

The Effect of Build Orientation on the Corrosion Behavior of SLM 304L Alloys

Ho Lun Chan, Armando Shehi
California State Polytechnic University, Pomona
3801 W. Temple Ave
Pomona, CA, USA, 91768

Tan Pan, Joseph Newkirk
Missouri University of Science and Technology
Parker Hall, 106, 300 W. 13th St,
Rolla, MO, USA, 65409

Vilupanur A. Ravi
California State Polytechnic University, Pomona
3801 W. Temple Ave
Pomona, CA, USA, 91768

ABSTRACT

The effect of build orientation on the corrosion resistance of 304L stainless steels (UNS S30403) produced by selective laser melting, was studied. Alloy coupons were obtained using three different build directions (vertical, horizontal, and 45° incline). The microstructures of these materials were characterized using optical microscopy and scanning electron microscopy coupled with energy dispersive spectroscopy. To provide insights into the corrosion behavior, electrochemical measurements were conducted and included open circuit potential measurements, linear polarization resistance scans, and Tafel tests. These tests were performed in a commercial corrosion cell containing a 3.5 wt% NaCl solution at room temperature. Results of the electrochemical and microstructural characterization are presented and discussed.

Key words: Selective laser melting, UNS S30403, Corrosion, Additive Manufacturing, Build Orientation

INTRODUCTION

The ongoing development of additive manufacturing (AM) technologies continues to revolutionize metallic alloy manufacturing by enabling rapid production of near-net shape components with complex geometries, improved properties and performance.¹⁻⁶ Published literature has widely confirmed the significance of AM processing parameters, including but not limited to, laser power density, hatch distance, scanning speed, in controlling material properties.⁷ These parameters share a common effect

in leading to non-uniform heat distribution during the solidification stage of AM powders.⁸ The subsequent result can lead to an inhomogeneous and anisotropic microstructure with phase segregation altering the corrosion characteristics of the material.⁹ This effect was observed in our previous work.¹⁰

Selective laser melting (SLM) is a popular AM technique for the fabrication of structural alloys for aerospace, biomedical, and energy industries.¹¹ During SLM fabrication, a laser beam produces a molten pool from the starting metal powders. The beam is traced along the x-y axis while the powder stage is lowered along the z-axis.¹² A unique feature of SLM technique is that by varying the tracing direction or movement, a hypothetical metallic part can be printed with different orientations, e.g. vertically, horizontally, or along the 45-degree angle with respect to the z-axis. The different build orientations can also result in gradients in thermal distribution, defects, grain orientation, and the overall microstructure.⁸

The corrosion behavior of SLM alloys built in different orientations has been reported for certain stainless steels, Ti-6 Al-4 V, and aluminum alloys.⁴⁻⁷ Corrosion studies performed on SLM Ti64 in 3.5 wt% NaCl, show that samples built in the vertical direction exhibit higher pitting resistance, while research performed on the pitting potential of SLM AISi10Mg alloys indicate that the XY plane build orientation samples perform better than the XZ plane samples.^{13,14} However, there is a lack of information in the public domain related to the corrosion behavior of SLM UNS S30403 (SLM 304L) alloys built in different directions. This paper reports on the corrosion behavior of SLM SS 304L built in horizontal, 45° inclined and vertical directions, in the presence of the 3.5 wt% NaCl simulated sea water.

EXPERIMENTAL PROCEDURE

In this project, the corrosion behavior of SLM 304L with three different build orientations (vertical, horizontal, and 45° inclined relative to z-axis) was studied. The SLM 304L alloys were fabricated using the same build parameters reported by Anime et.al.¹⁵ In addition, the nominal composition of the SLM powder is indicated in Table 1. A modified version of ASTM G59-97 standard was utilized to evaluate the electrochemical behavior of the alloys.¹⁶ Test coupons obtained from the cross-sections of SLM 304L built in three different orientations were metallographically prepared to a 800-grit surface finish followed by a three-minute ultrasonic cleaning sequentially in deionized water, acetone, and deionized water. The coupons were then placed in a three-electrode flat cell composed of a reference saturated calomel electrode (SCE), a platinum mesh counter electrode and a working electrode. A 250 mL 3.5 wt% NaCl solution prepared using ultrapure (type I) water served as the electrolyte. Electrochemical tests were conducted in a commercially available potentiostat in room temperature.

Corrosion tests were performed as follows: a 1-hour open circuit potential (OCP) period, a linear polarization resistance (LPR) scan, and then a Tafel polarization test. The scan rate (0.167 mV/s) and polarization range (-30 mV to +30 mV vs. OCP) of LPR follow the parameters stated in the ASTM G59-97 standard.¹⁶ Tafel polarization tests were performed using the same scan rate from -400 mV to +400 mV vs. OCP. Microstructural characterization of the as-built materials was conducted using optical microscopy. The ground and polished as-built specimens (1 µm surface finish) were electrolytically etched by immersion in a 60 wt% HNO₃ solution for 10 seconds while applying constant voltage of 1 V. X-Ray Diffraction (XRD) patterns were obtained for the as-built coupons. Phase identification and Rietveld analysis were performed.

Table 1: Nominal composition of the SLM 304L Alloy

Alloy	Weight Percent (wt%)										
	Fe	C	Cr	Cu	Mn	N	Ni	O	P	S	Si
SLM	Bal.	0.015	18.5	<0.100	1.40	0.090	9.90	0.020	0.012	0.004	0.630

RESULTS

Optical micrographs of the SLM 304L alloys built in the vertical, horizontal and 45° inclined directions are shown in Figures 1, 2 and 3, respectively. Pores with diameters in the 4 - 130 μm size range were observed in each coupon. Pore size measurements conducted on the alloy surfaces showed a variation in size; however, there was no clear relationship among pore size, pore density, and build orientation. For the etched surface, the optical micrograph of the vertical cross section of the SLM alloy (Figure 1b) showed hatch lines resulting from the laser scanning movement, while the horizontal and inclined cross sections reveal melt pool contrast.

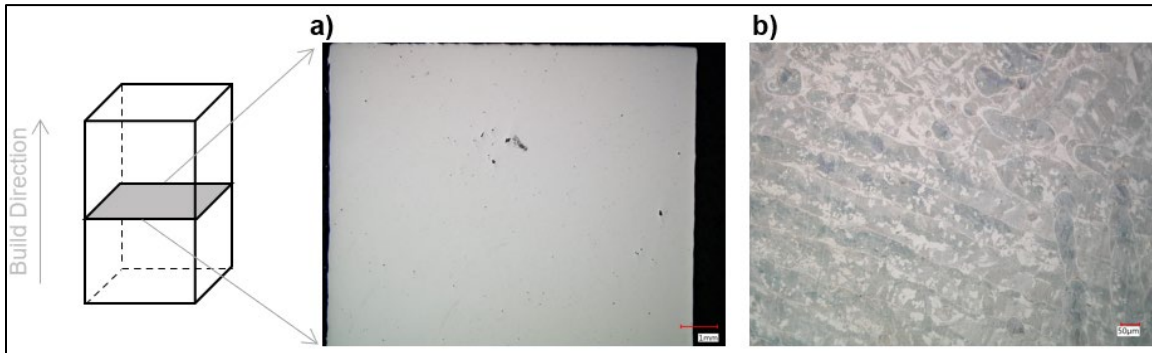


Figure 1: Optical micrographs of SLM 304L built in vertical direction (a) before etching (b) after electrolytic etching in 60 wt% HNO_3

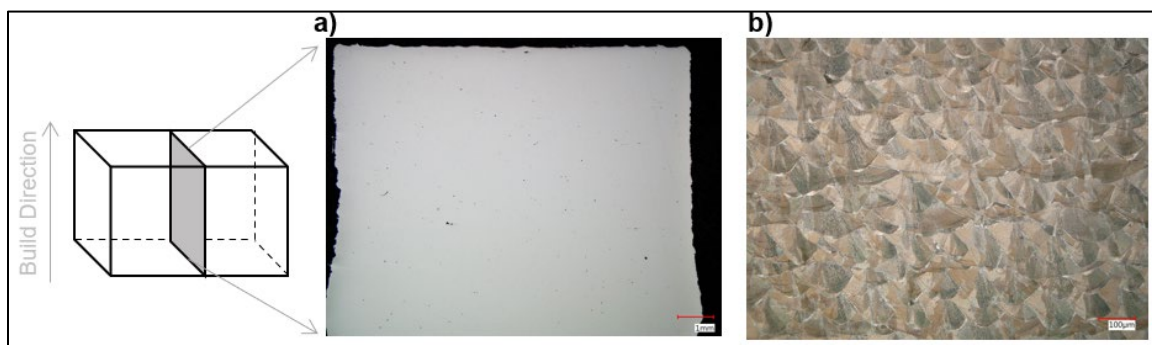


Figure 2: Optical micrographs of SLM 304L built in horizontal direction (a) before etching (b) after electrolytic etching in 60 wt% HNO_3

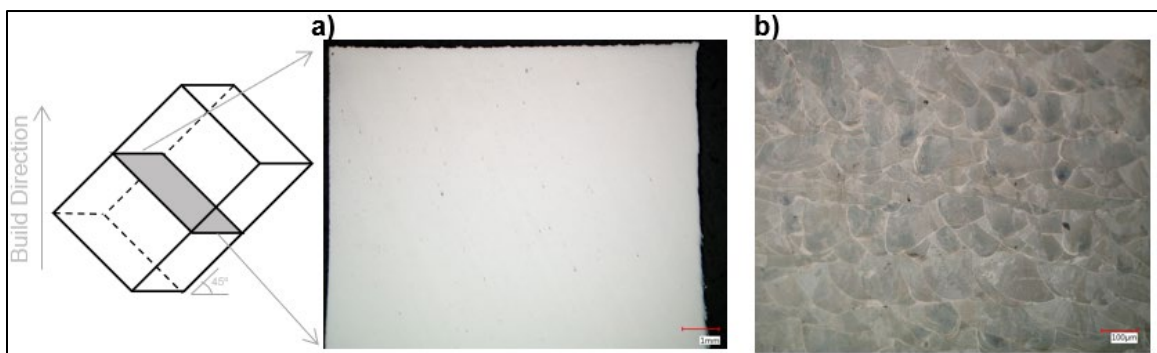


Figure 3: Optical micrographs of SLM 304L build in 45° inclined plane (a) before etching (b) after electrolytic etching in 60 wt% HNO_3