Effect of Heat Treatment on Corrosion Property of Laser Additively Manufactured Stainless Steel

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SUS316L stainless steel specimens were fabricated via selective laser melting, followed by stress relieving and solution treatments. The heat treatment conditions for conventional materials were applied. The mechanical properties, microstructure, and corrosion resistance properties were evaluated for the as-built and heat-treated specimens. The pitting potential measurements showed that the corrosion resistance of the heat-treated specimens was lower than that of the as-built specimens. Among the heat-treated specimens, no significant difference in corrosion resistance was observed. These results imply that further investigation of appropriate heat treatments is needed for the additively manufactured SUS316L stainless steel.

Keywords: *additive manufacturing, selective laser melting, stainless steel, heat treatment, microstructure*

1. Introduction

Additive manufacturing (AM) is a promising technology to produce metal parts with complex shapes. It offers high design flexibility. Selective laser melting (SLM), in which metal parts are built by selectively melting the powder bed layer-by-layer using a laser beam, is an AM process. Repetitive heating, rapid cooling, and solidification during the building process lead to residual stresses and anisotropy. Separation of built objects from the base plate while leaving residual stress causes distortion. To prevent the distortion, removing the residual stress or effect of anisotropy by heat treatment is necessary before separating the built objects. The properties of the built object will change by heat treatment. The corrosion resistance of SUS316L stainless steel (SS) objects processed via SLM has been actively researched in recent years [1–5]. However, a limited number of studies have reported on the effect of heat treatment on the corrosion resistance of SUS316L SS.

The purpose of this study was to investigate the effects of heat treatment on SUS316L SS objects fabricated via SLM. SUS316L SS specimens were fabricated by SLM. The mechanical properties, microstructures, and corrosion resistances of the as-built and heat-treated specimens were investigated.

2. Experimental

2.1 Specimen preparation and evaluation

Gas-atomized 316L (SS) powder (EOS StainlessSteel 316L, EOS GmbH, Germany) was used as a raw material for laser powder bed fusion. The nominal composition of the powder was Fe-18Cr-14Ni-2.5Mo-0.03C, and the median particle size was 39.5 μm. Circular plates of diameter 20 mm and thickness 5 mm were fabricated using a 3D printer (EOS M 100, EOS GmbH, Germany) with the standard parameters for EOS StainlessSteel 316L. The process parameters for fabricating specimens are listed in Table 1. Some of the specimens were subjected to various heat treatments, such as stress relieving and solution treatments. The heat treatment condition was varied to investigate the effect of the conditions. The heat treatment conditions were based on Japanese Industrial Standard (JIS) for conventional materials and are listed in Table 2.

The densities were measured using the Archimedes' method. The specimens were cut, as depicted in Figure 1, and used for the hardness test, microstructure observation, X-ray diffraction analysis, and pitting potential measurement. After the specimens were polished and etched using aqua regia, their microstructures of vertical and horizontal cross-sections were observed.

Table 1 Building conditions of specimens.

Laser power	77.1 W
Scan speed	827 mm·s^{-1}
Scan pitch	0.07 mm
Layer thickness	0.02 mm
Atmosphere	Argon

Table 2 Heat treatment conditions of specimens.

Code	Heat treatment	
	Stress relieving	Solution treatment
as-built	-	-
SR	1173 K for 7.2 ks	-
SR+ST1	1173 K for 7.2 ks	1423 K for 3.6 ks
ST2	-	1353 K for 3.6 ks

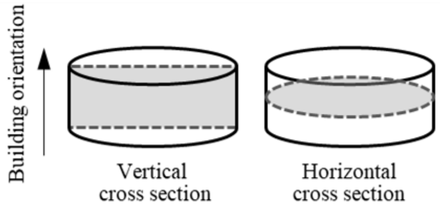

Fig. 1 Schematic for cutting specimens.

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2.2 Pitting potential measurement

After the cross sections of the specimens were polished, the terminal electrodes were attached to the specimens, and the specimens were covered with masking tape containing a ϕ3.3 mm hole. Potentiodynamic polarization curves were measured in nitrogen-saturated 1 mol·L^{-1} NaCl solution at 303 K using a potentiostat/galvanostat at a scan rate of 20 mV·min^{-1}. The potential at which the current density exceeded 5 A·m^{-2} was specified as the pitting potential, V'_C. All potentials were measured versus a silver-silver chloride electrode, and a platinum electrode was used as the counter electrode.

3. Results and discussion

3.1 Density and hardness

The densities and hardness of the specimens are listed in Table 3. The densities of the as-built and heat-treated specimens were almost the same, whereas the hardness decreased owing to the heat treatment. This implies that the reduction in the hardness of the specimens may have been caused by relieving of the residual stress.

Table 3 Densities and hardness of specimens.

Code	Density ρ / Kg·m^{-3}	Vickers Hardness HV10	
		Horizontal cross section	Vertical cross section
as-built	7.96	229	225
SR	7.97	196	199
SR+ST1	7.98	150	148
ST2	7.97	180	179

3.2 Results of pitting potential measurement

Figure 2 shows the potentiodynamic polarization curves of the as-built specimens. Oscillations in the current were observed above 0.2 V, and the current density exceeded 5 A·m^{-2} at 0.56 V or higher. Figure 3 shows the results of pitting potential measurements for the as-built and heat-treated specimens. The pitting potentials of the heat-treated specimens are lower than those of the as-built specimens. Furthermore, the corrosion resistance deteriorated due to the heat treatment. These results imply that the solid solution elements were fully dissolved by SLM, and these elements were slightly precipitated by heat treatment. The deterioration in corrosion resistance does not affect the usage of the heat-treated material, SUS316L. The pitting potentials of the heat-treated specimens were almost identical. The dispersion of the pitting potential of the vertical cross sections tended to be large.

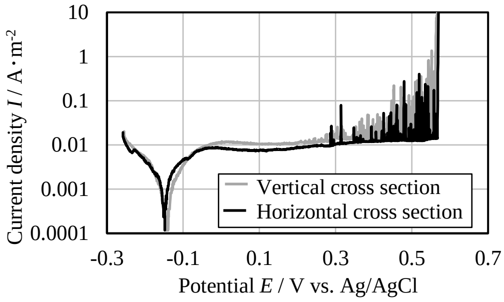

Fig. 2 Polarization curves of as-built specimens.

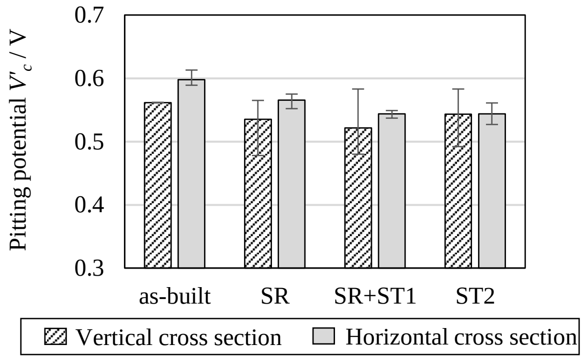

Fig. 3 Pitting potentials obtained from potentiodynamic polarization scans of the specimens.

3.3 Microstructure observation

The microstructures of the as-built specimens contained imprints of melt pools, which disappeared following the heat treatment. However, the anisotropy observed in the as-built specimens did not disappear with the heat treatments. Few precipitates were observed in the as-built specimens, whereas some precipitates were observed in the specimens subjected to stress relieving.

The solution treatment conditions were determined based on the JIS for conventional materials. However, these results imply that the solution treatments applied in this study may be insufficient for the additively manufactured SUS316L SS objects. Therefore, further studies are warranted.

4. Summary

In this study, the effects of heat treatment on the mechanical properties, microstructure, and corrosion resistance of SUS316L (SS) fabricated via SLM were investigated. The results are as follows:

(1) The hardness of the specimens decreased by the heat treatments.
(2) The pitting potentials of the as-built specimens and the heat-treated specimens were 0.56-0.61 V and 0.45-0.58 V, respectively. The corrosion resistance deteriorated due to the heat treatment.
(3) There was no significant difference in corrosion resistance among the heat-treated specimens.
(4) Few precipitates were observed in the as-built specimens, whereas some were observed in the specimens subjected to stress relieving.

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