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Influence of build orientation and surface finish on the corrosion of additively manufactured 316L stainless steel

Jesse G. Duran and Michael A. Melia

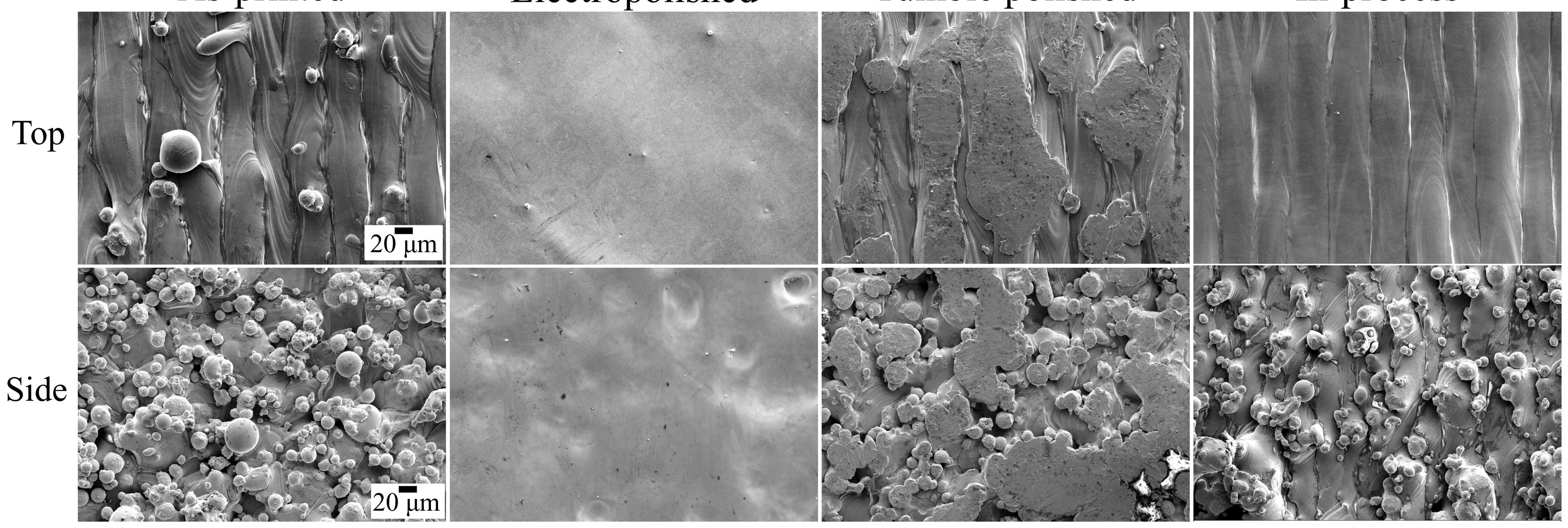
Introduction

Metal additive manufacturing is unique in its ability to produce complex metallic parts. The build process and rapid cooling times create non-equilibrium microstructures and tortuous surface finishes which lead to large variability in the surface's susceptibility to local corrosion. This study investigates how surface treatments and build orientation impact surface roughness and local corrosion initiation of 316L stainless steel parts built with a powder bed fusion technique (PBF).

Objective

- Investigate the impact of surface roughness on the susceptibility of localized corrosion of AM 316L stainless steel parts with different surface treatments.
- Determine which surface treatments improve the resistance to local corrosion initiation, and propose improved metrics that capture surface features important to corrosion behavior.

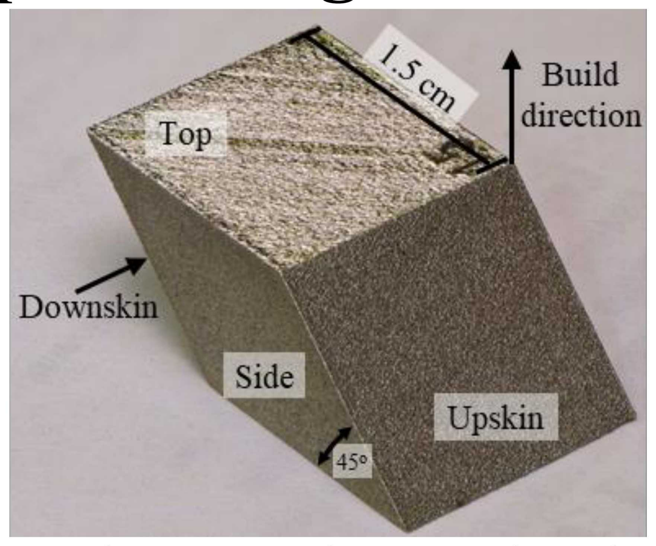
Effect of surface treatments

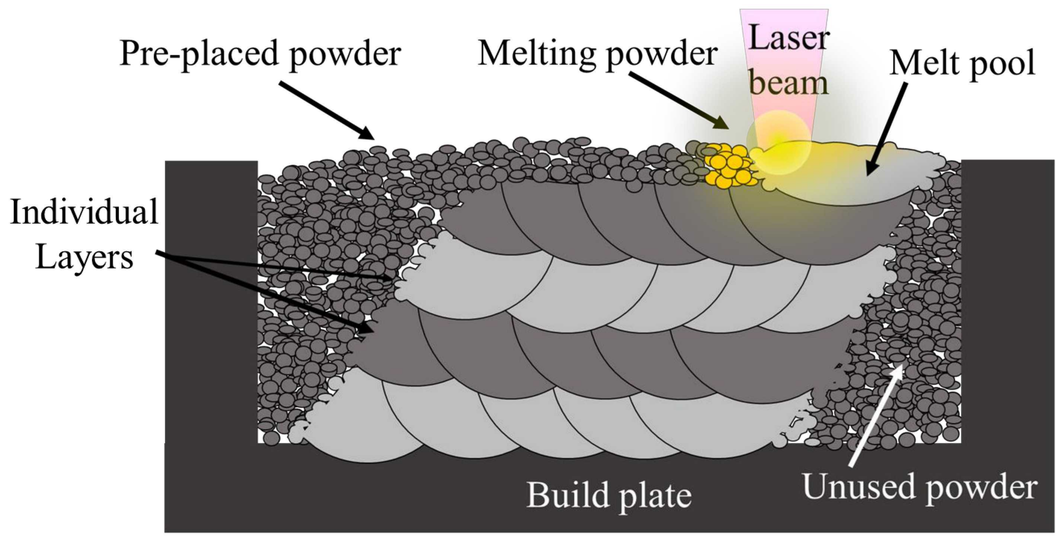


Secondary electron images of top and side orientations of the different surface treatments show the visual difference in surface roughness from a plan-view and how features on as-printed surface are altered with the different treatments.

Fabrication and surface processing

Parallelepiped prism samples were built using a powder bed fusion technique that melts layers of 316L powder (average diameter = 12 µm) with a 110W laser.

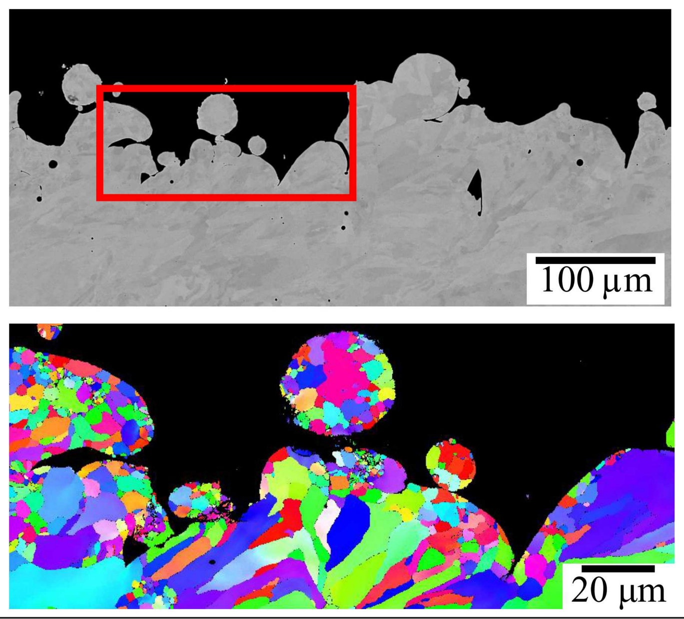


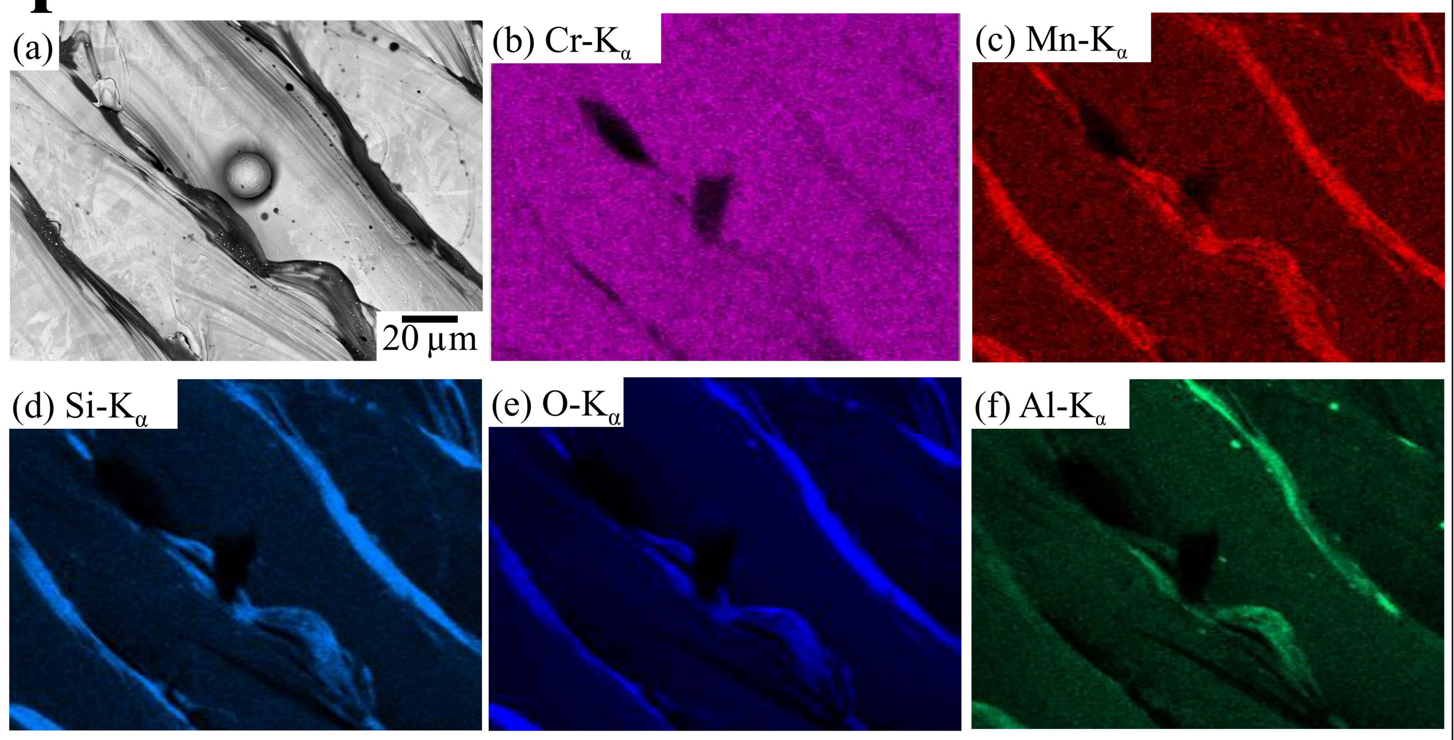


Treatments to improve the as-printed surface include: tumble polishing in abrasive media, electropolishing, an in-process laser polish, chemical passivation, and grinding with polishing paper (1200 grit).

As-printed microstructure

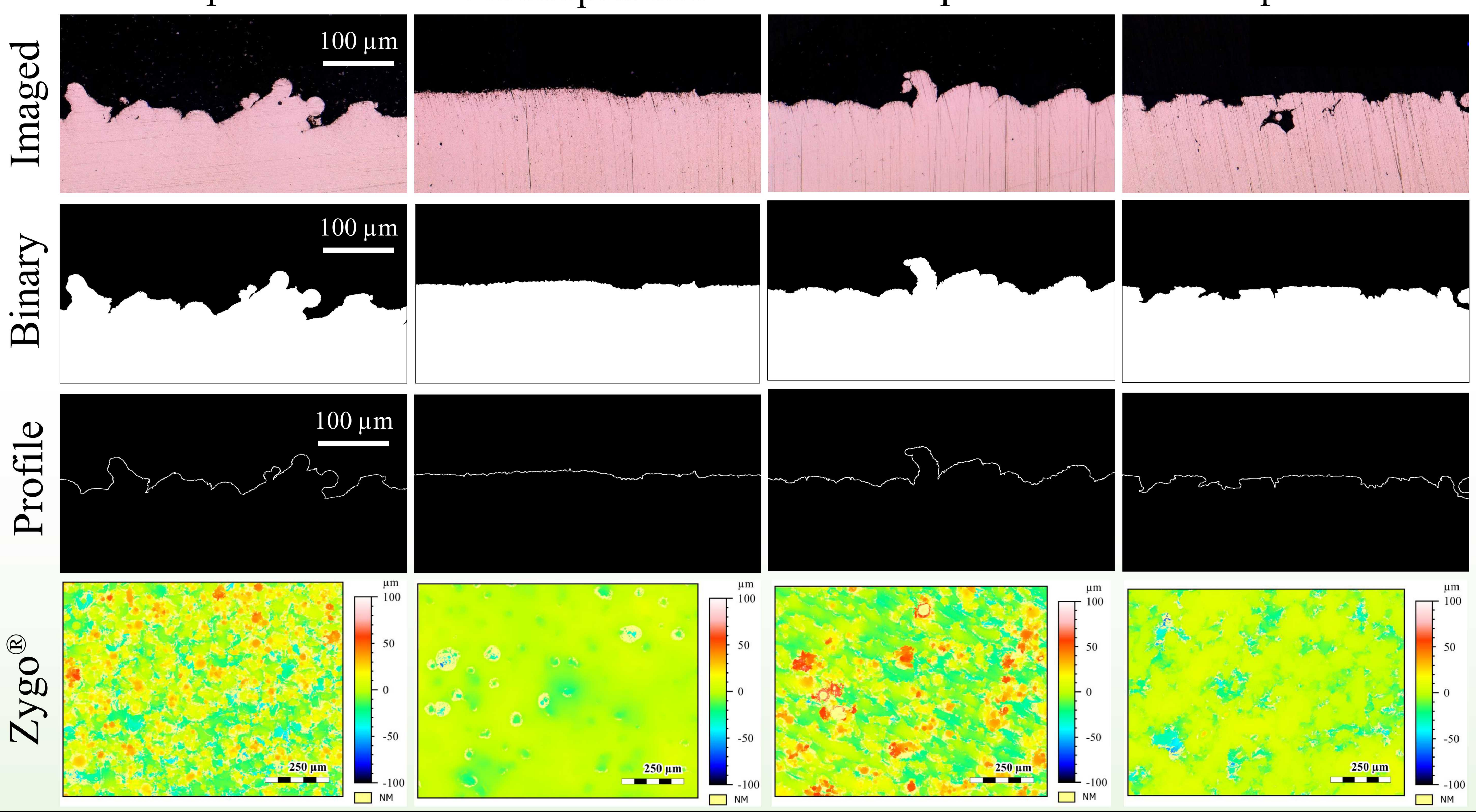
Backscattered electron image and Electron backscatter diffraction maps (**below**) showing the cross section of an as-printed sample.





Backscattered electron image (**a**) and energy-dispersive x-ray spectroscopy maps (**b-f**) of an as-printed top surface visualizing oxides deposited between melt-pools in the powder-bed process.

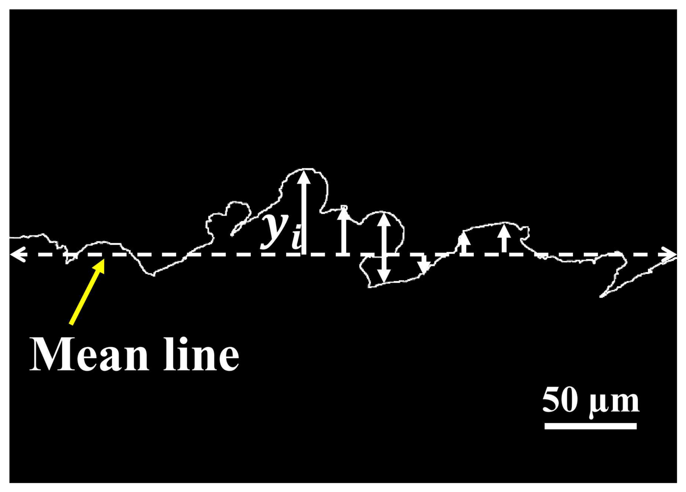
Measuring surface roughness and tortuosity



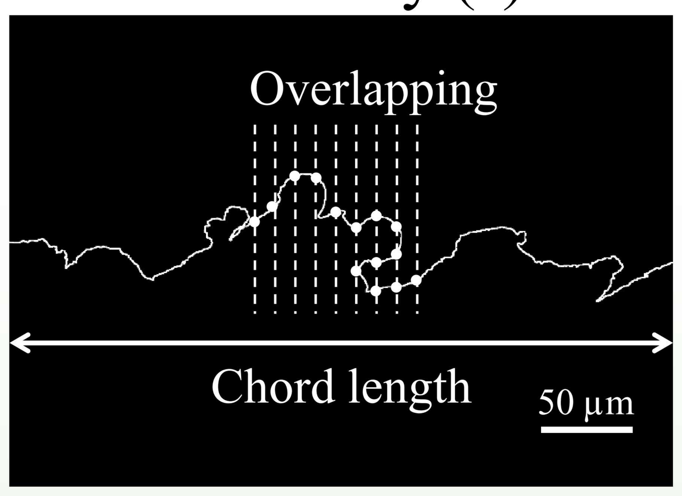
- Surface profiles were imaged, for each surface condition, using a digital microscope, with coaxial lighting and anti-glare.
- Each surface condition was isolated using image processing software (Fiji) in the stages shown in the **top three rows on the left**.
- Tortuosity (τ) and mean linear surface roughness (R_a) were measured from the surface profiles using MATLAB®.
- Average surface roughness (S_a) of a plan-view for each surface treatment and build orientation were analyzed with a Zygo® white light interferometer shown in the **bottom left row**.

Linear surface roughness (R_a)

$$R_a = \frac{1}{n}\sum_{i=1}^{n} |y_i|$$



Tortuosity (τ)



$$\tau = \frac{\frac{\text{Profile length}}{\text{Chord length}} + \textit{overlaps}}{2}$$

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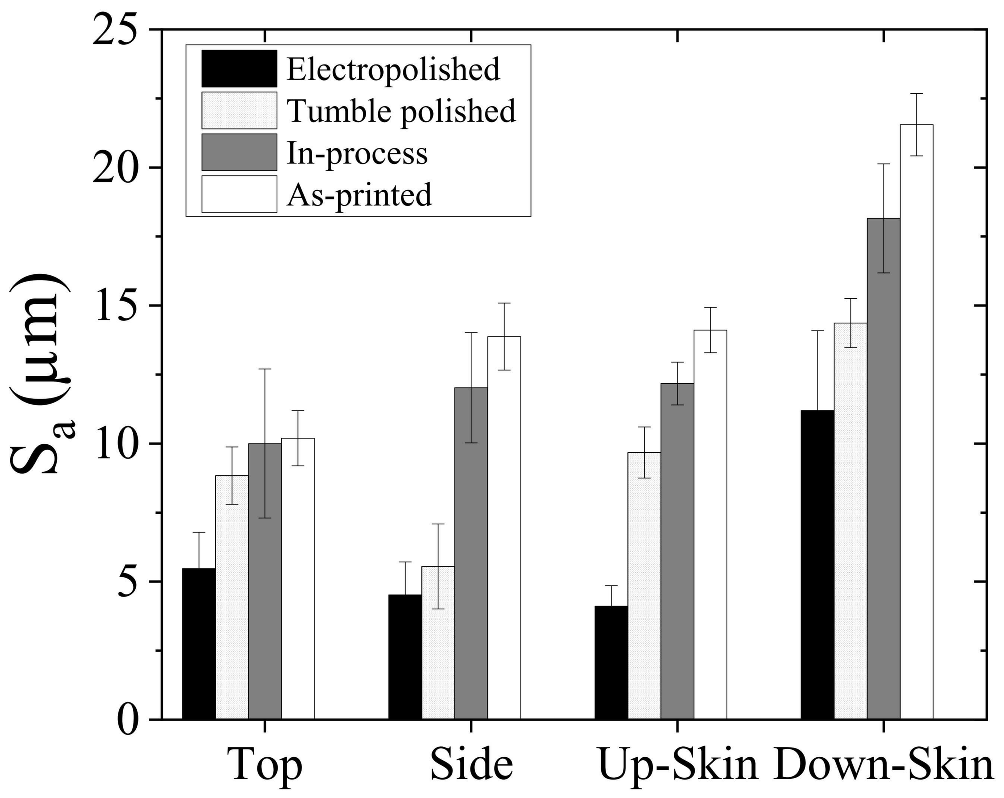
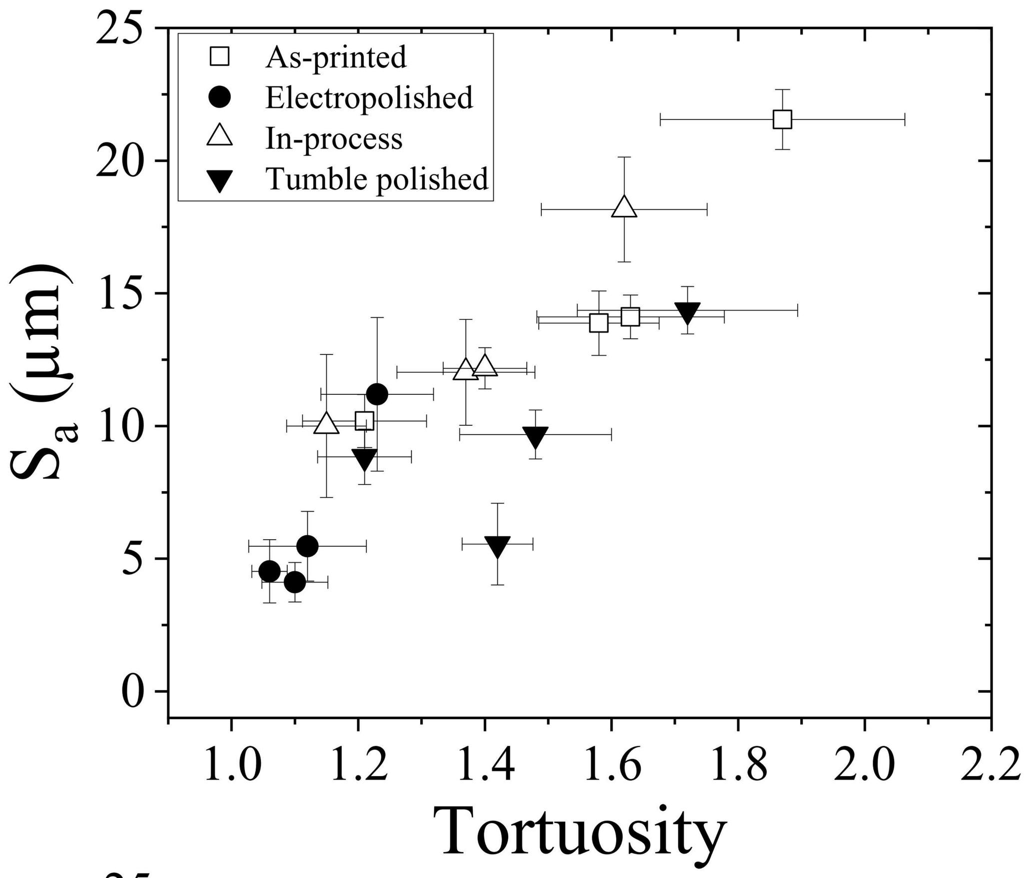
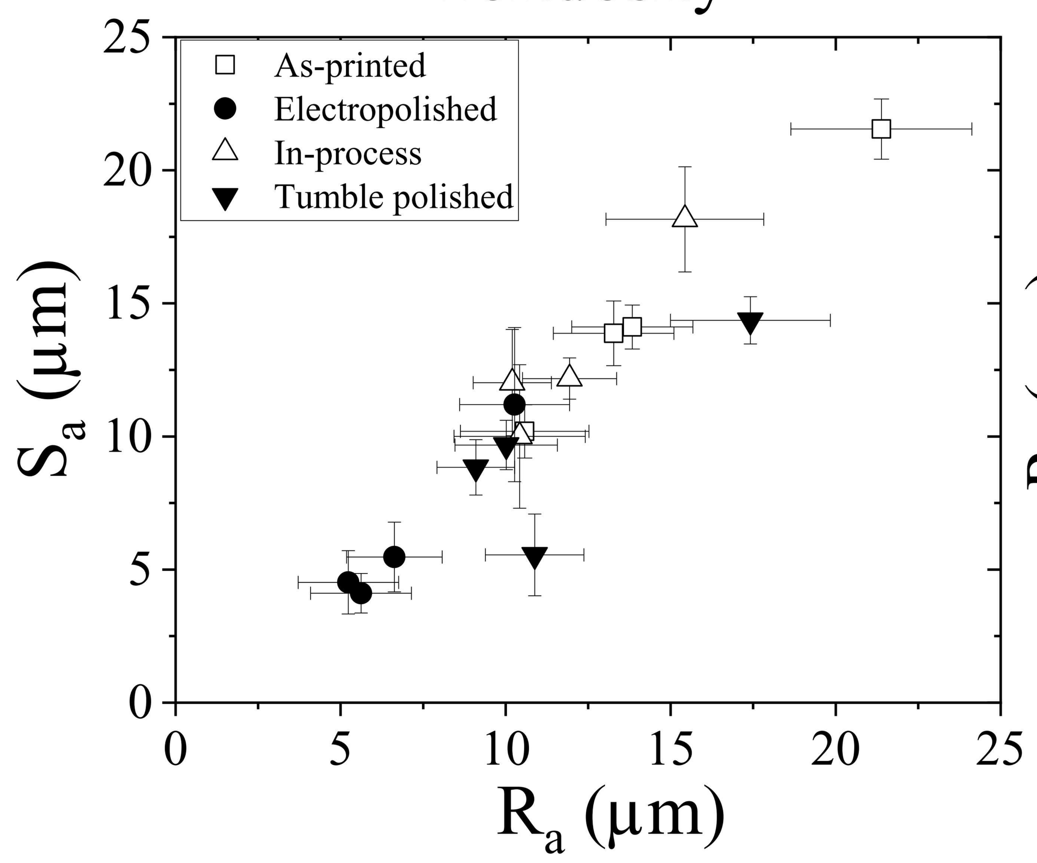
Comparisons of surface roughness

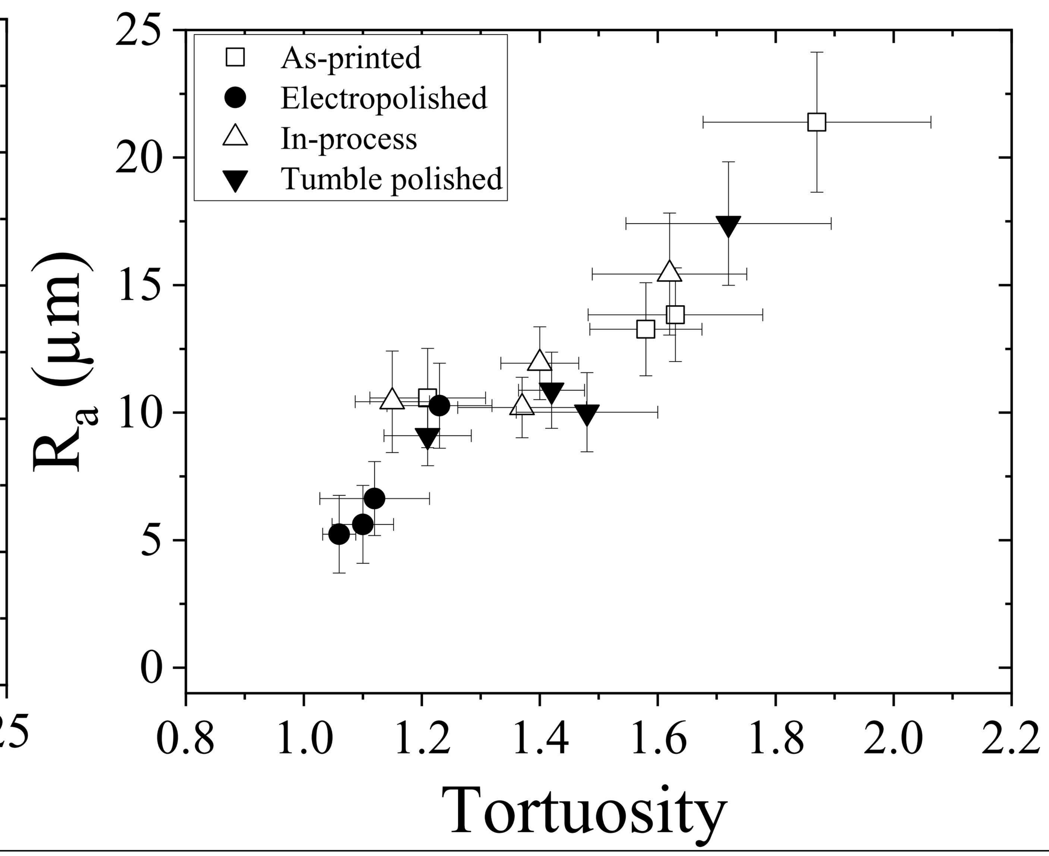
S_a is a widely used metric for surface roughness. The build orientation impacted the surface roughness regardless of surface treatment as shown on the **right**. Downskin statistically resulted in the largest surface roughness, whereas top typically resulted in the smallest, and side and upskin often expressed similar values.





Plots comparing the three surface roughness metrics express the differences between the destructive measurements of R_a and Tortuosity and the non destructive line of sight measurement S_a. R_a and S_a resulted in similar values. Tortuosity gave a similar linear proportionality, where a value of one corresponds to a completely smooth surface.

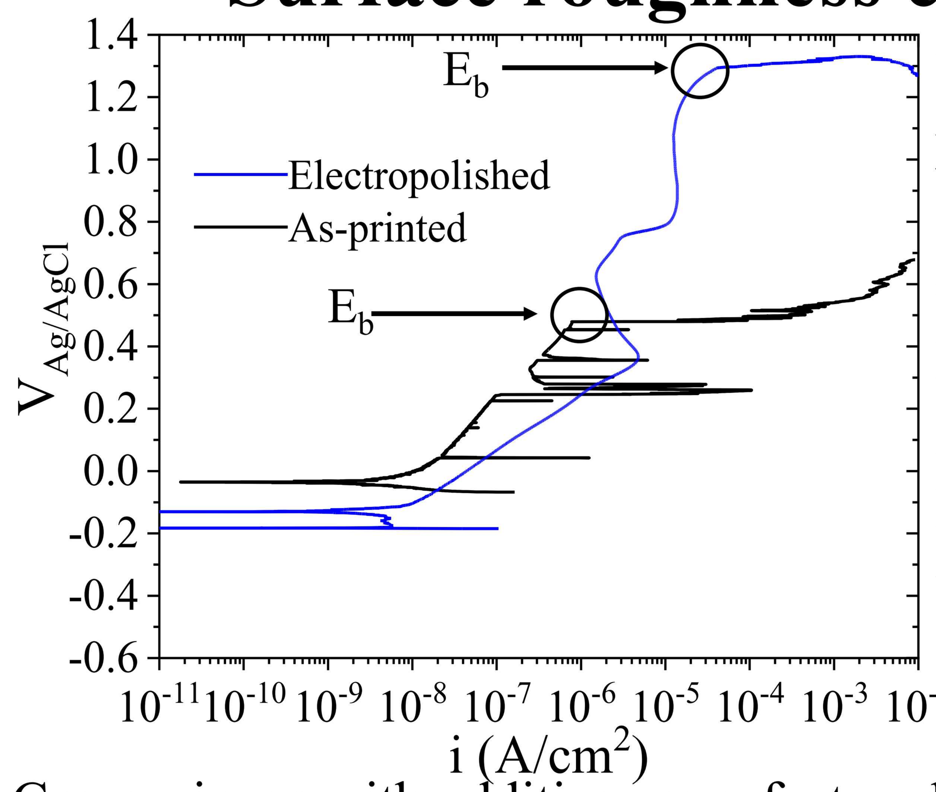




Conclusions

- Cross-section images used for the destructive roughness measurements, R_a and tortuosity, reveal tortuous features, lost by line of sight techniques such as in optical profilometry.
- Regardless, a good correlation between R_a/tortuosity and S_a determined by white light interferometry was found.
- The rougher and more tortuous surface finishes (as-printed, in-process, and tumble polished) exhibited orientation dependent E_b values from 0.15-0.90 $V_{Ag/AgCl}$. The downskin orientation consistently exhibited the lowest E_b, regardless of surface treatment.
- Smaller S_a, R_a, and tortuosity values led to larger E_b, shown for the electropolished and ground surface treatments ranging on average from 0.95-1.22 $V_{Ag/AgCl}$.
- Removing the oxides formed during the PBF build process prior to determining E_b emphasized the surface roughness as the dominant factor in pit initiation.
- Additive manufactured 316L with PBF exhibits a lower E_b, correlating to less susceptibility to localized corrosion than wrought 316L stainless steel.

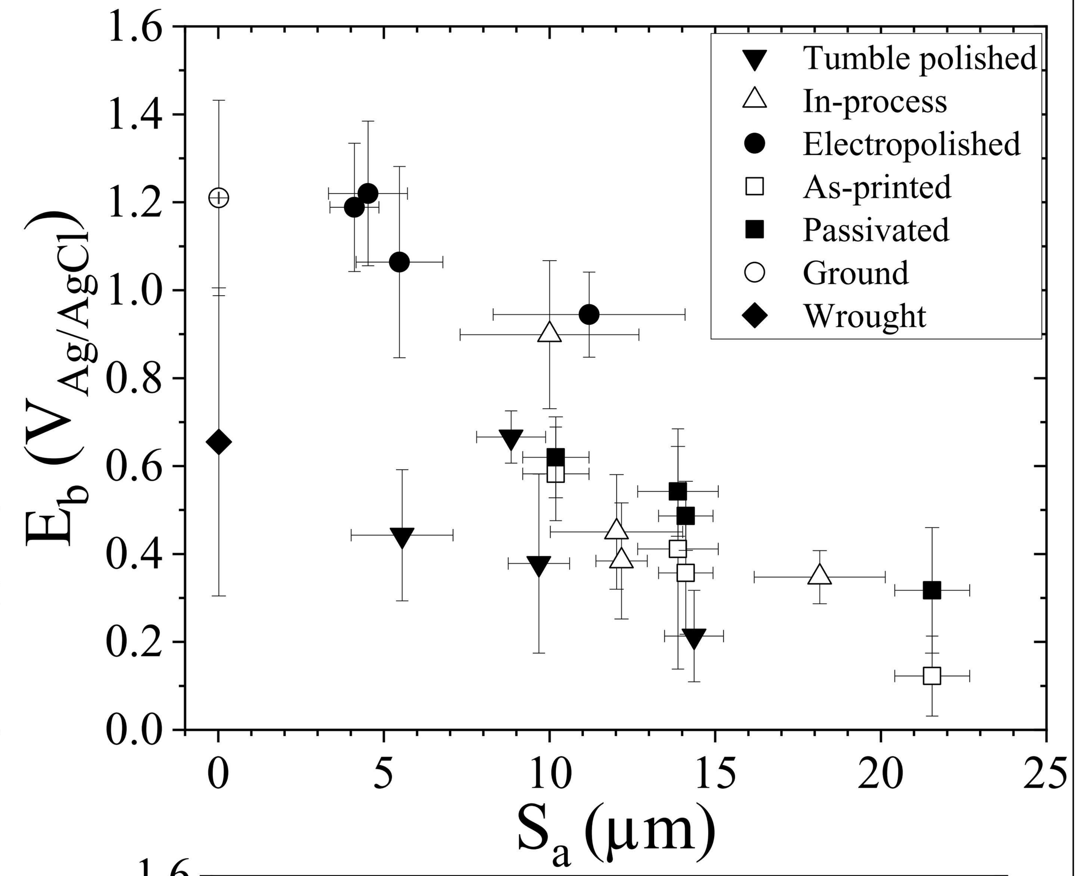
Surface roughness compared to breakdown potential

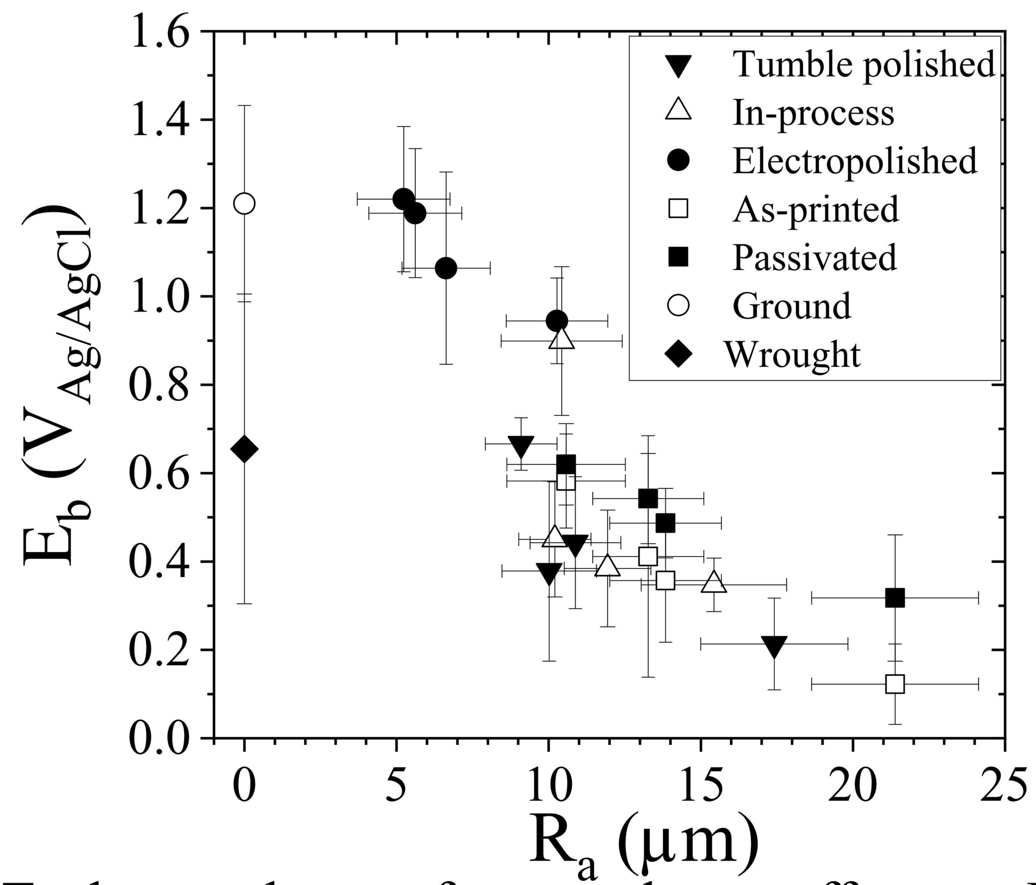


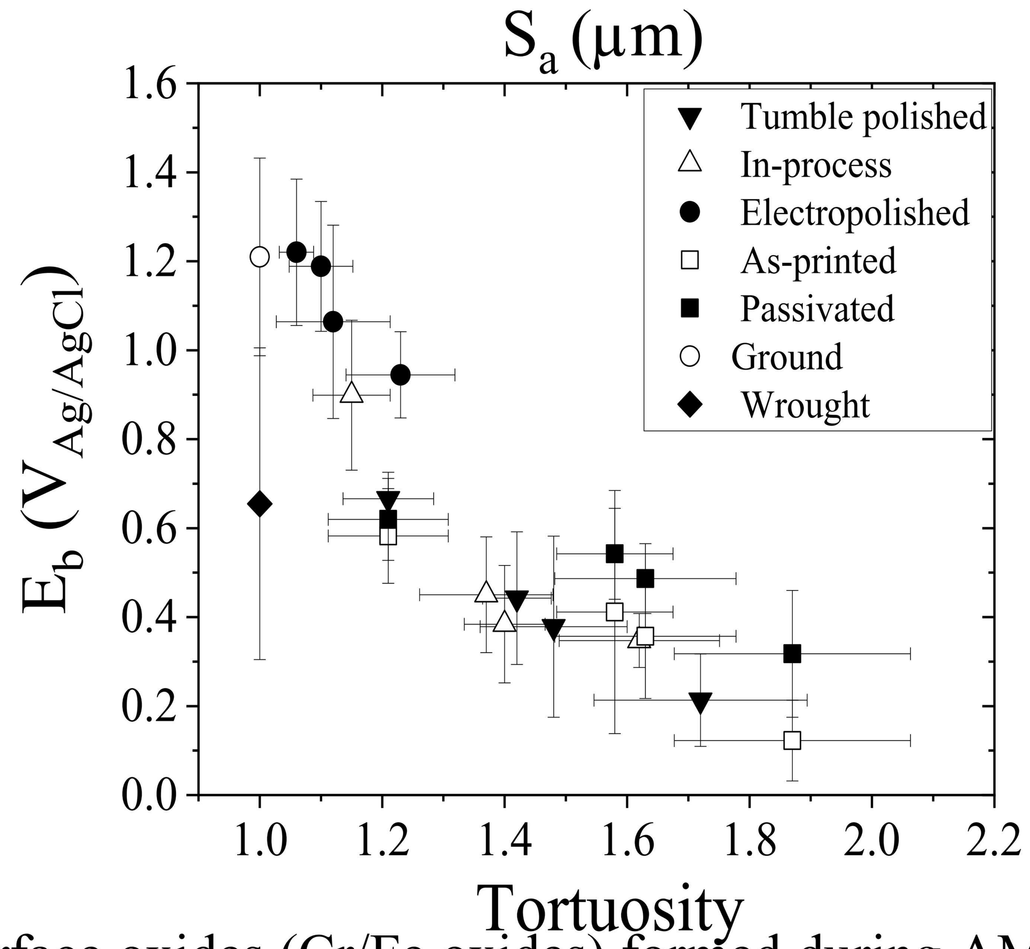
The corrosion behavior was measured by anodic potentiodynamic measurements of the surface in a quiescent 0.6 M NaCl solution to determine a breakdown potential (E_b), an indication of pit susceptibility.

Representative potentiodynamic measurements comparing the side orientation of as-printed and electropolished samples. Eight similar experiments were performed for all surface treatments and sample orientations.

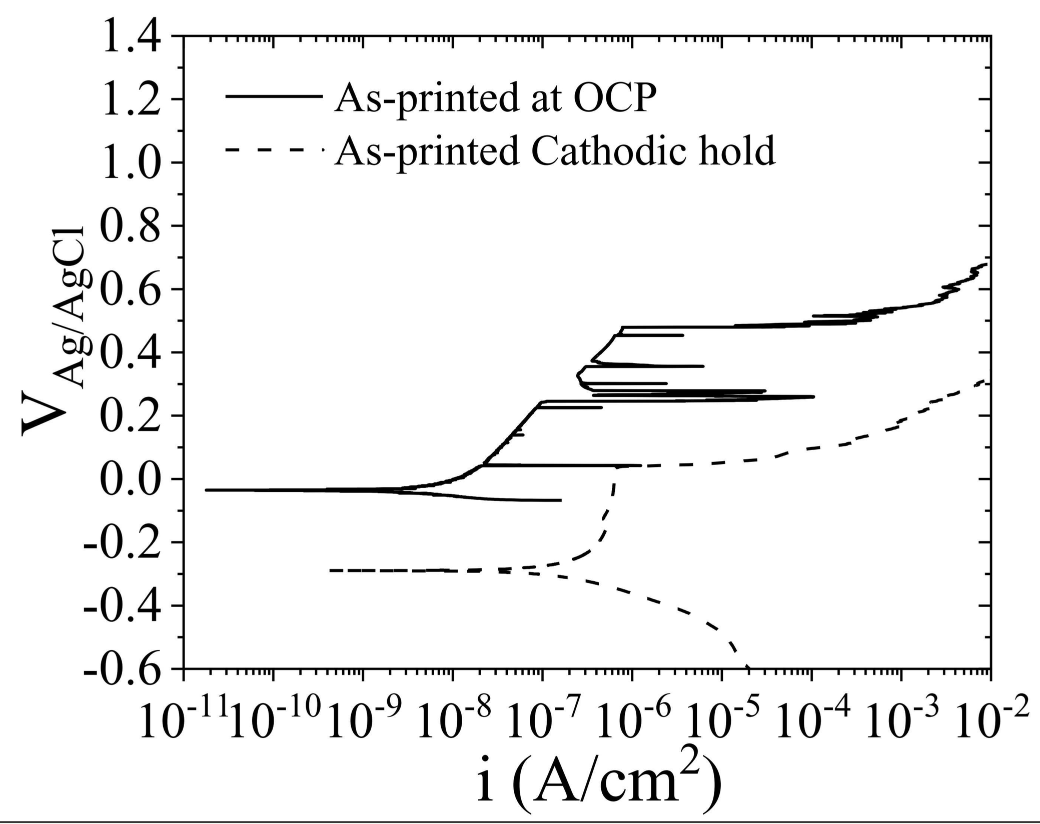
Comparisons with additive manufactured 316L samples and ground wrought 316L, indicate additive manufactured 316L is a greatly improved material. The impact of orientation is shown for S_a (**right**), Ra (**lower-left**), and tortuosity vs. E_b (**lower-right**) is shown to behave similarly. A larger value of roughness typically corresponded with a lower E_b, however outliers exist likely due to limitations of white light interferometry. There is a stronger correlation comparing R_a or tortuosity to E_b.

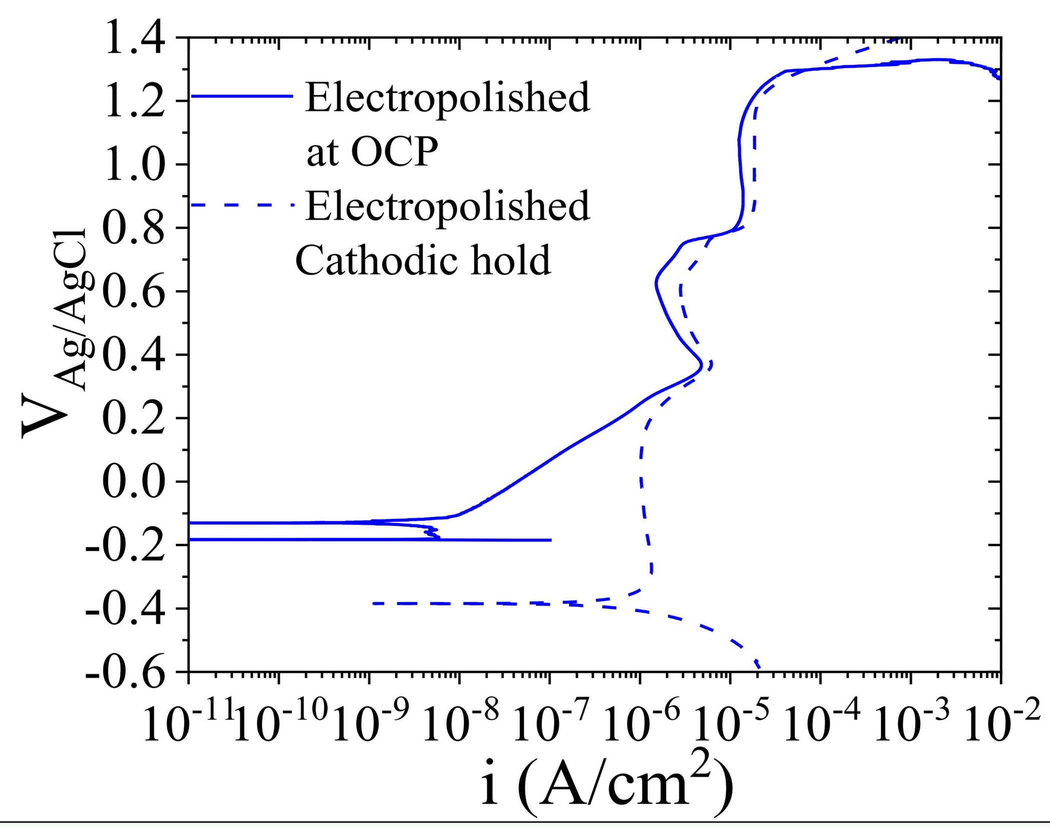






To deconvolute surface roughness effects on E_b from surface oxides (Cr/Fe oxides) formed during AM processing, a potentiostatic cathodic hold of -1.8$V_{Ag/AgCl}$ was applied to the side orientation of an electropolished and as-printed sample prior to a potentiodynamic measurement. Minimal change in E_b magnitude further suggests E_b is largely dictated by the surface roughness.





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