Investigation of Pitting Corrosion Initiation and Propagation of a 316L Stainless Steel Manufactured by the Direct Metal Laser Sintering Process

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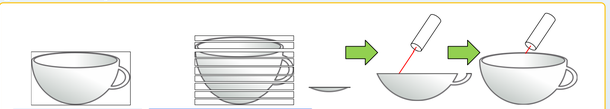
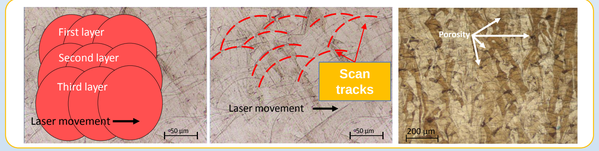
Introduction

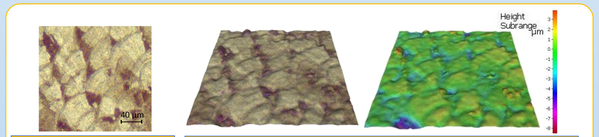
Direct metal laser sintering (DMLS) is an additive manufacturing process that uses a laser to sinter powdered metal to make geometrically complex parts[1]:



a) Generate a CAD file for an object | b) The object is divided into horizontal layers | c) The machine reads the CAD file for the layered object and sinters metal powder

Despite advantages for manufacturing, this process produces microstructural defects called scan tracks as well as porosity:





316L SS DMLS porosity | 3-D image of the porosity in a DMLS 316L SS

Those defects can potentially compromise the corrosion resistance of the metal manufactured by DMLS.

Objectives

- Evaluate the pitting corrosion resistance of a 316L SS manufactured by DMLS, using ASTM standards (G5 and G48).
- Investigate the microstructural defects of the 316L SS DMLS (scan tracks) and their relationship to corrosion initiation and propagation.

Hypotheses

"The corrosion resistance of a 316L SS manufactured by the DMLS process is hypothesized to be compromised due to inherent porosity and scan tracks produced during the DMLS process."

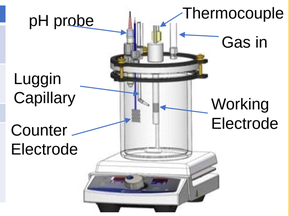
"By heat treatment, the recrystallization of steel grains is promoted and the scan tracks and porosity are 'healed', increasing the corrosion resistance of a 316L SS manufactured by the DMLS process."

Experimental Procedure

Electrochemistry

Parameters	Value
Specimens	316L SS Cold rolled, 316L SS DMLS
Working Electrolyte	N_2-sparged (deaerated) 1 N H_2SO_4 (ASTM G5)
Temperature	30 °C
Technique	Potentiodynamic polarization. Scan rate: 0.1667 mV/s from -20 mV wrt OCP up to 1.2 V vs Ag/AgCl

Apparatus



Chemical Composition of Steel Specimens

	Al	C	Cr	Cu	Mn	Mo	N	Nb	Ni	P	S	Si	Ti	W
Rolled	0.011	0.01	16.96	0.41	1.23	2.02	0.04	0.014	10.22	0.032	0.006	0.36	0.013	0.05
DMLS	0.007	0.007	17.61	0.21	1.64	2.68	0.07	0.01	12.1	0.017	0.008	0.26	0.035	0.024

Heat treatment

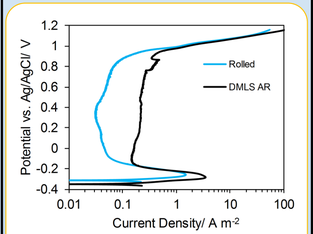
Parameters	Value
Annealing in an argon atmosphere	1100 °C Soaking time: 45 min Argon quenched

Pitting Resistance Test (ASTM G48)

Parameters	Value
Specimens	316L SS Cold rolled, 316L SS DMLS
Working Electrolyte	6 wt.% $FeCl_3$ (ASTM G48)
Temperature	55 °C
Techniques	EDS, Optical microscopy, profilometry

Results and Discussion

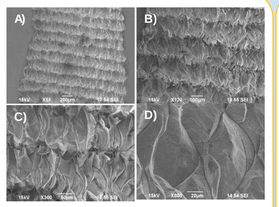
Electrochemistry



Anodic behavior of the 316L SS cold rolled as received (AR) and DMLS AR

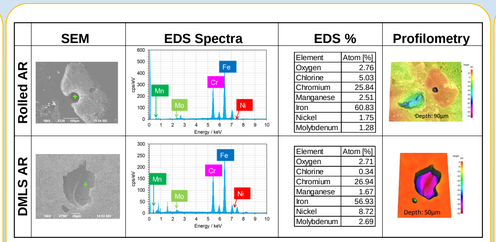
DMLS specimens corrode faster than the rolled specimens in the passivation zone.

ASTM G48 Corrosion Test Results Before Heat Treatment



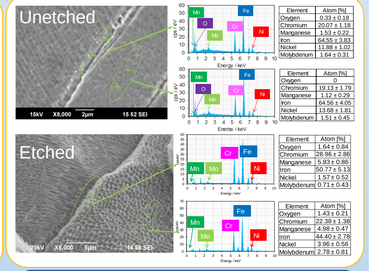
General corrosion of the DMLS 316L SS: A) general appearance; B), C) and D) zooms in on the affected zones

General corrosion follows the scan track patterns



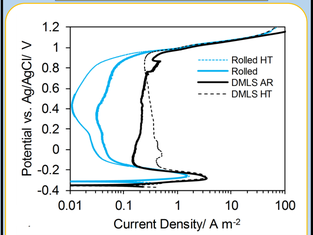
Pits morphology also follows the scan tracks

EDS on DMLS Specimens



Chemical segregation of protective compounds in scan tracks can explain the preferential corrosion.

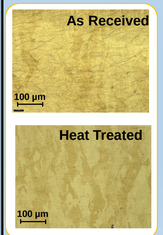
Electrochemistry



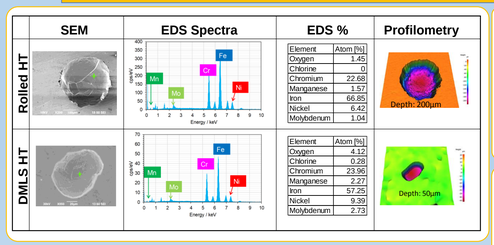
Anodic behavior of the 316L SS cold rolled as received (AR) and DMLS AR

The heat treatment did not have a significant effect on the passivation behavior of the DMLS 316L SS

ASTM G48 Corrosion Test Results After Heat Treatment

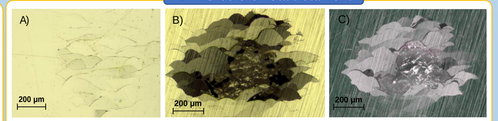


Heat treatment annihilates the scan tracks



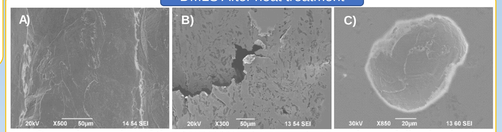
Without scan tracks, the general and localized corrosion does not have a specific pattern

DMLS before heat treatment



General corrosion initiation of the DMLS 316L: A) Zone with corrosion initiation, B) Zone with damage from corrosion, C) same zone as B) with a polarized lens filter.

DMLS After heat treatment



General corrosion of the DMLS 316L stainless steel specimens following heat treatment: A) general appearance, B) corrosion initiation, C) pit morphology

Conclusions

- 316L stainless steel specimens made by direct metal laser sintering (DMLS) corroded preferentially through the microstructural defects inherent to the manufacturing process (scan tracks).
- The preferential corrosion can be attributed to voids and porosity on the surface due to the sintering process as well as chemical segregation within the boundaries of the scan tracks.
- Heat treatment reduced the presence of microstructural defects (scan tracks) in DMLS specimens. Such a condition changed the corrosion damage patterns and the morphology of pits formed

Future Work

- Investigate the effect of chlorides on the anodic behavior of the DMLS 316L SS.
- Study effects of cold work in combination with heat treatment on the corrosion resistance of the DMLS 316L SS.

Reference

1.- I. Gibson, D. Rosen, and B. Stucker, *Additive Manufacturing Technologies*, 1st ed. (New York, NY: Springer, 2010), pp. 1-42.

Acknowledgements

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