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The susceptibility to local corrosion for 304L, additively manufactured by a high and low power laser engineered network shape (LENS) technique

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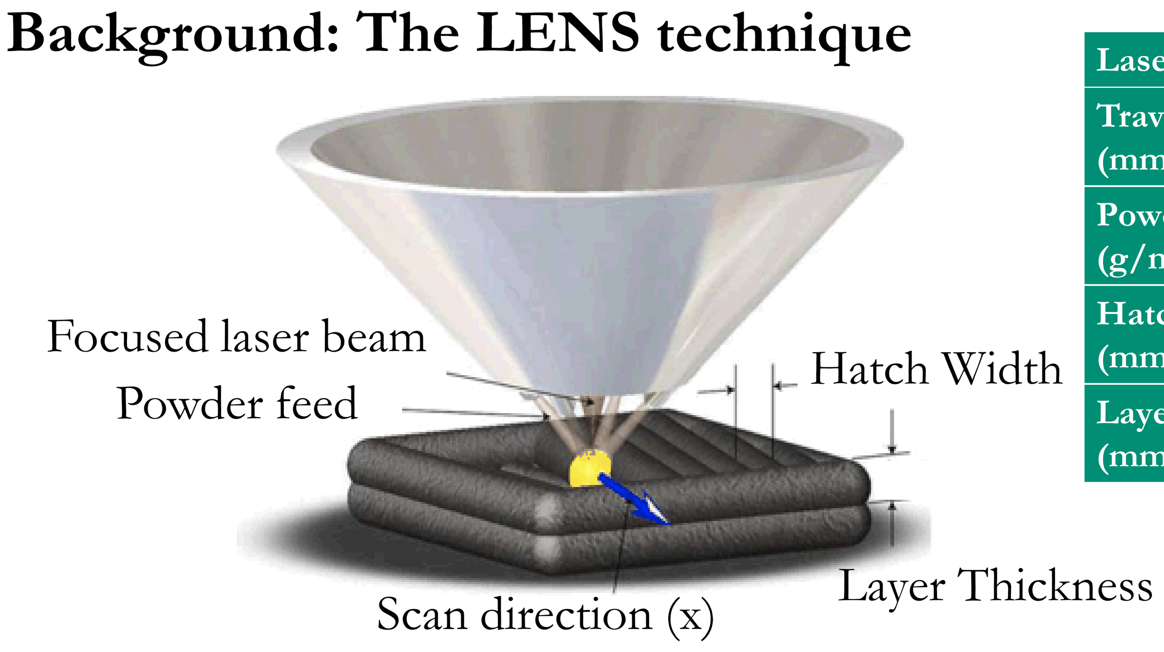
Abstract

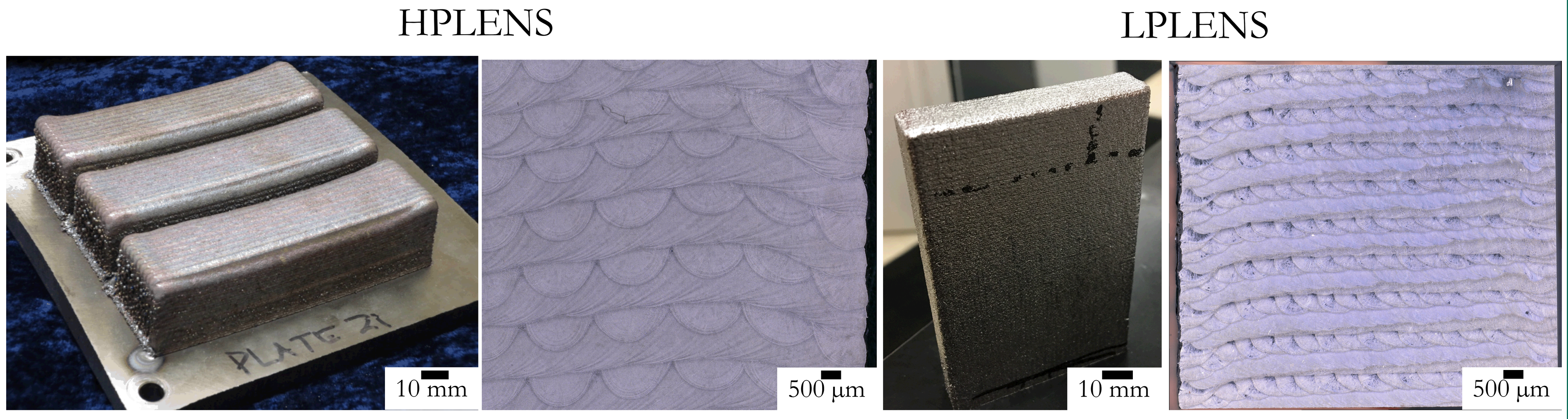
In recent years a desire to rapidly prototype complex metallic parts has driven the advancement of metal additive manufacturing (AM). Powder bed selective laser melting (SLM) and laser engineered net shape (LENS) have emerged as prevalent techniques for producing a wide range of complex metal components. The microstructure and surfaces of these materials are considerably different than their conventionally processed counterparts, resultant from rapid, directional solidification and dynamic thermal cycling associated with layer-wise melting. This presentation will investigate and compare the corrosion behavior of 304L stainless steel produced by typical processes (wrought) and two varieties of LENS processes, high power LENS (HPLENS) and low power LENS (LPLENS). An emphasis will be on understanding the relationship between characteristic microstructural features of the AM materials and localized corrosion behavior in chloride media.

Background: The LENS technique



Laser Power (W)	200 (LPLENS)	3800 (HPLENS)
Travel Speed (mm/min)		508
Powder Feed Rate (g/min)		23
Hatch Spacing (mm)		2
Layer Thickness (mm)		1.25

Starting Powder
Ø = 45-90 μm
N_2-atomized single use (not recycled)



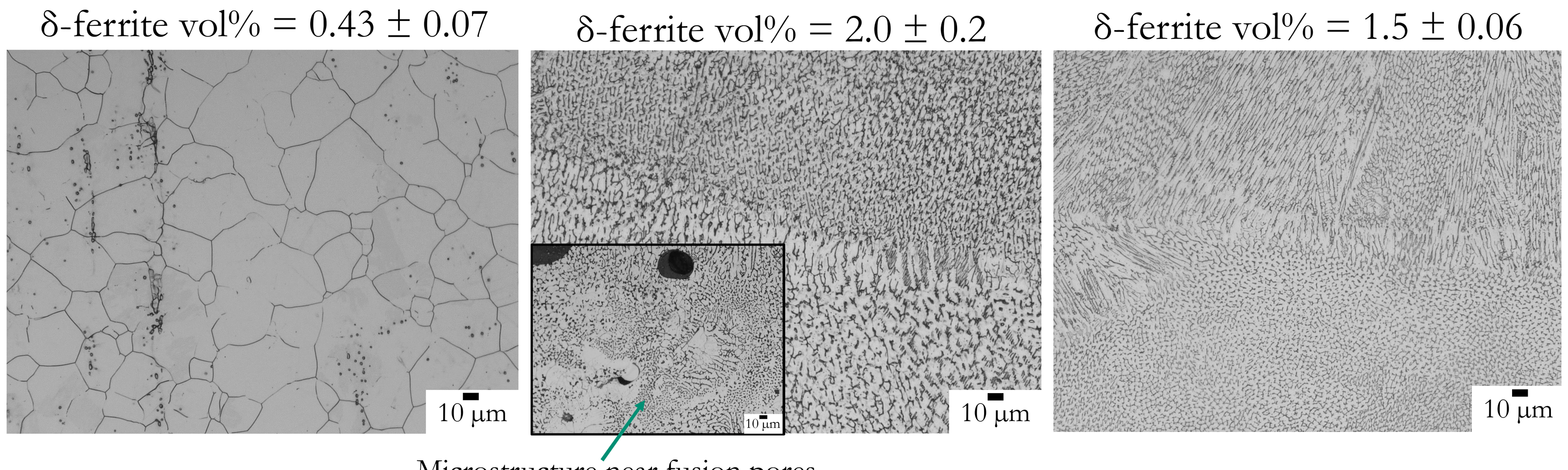
Composition (wt%)	Cr	Ni	Mn	Si	Mo	Cu	N	P	C	S	O	PREN
Starting powder	19.1	10.4	1.6	0.50	0.04	0.03	0.089	0.006	0.015	0.006	0.017	20.8
LPLENS	18.62	9.86	1.48	0.59	0.004	0.01	0.044	0.01	0.011	0.005	0.018	19.3
HPLENS	19.22	10.06	1.45	0.57	0.042	0.034	0.087	0.008	0.012	0.004	0.031	20.8
Wrought 304L	18.43	8.26	1.76	0.25	0.31	0.56	0.073	0.03	0.024	<0.001	0.009	20.6

Microstructural characterization

Wrought
δ-ferrite vol% = 0.43 ± 0.07

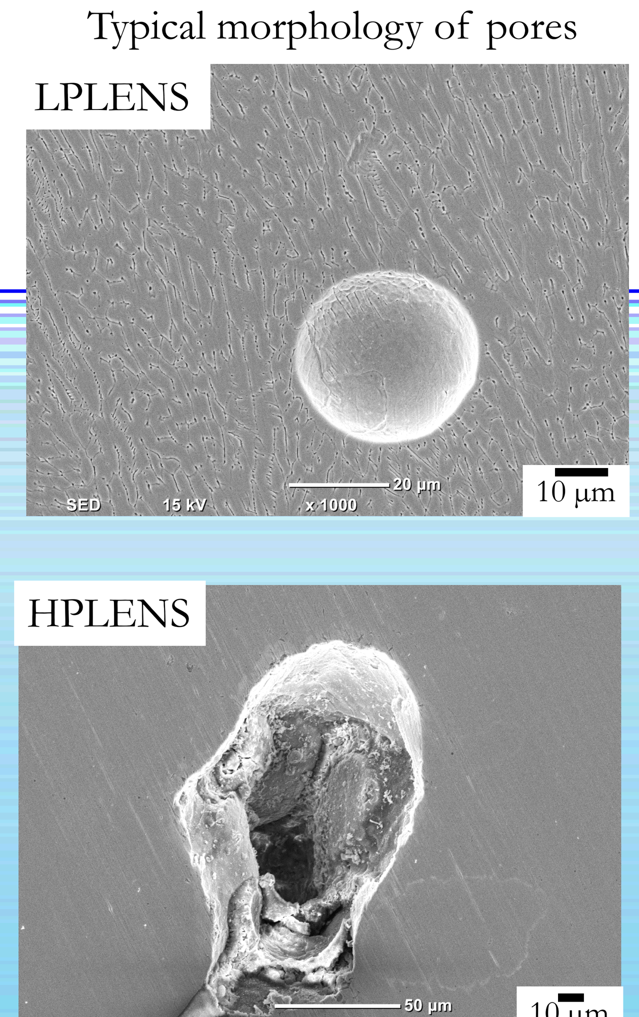
HPLENS
δ-ferrite vol% = 2.0 ± 0.2

LPLENS
δ-ferrite vol% = 1.5 ± 0.06

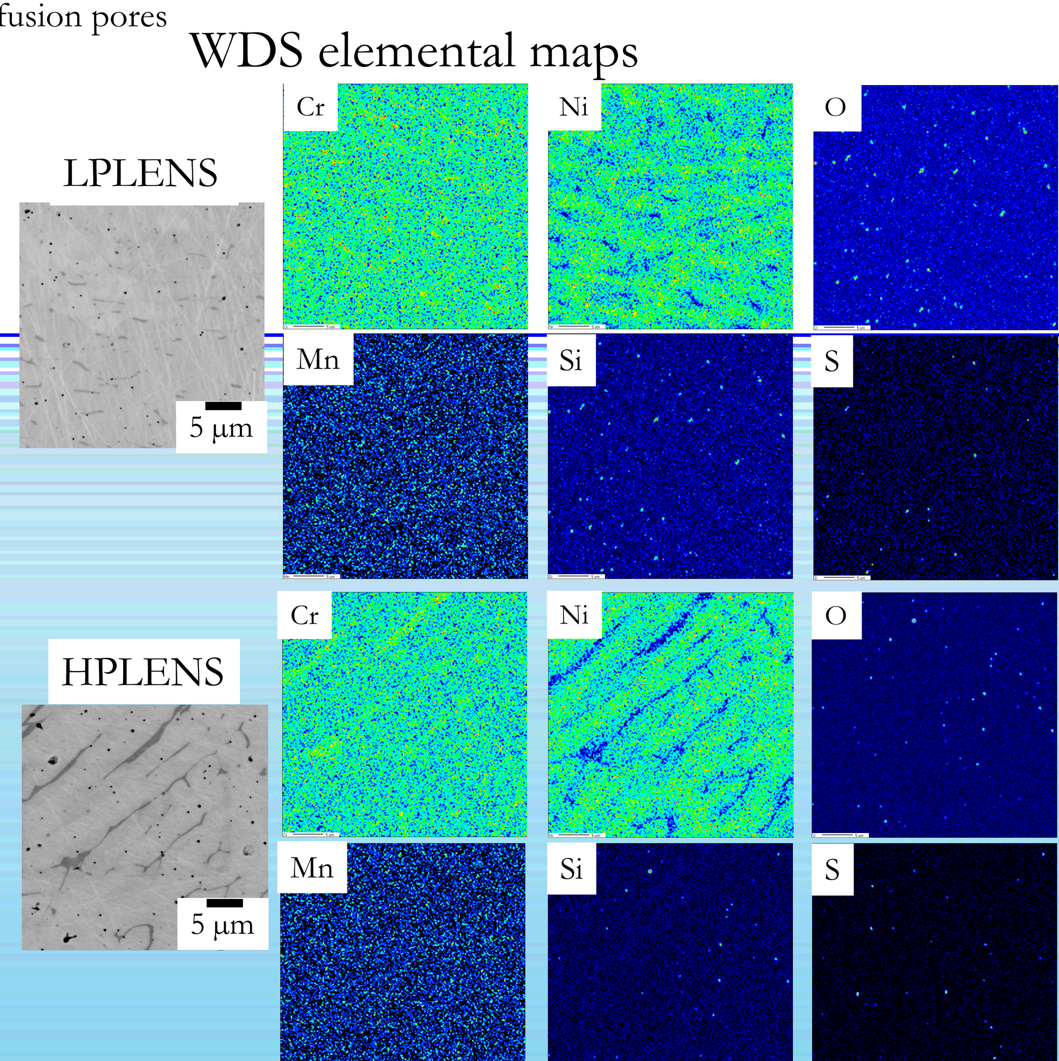


Microstructure near fusion pores

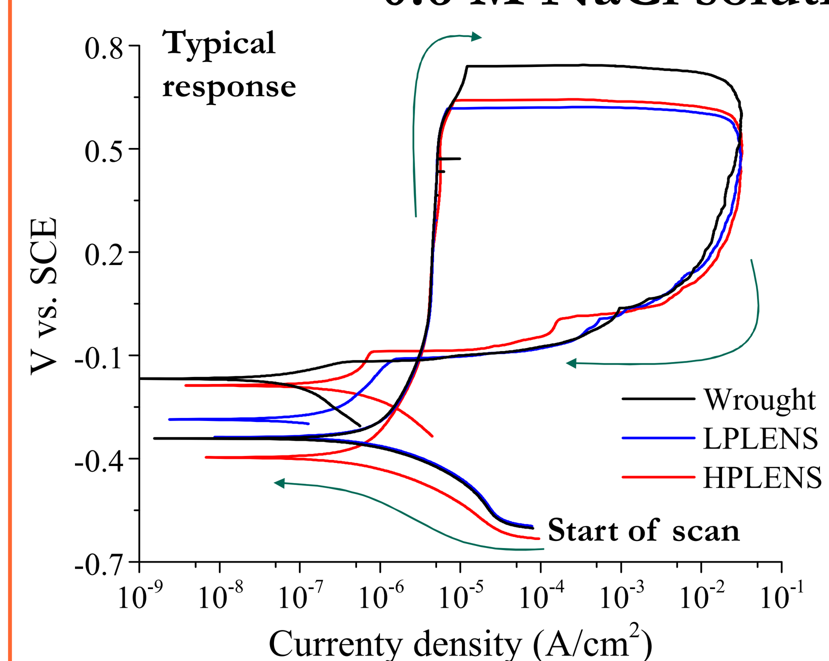
Typical morphology of pores

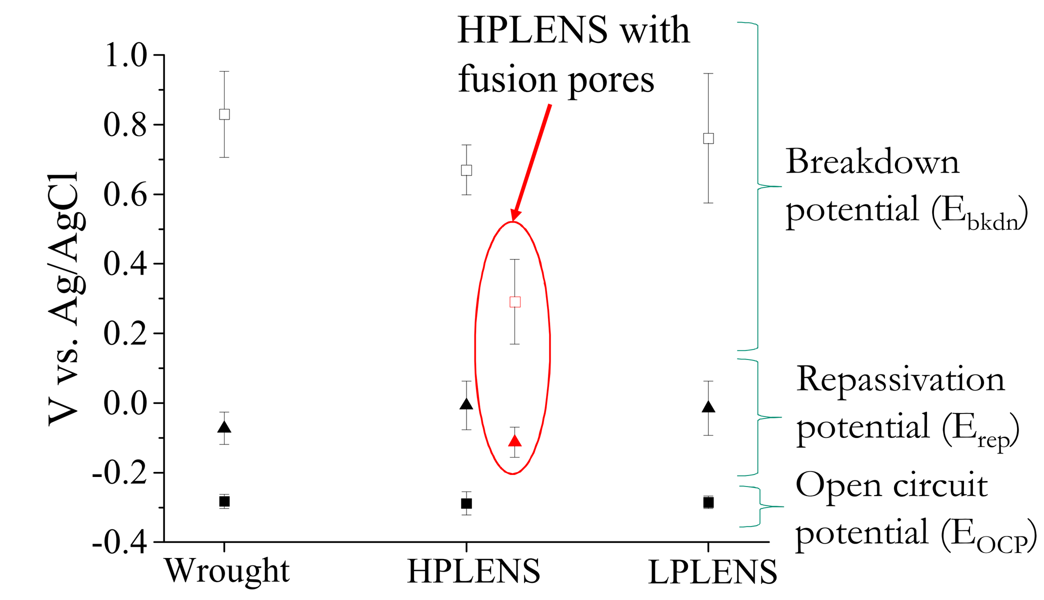


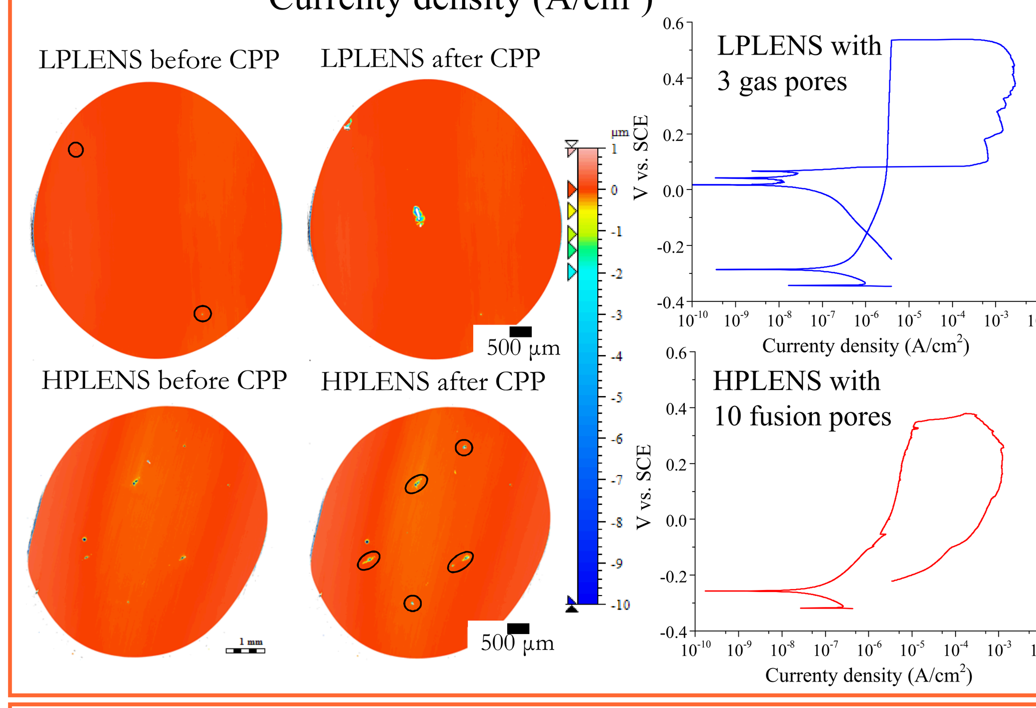
WDS elemental maps



Cyclic potentiodynamic polarization (CPP) measurements in quiescent 0.6 M NaCl solution – scan rate = 1 mV/sec.

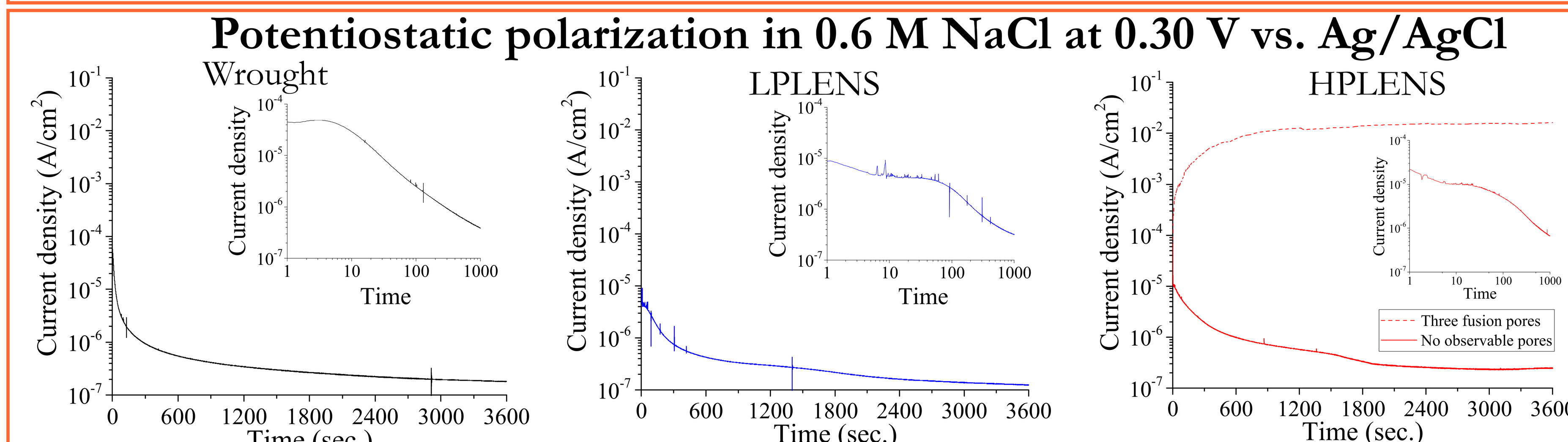






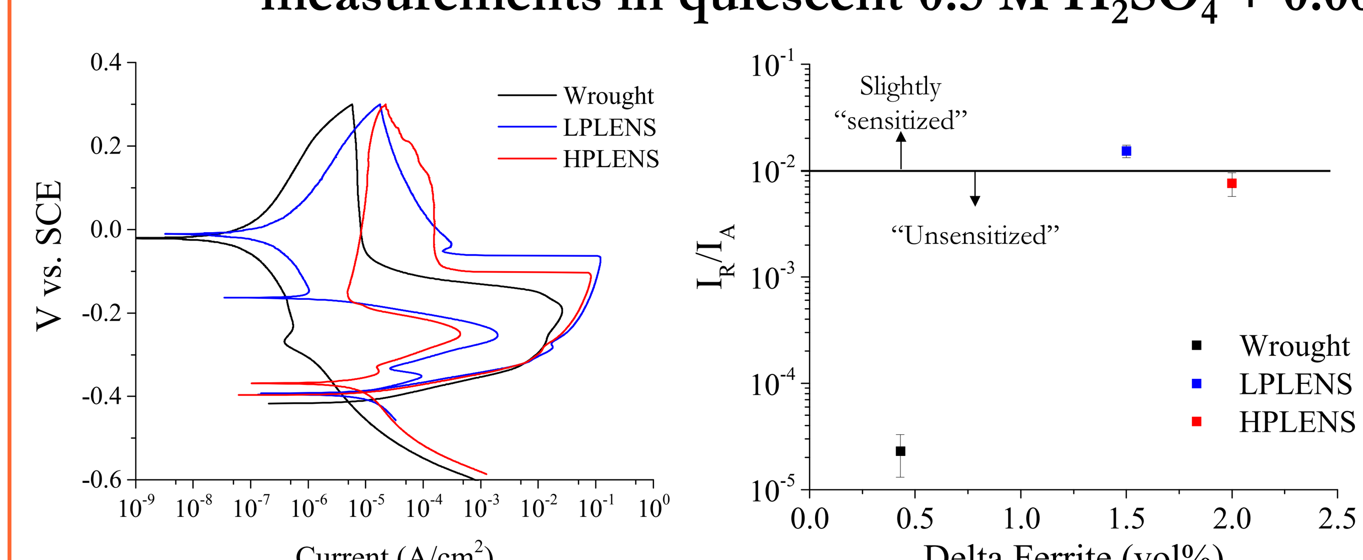
Cyclic polarization measurements revealed minimal difference, within a standard deviation, for E_{OCP}, E_{bkdn}, and E_{rep} for all specimen (all experiments were repeated at least 5 times). However, the abundance of fusion pores in the HPLENS material led to preferential pit initiation at these pores, while the gas pores typically found in the LPLENS material was not observed as a preferential pit initiation site. Severe corrosion initiating within fusion pores was expected because of their irregular shape and sharp features, similar to that creates an occluded cell. The smooth hemispherical gas pores should not lead to such a response.

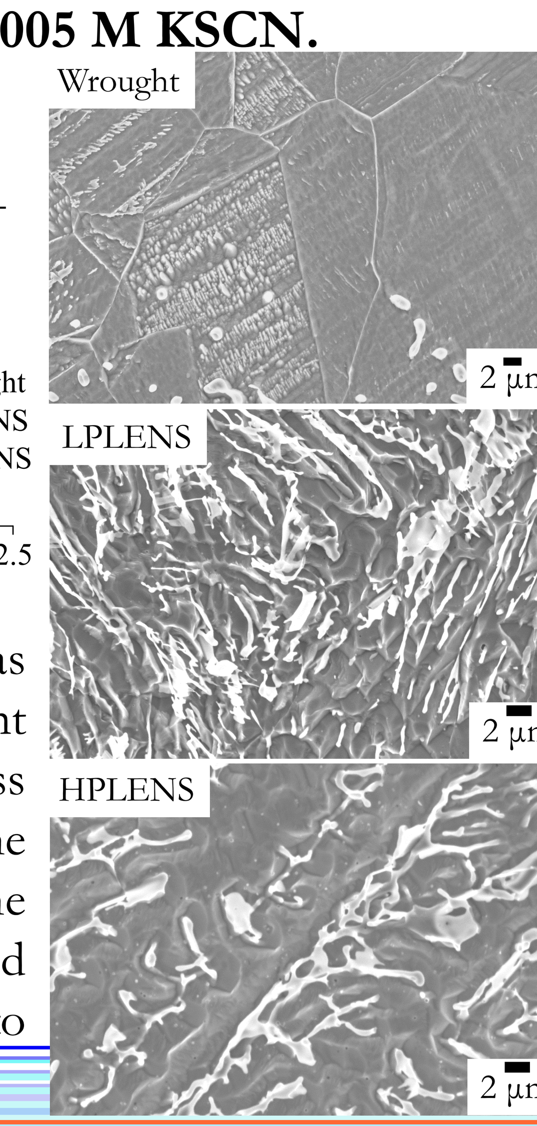
Potentiostatic polarization in 0.6 M NaCl at 0.30 V vs. Ag/AgCl



The metastable pit rate was noticeably reduced for the wrought specimens compared to both LENS material. In addition when fusion pores were included in the HPLENS corrosion area, stable pitting (dramatic rise in current density) started.

Double loop electrochemical potentiokinetic reactivation (DLEPR) measurements in quiescent 0.5 M H_2SO_4 + 0.005 M KSCN.





Quantification of chemical segregation for each specimen was performed by DLEPR, revealing a substantial reactivation current for both LENS materials, behaving similarly to sensitized stainless steel. A majority of the local corrosion attack occurring in the austenite located adjacent to δ-ferrite for the LENS material. The large Cr content in the δ-ferrite observed in the LENS material led to a more protective passive corrosion product compared to austenite, leading to the preferred corrosion of the austenite.

Conclusions

The microstructure and corrosion response of 304L stainless steel manufactured using two LENS processes was investigated. The cyclic potentiodynamic polarization measurements revealed the breakdown and repassivation potentials for LP and HP LENS were comparable to wrought 304L. The abundance of fusion pores present in the HPLENS material often led to premature breakdown while the gas pores in the LPLENS had much less impact on pit initiation. The DLEPR experiments verified the presence of δ-ferrite can lead to local dissolution of the austenite phase, however this effect did not appear to correlate to an increased susceptibility to pit initiation. Fusion pores were evidently observed to be the controlling factor in pit initiation for these materials., with their mechanism for increased corrosion activity similar to that for crevice corrosion.

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