken at 10% load drop from maximum load

Print Tensile Properties

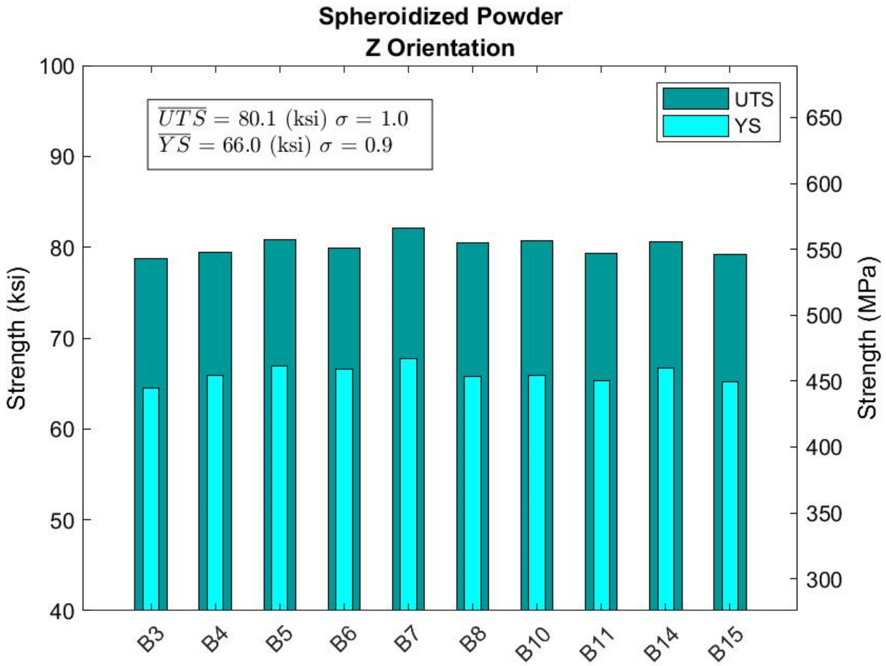
Print Orientations
- **Vertical**
- Tilted
- (Near) Horizontal



Normal



Spheroidized



- The Ultimate Tensile Strength of the printed normal (83 ksi) and spheroidized (80 ksi) powder samples is similar
- The Yield Strength of the printed normal (72 ksi) powder sample is slightly higher than the spheroidized (66 ksi) powder sample
- The results for the spheroidized powder samples are less variable

Print Tensile Properties

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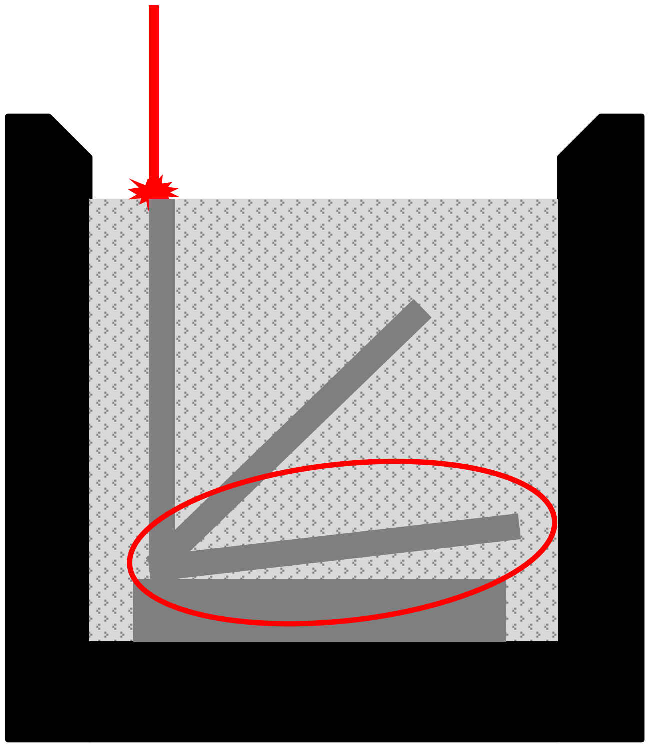
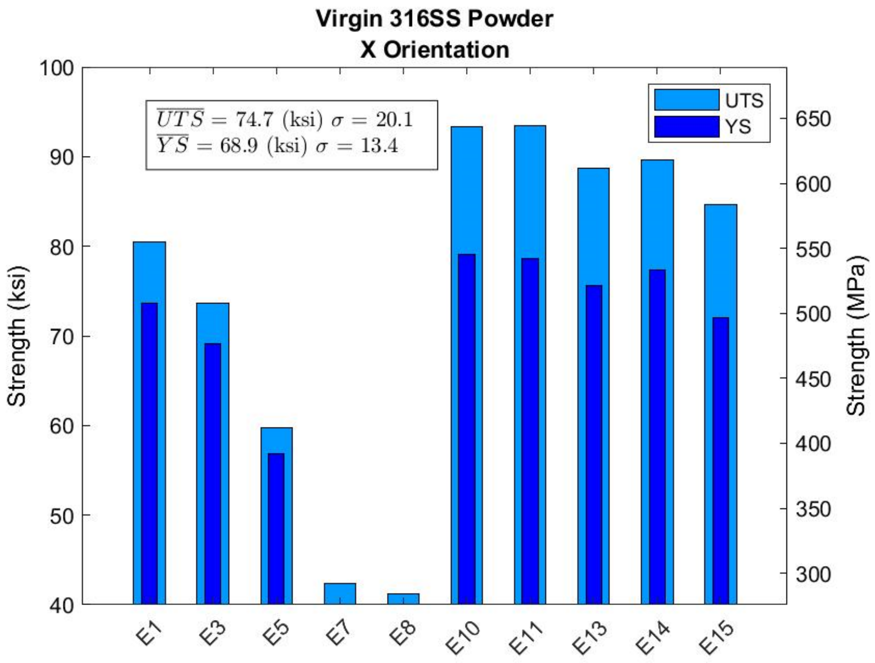
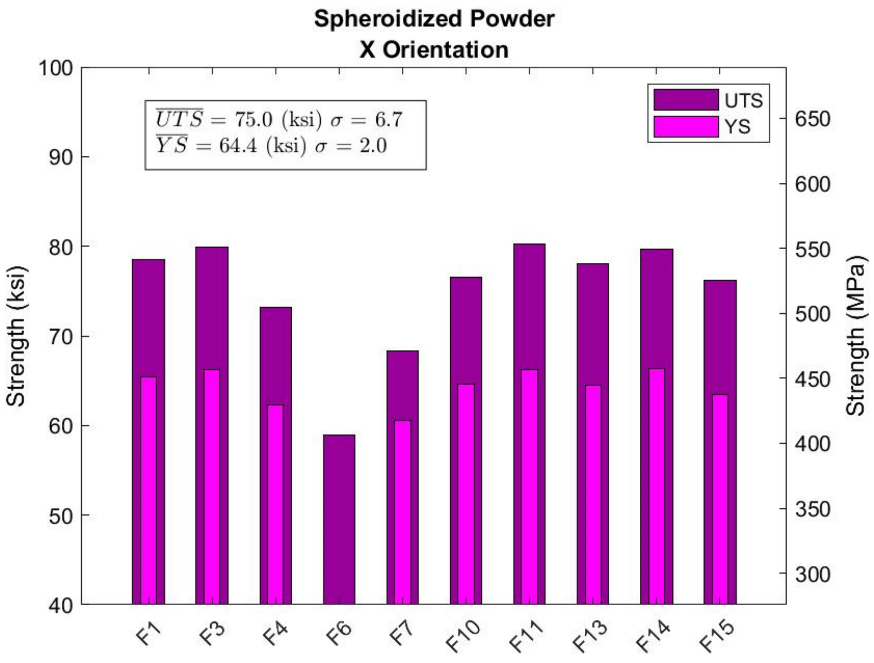
Print Orientations
- Vertical
- Tilted
- **(Near) Horizontal**



Normal

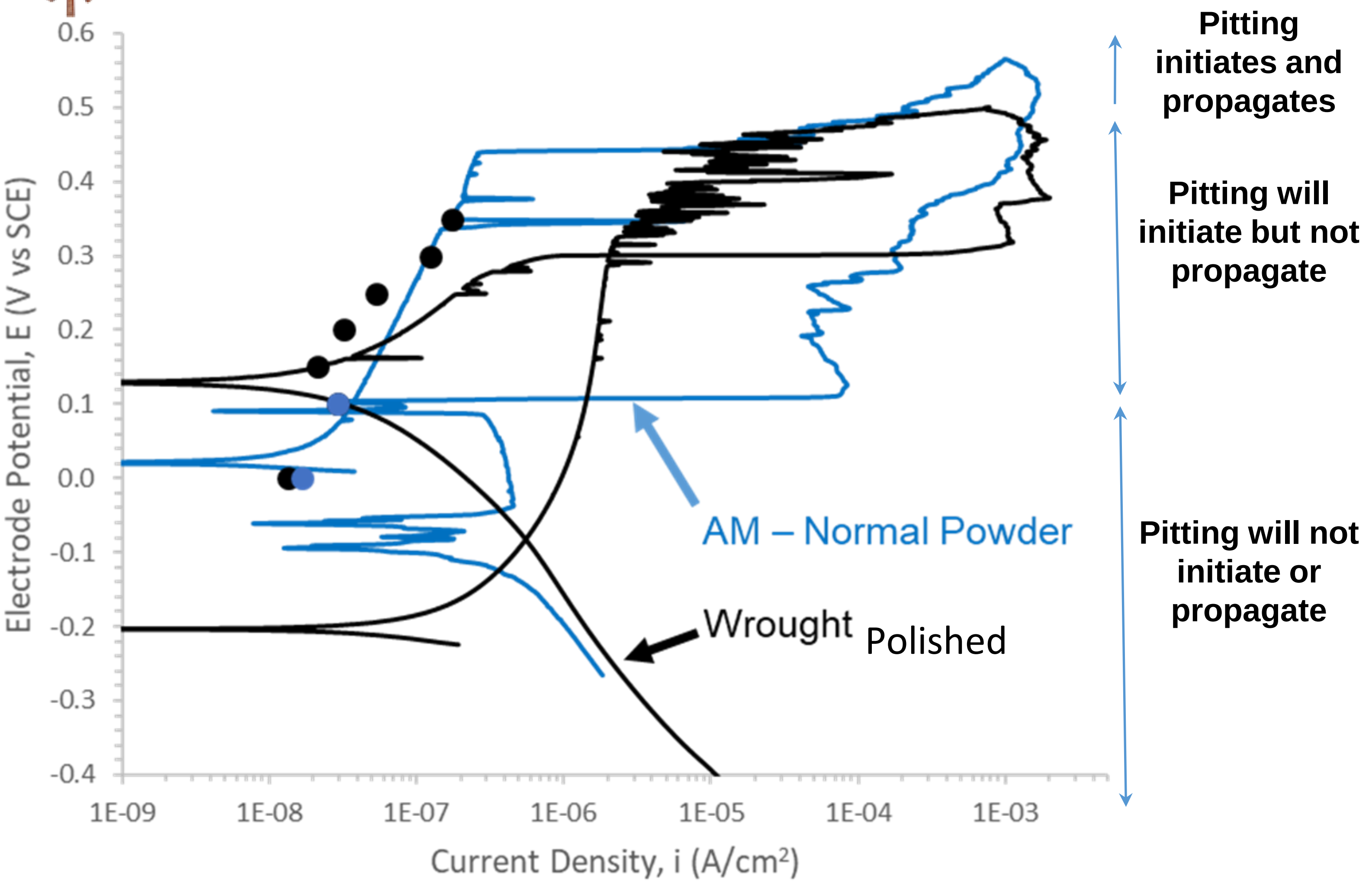


Spheroidized



- The Ultimate Tensile Strength is similar (at 75 ksi) for both the printed normal and spheroidized powder samples
- The Yield Strength of the printed normal (69 ksi) powder sample is slightly higher than the spheroidized (64 ksi) powder sample
- The results for the spheroidized powder samples are less variable

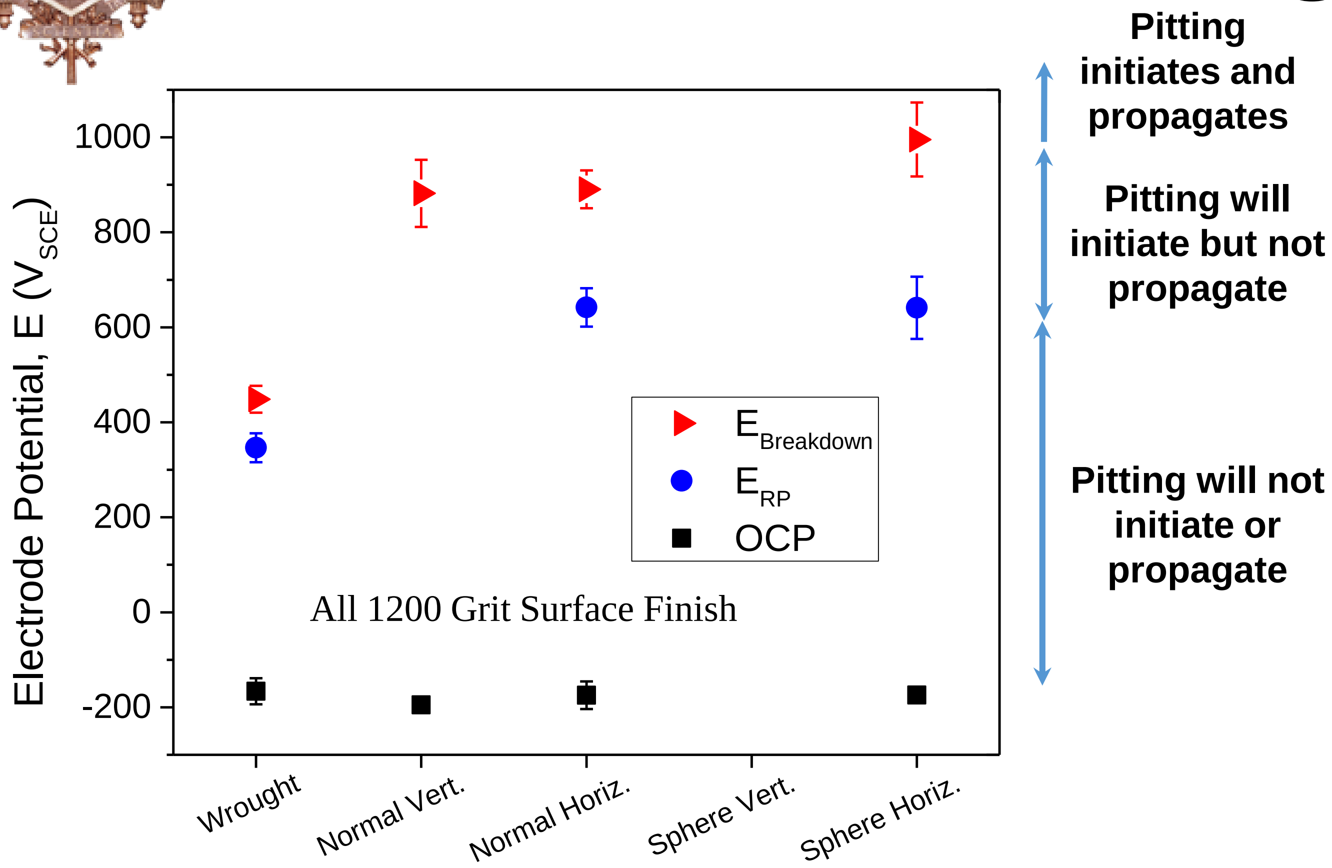
Print Corrosion Testing

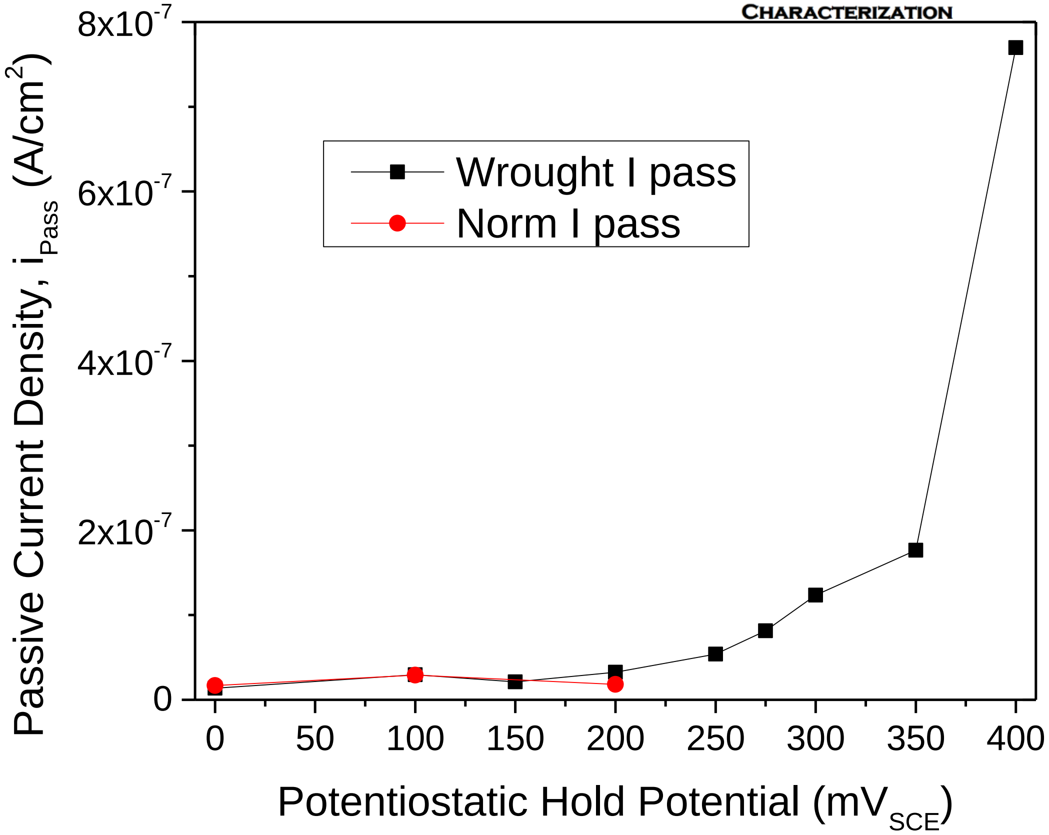


- Testing conducted in 0.6 M NaCl solution
- Wrought and AM (as-printed and polished) are evaluated
- Potentiodynamic and Potentiostatic Testing

- As-printed surface native oxide is passivating

Print Corrosion Testing





- The passive window is extended for AM samples compared to wrought
- All critical potentials are more positive for the AM samples compared to wrought
- The stable film passive dissolution kinetics are similar between wrought and the printed normal powder samples

Thank you

Questions?