Corrosion Behavior of Selective Laser Melted AlSi10Mg Alloy in NaCl Solution and Its Dependence on Heat Treatment

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Abstract

This work investigates the corrosion behavior of AlSi10Mg alloy produced by selective laser melting (SLM) and the counterparts heat-treated at 450–550 °C in 3.5 wt% NaCl solution. Electrochemical measurements and weight loss tests together with microstructural characterizations were conducted. The SLM-produced alloy displays a microstructure with a continuous network of Si particles, exhibiting superior corrosion behavior. After heat treatment, the Si particles are coarsened and isolated and Al matrix dissolves into their surrounding area, thereby degrading the corrosion resistance properties. Therefore, the corrosion resistance of AlSi10Mg alloy degrades with increasing the heat treatment temperature.

Keywords Aluminum · Selective laser melting · XRD · Electrochemistry · Pitting corrosion

1 Introduction

Si-containing aluminum (Al) alloys are widely used because of their great cast property, low shrinkage and relatively low melting temperature [1–4]. Among the Si-containing Al alloys, the hypoeutectic AlSi10Mg alloy with low density, low thermal diffusion coefficient and low reclamation cost has been largely applied in aerospace, marine and automotive industries [5], due to its high mechanical properties and great corrosion resistance in the applied environments [6]. As a multiphase alloy, the microstructure of AlSi10Mg alloy is composed of α -Al phase, eutectic Si particles and secondary phases such as Mg₂Si (generally referred to β -phase). Considerable work has been carried out to investigate the performance of AlSi10Mg alloy with various microstructures [7–10]. The results indicate that the eutectic Si

particles with coarse and acicular morphology degrade the mechanical properties of AlSi10Mg alloy [11–13]. Therefore, it is vital to manipulate the microstructure to improve the mechanical properties of AlSi10Mg alloy. With regard to the refinement of the microstructure and the homogeneous distribution of the eutectic Si particles, the rapid solidification with cooling rate up to 10⁶ °C/s seems to be a feasible method according to the previous reports [14–19]. However, the cooling rate of traditional processing methods for producing AlSi10Mg alloy is approximately about 100 °C/s or even lower [19], which is far less than the required cooling rate of 10⁶ °C/s.

Fortunately, selective laser melting (SLM), as one of the most popular the additive manufacturing (AM) technologies, is based on selectively melting metallic powder on the bed by high-power laser beam, which could heat and cool the materials at a very high rate [20–28]. The SLM possesses many advantages, such as topology optimization, short production cycle and high material utilization. Such a technique breaks the complex geometrical restriction structure and has been adopted to fabricate AlSi10Mg alloy [29]. However, due to the fast cooling and great temperature gradient during the SLM process, SLM products are subjected to high residual stresses, which are detrimental to their mechanical properties [29–31]. Therefore, post-heat treatments are always employed to reduce majority of residual stresses in SLM products with the aim to achieve better mechanical property [32–34]. So far, endeavors have been made to investigate

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the heat treatment on SLM-produced AlSi10Mg alloy. For example, T6 heating treatment system, which contains the procedure of solution treatment, hydro-cooling and artificial aging, is often adopted to improve the mechanical properties of SLM-produced AlSi10Mg alloy [9, 35–38]. Generally, the SLM-produced AlSi10Mg alloy has a supersaturated Si solid solution in the Al matrix due to fast cooling in SLM process [29]. Hence, the supersaturated lattice Si would precipitate and form Si particles during heat treatment. In this case, the size of Si particle increases with the rise of heat treatment temperature. As mentioned above, the coarse Si particles would play a detrimental role in the mechanical properties of AlSi10Mg alloy. So, tailoring the microstructure by heat treatment at a proper temperature is extremely significant with the purpose to obtain enhanced properties of the SLM-produced AlSi10Mg alloy [29].

Considering the applied environment (i.e., marine environment), corrosion resistance is also one of the most important properties, which may affect the service performance of AlSi10Mg alloy. The traditional AlSi10Mg alloys are susceptible to intergranular corrosion, which is ascribed to the Si concentration in the excess of Mg₂Si ration [39], precipitation of Si [40, 41] or the anodic dissolution of the intermetallic phase Mg₂Si [42–44]. The heterogeneous phase and principal phase of the AlSi10Mg alloy, respectively, serve as anode and cathode to execute corrosion reaction during electrochemical corrosion in working environment. The electrochemical corrosion of large cathode and small anode can accelerate the corrosion of the AlSi10Mg alloy [45, 46]. By contrast, the electrochemical corrosion of small cathode and large anode can accelerate the generation of compact oxidation film to restrain corrosion reaction [45]. Hence, the distribution and size of heterogeneous phase would significantly affect the corrosion resistance of the AlSi10Mg alloy [6, 47]. As the mechanical properties of AlSi10Mg alloy could be varied by heat treatment which modifies the morphologies, distributions and sizes of the Si particles, such an altered microstructure would also result in different corrosion behaviors of the heat-treated AlSi10Mg alloy produced by SLM [48]. Therefore, considering their applications, it is highly significant to further investigate the corrosion behavior of SLM-produced AlSi10Mg alloy as well as the heat-treated counterparts. This will give insight into further improving the overall performance of the SLM-produced AlSi10Mg alloy.

As such, this work aims to investigate the relationship between corrosion behavior of SLM-produced AlSi10Mg alloy and the counterparts after heat treatment. It has been

reported that high temperature heat treatment will promote the growth of Si particle size [29]. Therefore, ranging 450–550 °C was selected as the heat treatment temperature. The statistical analysis was carried out to confirm the variation in Si particle size during heat treatment. The weight loss tests and electrochemical measurements were employed to study the corrosion behavior of AlSi10Mg alloy in 3.5 wt% NaCl solution. The morphology and microstructure characterizations of corroded samples were adopted to explore the corrosion mechanism.

2 Experimental

2.1 Materials and Solution Preparation

The SLM-produced AlSi10Mg alloy cubes with dimension of 10 mm × 10 mm × 10 mm was fabricated by an MTT SLM 250H machine (Realizer GmbH, Germany) equipped with a 300 W Yb: YAG fiber laser with a spot size of 80 μm was under the high purity argon atmosphere. No preheating of the substrate was applied. The following processing parameters were adopted in SLM processing: the laser power was 200 W; the laser scanning speed was 1600 mm/s; and the hatch spacing and layer thickness were 105 μm and 50 μm, respectively. During the successive scanning layers, the scanning direction was rotated 90°. The relative density of SLM-produced AlSi10Mg alloy estimated by Archimedes' method was greater than 99%. Table 1 lists the chemical compositions of SLM-produced AlSi10Mg alloy which was measured by inductively coupled plasma atomic emission spectroscopy (ICP-AES, ICPE-9800, Japan).

The solution treatment of SLM-produced AlSi10Mg samples were executed at 450 °C, 500 °C and 550 °C for up to 2 h, respectively, under the protection of argon atmosphere followed by water quenching. The heat-treated samples at different temperatures were hereafter labeled as 450 °C heat-treated, 500 °C heat-treated and 550 °C heat-treated, respectively. The cubes were used for microstructure analysis and electrochemical measurements. From the produced cubes, the AlSi10Mg flakelets with dimensions of 10 mm × 10 mm × 1 mm were cut along the building plane for weight loss tests. The samples used for electrochemical measurements were connected with copper wires and sealed in the epoxy resin. The surfaces of all samples were mechanically ground up to 4000 grits with SiC papers and then polished with CeO₂ powder suspension for weight loss tests and electrochemical measurements. Afterward, the

Table 1 Chemical compositions of SLM-produced AlSi10Mg (wt%)

Si	Mg	Fe	Mn	Ti	Cu	Zn	C	Ni	Pb	Sn	Al
10.00	0.45	0.55	0.45	0.15	0.10	0.10	0.05	0.05	0.05	0.05	Bal.

prepared samples were ultrasonically cleaned with deionized water and finally dried with compressed air.

The aerated 3.5 wt% NaCl solution was prepared for electrochemical measurements and weight loss tests at room temperature (25 °C). Chemical polishing was adopted for microstructural characterization of the alloy samples. During the chemical polishing process, the samples were immersed in a three-acid-type polishing solution composed of 85% H₃PO₄, 10% H₂SO₄ and 5% HNO₃ (in vol%) at 100 °C for 2.5 min [49]. After chemical polishing, the samples were washed ultrasonically in alcohol for 10 min and then dried. All relevant reagents during the experiment were of analytical grade.

2.2 Weight Loss Tests

For the weight loss tests, four uncorrelated sides of flakelets were sealed with epoxy resin. The masses of flakelets were measured by an electron balance (MS104, Mettler-Toledo, Swiss) with an accuracy of 0.1 mg before weight loss tests. Four flakelets of each sample batches (i.e., SLM-produced AlSi10Mg, 450 °C heat-treated, 500 °C heat-treated and 550 °C heat-treated) were immersed in 3.5 wt% NaCl solution simultaneously for 45 days. The corrosion products were purged referring to international standard: ISO 8407-1991 after the weight loss tests. The corrosion surface of the immersed sample was cleaned by nitric acid for 5 min at room temperature. The flakelets were washed in deionized water after acid pickling and subsequently dried in hot air. Finally, the immersed and washed flakelets were weighed again. To measure the dissolution of the Al matrix and the water absorption of the epoxy resin, two background parameters of the weight for flakelets without immersion at the beginning and ending of the pickling progress were measured. The epoxy resin with the same size of the flakelets was also immersed in NaCl solution. The mass loss rate (g m⁻² h⁻¹) could be calculated as follows:

$$\nu = [(w_1 - w_2 + \Delta w) - (m_1 - m_2)] / (S \times t), \quad (1)$$

where ν is the mass loss rate of metal flakelet, w_1 and w_2 are the weight of metal flakelet at the beginning and ending of weight loss tests, m_1 and m_2 are the weight of background metal flakelet without immersion at the beginning and ending of pickling progress, respectively and Δw is the weight of the water absorption of epoxy resin flakelets of four sides. In addition, the erosion area is represented by S and immersion time is denoted as t .

2.3 Electrochemical Measurements

The electrochemical measurements were carried out by using an electrochemical workstation (Reference 1000, Gamry, USA). Three-electrode system was applied to

measure the corrosion behavior of the samples according to ASTM G3-89. The installation was made up of a working electrode which was the surface treated alloy sample (after polished) with the presented area of 1 cm², an auxiliary electrode which was a platinum plate electrode and a reference electrode which was a saturated calomel electrode (SCE) linked with a Luggin capillary bridge. Potentiodynamic polarization tests were conducted from -0.1 to +0.1 V versus open circuit potential (OCP) at a scanning speed of 0.1667 mV s⁻¹. Electrochemical impedance spectroscopy (EIS) tests were carried out with 0.01 V perturbation amplitude in the frequency ranging from 10⁵ to 10⁻² Hz. Prior to EIS measurements, the OCP was detected for 24 h. All electrochemical measurements in this work were repeated more than three times to ensure the data reproducibility. The electrochemical data tested were fitted by Gamry Echem Analyst (version 6.25).

2.4 Microstructural Characterization

The microstructures of untreated and heat-treated SLM-produced AlSi10Mg samples before and after weight loss tests were characterized using a JSM-7800F (JEOL, Tokyo, Japan) field emission scanning electron microscope (FE-SEM) furnished with energy-dispersive spectrometry (EDS, Oxford Instruments). The size, morphology and area proportion of Si particles were analyzed by the Software of Image Pro Plus (IPP). The phase constituents of untreated and heat-treated samples after heat treatment and weight loss tests were performed by X-ray diffraction (XRD, Bruker D8Advance X-ray diffractometer) with CuK_α radiation (0.15406 nm) at 40 kV and 40 mA. The scanning range of 2 θ was set from 30° to 90°. Lattice constants were evaluated by fitting the data using Rietveld refinement and correcting for instrumental broadening by using LaB₆ (NIST: 660 Å). The software of Jade 5.0 was selected to analyze the data.

3 Results

3.1 XRD Analysis

Figure 1 displays the XRD results of untreated and heat-treated SLM-produced AlSi10Mg samples. Referring to JCPDS patterns of 89-2837, 89-5012 and 01-1192, the main peaks of Al, Si and Mg₂Si are observed. As shown in Fig. 1, the major peaks of the heat-treated samples are the same as in the untreated sample. After heat treatment, the intensities of Si peaks become stronger. Such a phenomenon is related to the precipitation of Si from the Al matrix [37]. The lattice parameters of the Al matrix calculated by analyzing XRD pattern increase from 0.404615 nm for the SLM-produced AlSi10Mg alloy to 0.404865 nm

Fig. 1 XRD patterns of SLM-produced AlSi10Mg and heat-treated counterparts

for the sample heat-treated at 550 °C. Hence, we estimated that the solubility of the Si decreases with the increase in heat treatment temperature. Besides, the peak intensity of Mg_2Si prominently increases with rising temperature of heat treatment, indicating the formation of Mg_2Si via the segregated Si reacting with Mg during heat treatment [50]. The similar results were obtained by Li et al. [29].

3.2 Microstructural Features

The microstructures of the untreated and heat-treated AlSi10Mg samples are presented in Fig. 2. Figure 2a reveals the microstructure of SLM-produced AlSi10Mg. As examined by EDS (Fig. 3), the gray cellular phases are Al matrix and the light fibrous phases are the eutectic Si particles. It could be found that the fibrous Si particles in nanoscale are continuously distributed in the Al matrix [51], which is different from microstructure of cast AlSi10Mg alloy composed of a large number of scattered rod-like and/or claw-like Si particles [45]. By comparing Fig. 2a–d, the microstructures of the samples are gradually coarsened with increasing the heat treatment temperature (i.e., the growth of Si particles). Such a result is in line with the XRD results. In order to quantify their growth behavior during heat treatment, the size distributions, the volume fractions, the sizes and the densities of Si particles for the untreated and heat-treated samples are calculated from at least ten SEM micrographs and the statistical results are summarized in Fig. 4. The majority of Si particles vary from 0.1 to 5 μm in size after heat treatment (Fig. 4a). Meanwhile, the increasing volume fractions of Si particles confirm the precipitation of Si during heat treatment (Fig. 4b). As the heat treatment proceeds, the average size of Si particles increases associated with

Fig. 2 SEM images of SLM-produced AlSi10Mg alloy for **a** untreated and heat-treated at **b** 450 °C, **c** 500 °C, **d** 550 °C for 2 h

Fig. 3 a SEM micrograph and EDS mappings of b Mg, c Al, d Si of SLM-produced AlSi10Mg alloy after heat treatment at 550 °C for 2 h

the reduction in the density number (Fig. 4c). Figure 3 shows the EDS results of SLM-produced AlSi10Mg alloy after heat treatment at 550 °C for 2 h. It can be observed that Mg is more evenly distributed compared with Si. But the Mg content on the Si particles is higher than that in the Al matrix. Al is hardly found in Si particles and vice versa. Such a phenomenon indicates that no Al–Si compounds are formed after heat treatment, which agrees with the XRD results.

3.3 Weight Loss Tests

Figure 5 manifests the weight loss curves for the untreated and heat-treated SLM-produced AlSi10Mg samples immersed in 3.5 wt% NaCl solution for 45 days, indicating that the samples heat-treated at a high temperature exhibit greater weight loss.

Figure 6 displays the SEM micrographs of the untreated and heat-treated SLM-produced AlSi10Mg samples after 45 days immersion. The surface of the untreated SLM-produced AlSi10Mg samples displays a porous cellular morphology and the coarse cellular zone corresponding to the boundary of melt track having the relatively coarser cellular microstructure bears more severe corrosion (Fig. 6a, b), which is attributed to the selectively attack to the Al matrix. Figure 6c–h shows that the cellular Si particles transform

to uniformly distributed Si particles with different sizes in the Al matrix, which is similar to the microstructures of the samples before immersion. It is observed that the dissolution of the Al matrix is inhomogeneous. That is, the Al matrix surrounding the Si particles is prone to be corroded. The analogous exposed Si network after immersion tests was reported by Prashanth et al. [6] and Cabrini et al. [52].

Figure 7 shows the microstructures of longitudinal sections of the samples after 7 days immersion. As shown in Fig. 7a, the corrosion product layer of the untreated sample is very thin and the matrix is nearly undamaged. With increasing the heat treatment temperature, the thickness of corrosion product layers gradually increase and the damage to matrix becomes more severe. Particularly, corrosion is prone to take place in the area of the Al matrix surrounding the large Si particles. For example, as seen in Fig. 7d, severe corrosion is always observed in the areas surrounding the large Si particles. This result confirms the observation in Fig. 6.

3.4 Electrochemical Property

The relatively stable OCPs are acquired after the samples to be immersed in 3.5 wt% NaCl solution for 24 h. Figure 8 shows the potentiodynamic polarization curves to verify the electrochemical process of the untreated and heat-treated

Fig. 4 Statistical analysis of **a** size distribution, **b** volume fraction and **c** size and number density of Si particles as a result of heat treatment

samples in 3.5 wt% NaCl solution at room temperature. The result indicates that all samples have a similar corrosion behavior. Since the corrosion rate is determined by the competition between anode reaction and cathode reaction, the calculation of the corrosion current densities is based on the combination of anodic and cathodic branches of potentiodynamic polarization curves. The fitting results (i.e., corrosion potential and corrosion current density) by using least square method from weak-polarization region (± 70 mV) of potentiodynamic polarization curves are listed in Table 2 and show that the corrosion current density increases and the corrosion potential decreases monotonously for the samples with increasing the heat treatment temperature. It is generally

Fig. 5 Weight loss curves for untreated and heat-treated SLM-produced AlSi10Mg samples after weight loss tests

recognized that the sample with smaller corrosion current density has better corrosion resistance and lower corrosion rate [53]. Therefore, the corrosion resistance of the samples decreases with increasing the heat treatment temperature.

The EIS measurements are shown in the form of Nyquist plots and Bode plots in Fig. 9a–c. As seen from the Nyquist plot (Fig. 9a), it is observed that only a huge single capacitive loop appears for all samples. However, the Bode phase angle plots (Fig. 9c) show a wide plateau from middle frequencies to low frequency. In low-frequency range, the small peaks of the heat-treated samples are observed. This phenomenon is caused by the insufficiently dense corrosion product layers of heat-treated samples, which act as finite diffusion layers [45]. Hence, the equivalent circuit with two constant phase elements, as shown in Fig. 9d, is employed to analyze the electrochemical impedance spectra data [54]. In the equivalent circuit, solution resistance (R_s), film resistance (R_f), charge transfer resistance (R_{ct}), cotangent-hyperbolic diffusion impedance (O) and two constant phase elements (CPE_1 and CPE_2) are included [55]. The use of a constant phase element is considered to be the electrical double layer due to the inhomogeneous electrode surface [56, 57]. Cotangent-hyperbolic diffusion impedance represents the finite length diffusion [58, 59]. For the heat-treated alloys, the thick corrosion product layer was formed on the electrode surface. During the corrosion process, the dissolved oxygen as a depolarizing agent needs to go through the thick corrosion product layer before reaching the electrode reaction interface. The diffusion of cathode depolarizing agent through the thick corrosion product layer is shown O in the impedance response. Table 3 reveals the results after fitting the electrochemical impedance spectra. The Chi-squared values of fitting results are lower than 3×10^{-3} , indicating the superior grades of fitting results. R_f and R_{ct} represent the film resistance on the metal surface and charge transfer resistance, respectively [60–62]. As seen from Table 3, the

Fig. 6 SEM micrographs of SLM-produced AlSi10Mg samples after 45 days immersion for **a, b** untreated and heat-treated at **c, d** 450 °C, **e, f** 500 °C, **g, h** 550 °C for 2 h

Fig. 7 Longitudinal section micrographs of SLM-produced AlSi10Mg samples after 7 days immersion for **a** untreated and heat-treated at **b** 450 °C, **c** 500 °C, **d** 550 °C for 2 h

Fig. 8 Potentiodynamic polarization curves of SLM-produced AlSi10Mg alloys and heat-treated counterparts in 3.5% NaCl solution at room temperature (E potential; i current density)

decreasing trends of R_f and R_{ct} with the corresponding heat treatment temperature indicate that the corrosion resistance of the samples progressively decreases as the heat treatment temperature elevates.

Table 2 Fitting results by using least square method from weak-polarization region (± 70 mV) of potentiodynamic polarization curves

Sample	Corrosion current density, i_{corr} ($\mu\text{A cm}^{-2}$)	Corrosion potential, E_{corr} (V)
As-SLMed	$0.07 (\pm 0.014)$	$-0.69 (\pm 0.013)$
Treated at 450 °C	$0.11 (\pm 0.063)$	$-0.72 (\pm 0.011)$
Treated at 500 °C	$0.66 (\pm 0.086)$	$-0.73 (\pm 0.012)$
Treated at 550 °C	$2.05 (\pm 0.147)$	$-0.74 (\pm 0.009)$

4 Discussion

4.1 Effect of High Temperature Heat Treatment on Particle Size of Si

During the process of selective laser melting, due to the high cooling solidification process, the sustainable growth of α -Al phase results in the increase in Si content in the residual liquid phase [63, 64]. The high concentration of Si triggers the generation of the eutectic Si phase during the later period of solidification because of the cooperative growth mechanism between Si and Al [65]. Based on the XRD results (Fig. 1), the reject of Si from oversaturated

Fig. 9 Electrochemical impedance spectra of SLM-produced AlSi10Mg alloys and heat-treated counterparts in 3.5% NaCl solution at room temperature: **a** Nyquist plots; **b, c** bode plots; **d** equivalent circuit diagram

Table 3 Fitting results of electrochemical impedance spectra for SLM-produced AlSi10Mg alloys and heat-treated counterparts in 3.5 wt% NaCl solution at room temperature (n_1 , n_2 index that represents the deviation from a pure capacitor of CPE)

Sample	$CPE_1 \times 10^{-6}$ ($\Omega^{-1} \text{cm}^{-2} \text{S}^{-n_1}$)	n_1	R_f (kΩ cm²)	$CPE_2 \times 10^{-4}$ ($\Omega^{-1} \text{cm}^{-2} \text{S}^{-n_2}$)	n_2	R_{ct} (kΩ cm²)	$O \times 10^{-4}$ ($\Omega \text{cm}^2 \text{S}^{-0.5}$)
As-SLMed	10.0 (± 0.13)	0.8	141.1 (± 11.91)	0.3 (± 0.03)	0.8	114.0 (± 11.91)	—
Treated at 450 °C	12.6 (± 0.21)	0.9	31.8 (± 2.94)	1.9 (± 1.52)	1.0	14.7 (± 1.51)	5.1 (± 0.63)
Treated at 500 °C	16.8 (± 0.17)	0.9	7.9 (± 0.49)	11.5 (± 1.86)	1.0	4.7 (± 0.53)	60.4 (± 7.51)
Treated at 550 °C	18.1 (± 0.29)	0.8	6.9 (± 0.32)	15.4 (± 2.13)	1.0	1.3 (± 0.21)	61.4 (± 6.93)

Al matrix takes place during heat treatment. Combining the results in Fig. 2, it is found that the sizes of Si particles gradually increase with increasing the heat treatment temperature, which reduces the density of Si particles (Fig. 4). With the increase in heat treatment temperature, the increasing original driving force gives rise to the reject of Si from the Al matrix and a thermally activated growth of Si phase. Similar results showing that the size of Si particles grows up with increasing the heat treatment temperature are reported by Li et al. [66]. With coarsening of Si particles, the number density of Si particles decreases, attributing to the Ostwald ripening mechanism, which

indicates that the formation of large particles is at the cost of small ones [66].

4.2 Mechanism of Si Particle Size on Corrosion Process

During the immersion, the Cl^- ions in 3.5 wt% NaCl solution destroy nascent oxidation film. Then, the reaction interface forms between matrix and electrolyte; it facilitates the corrosion of the Al matrix. Therefore, the Si networks or eutectic Si particles in SLM-produced AlSi10Mg alloys naturally act as cathodes to facilitate the selective corrosion of the anode

Al matrix. This mechanism could explain the phenomenon of sharply corroded Al matrix and nearly intact Si particles in Fig. 6. The untreated counterpart has an intact and ultrafine Si network, which contributes to the small cathode and large anode in the microstructure. The micro-galvanic couples in the microstructure are available to quickly form compact films for the inhibition of further corrosion [45, 67, 68]. As such, the existence of continuous Si networks impedes the direct contact of the subsequent metal matrix and electrolyte. The inhibiting effect imposes the restrictions on the transferring rate of Al^{3+} ions derived from corrosion surface to electrolyte, contributing to the decline of the corrosion rate (Tables 2, 3). However, as seen from Figs. 6 and 7, larger pits, thicker layer of corrosion products and worse intactness of matrix are observed with increasing the heat treatment temperature. As seen in Figs. 2 and 3, the cathode Si particles intensively grow and distribute randomly after heat treatment, contributing to the huge cathodes during corrosion [69, 70]. Because the growth size of Si particles is ascribed to Si reject from the oversaturated Al matrix, the activity of the Al matrix which as the anode depleted of Si is increased with the increase of heat treatment temperature. These isolated Si particles are no longer interconnected and effectively accelerate the corrosion of the subsequent metal matrix. Consequently, the anode Al matrix surrounding the large cathode is prone to be dissolved. Therefore, it is impossible to form compact films to protect the metal matrix [71]. The intactness of the formed film on metal surface is unsatisfactory corresponding to progressively decrease in R_f and R_{ct} because of the rapid corrosion of the subsequent metal matrix in the electrolyte in the preliminary stage of corrosion. Therefore, the film formed on the heat-treated sample is prone to be destroyed. Such a result leads to a downside of the corrosion resistance of the samples with the increase in heat treatment temperature. This is attributed to a faster corrosion rate of the experimental alloy. Hence, the degradation of the corrosion resistance leads to the increase in the mass loss of the samples (Fig. 5). In the meantime, the larger Si particles lead to the worse property of the film. As a result, the pitting frequently takes place at the surrounding area of Si particles, thereby forming large and deep corrosion pits [72]. The resultant pits expand rapidly and connect together, which leads to a more severe corrosion on the surface of the samples. Therefore, these results demonstrate that the corrosion resistance of the SLM-produced AlSi10Mg alloy degrades under the conditions of heat treatment at 450–550 °C, which results from the growth of Si particles.

5 Conclusion

The corrosion behavior of the AlSi10Mg alloys manufactured by selective laser melting (SLM) and the heat-treated counterparts at 450–550 °C has been systematically

investigated by weight loss tests, electrochemical measurements and detailed microstructural characterization. A continuous network of eutectic Si is formed in the SLM-produced AlSi10Mg alloy due to the fast cooling rate. After heat treatment, the Si becomes isolated ones with larger size and lower density. The results reveal that untreated sample possesses the best corrosion resistance in 3.5 wt% NaCl solution, which indicates that the formation of continuous Si network impedes the contact of the subsequent metal matrix and electrolyte and further restricts the transferring rate of Al^{3+} ions derived from electrode surface to electrolyte. The isolated Si particles generated during heat treatment lead to more severe corrosion in the surrounding area of the Al matrix. Therefore, the corrosion resistance of the samples degrades with the growth of Si particles, which is represented in the greater corrosion current density, lower corrosion potential, lower film resistance and charge transfer resistance for the heat-treated samples. As a result, larger pits, thicker layer of corrosion products and worse intactness of matrix are observed in the heat-treated samples after corrosion.

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