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Size dependence of microstructure of AlSi10Mg alloy fabricated by selective laser melting

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A B S T R A C T

In order to investigate the size dependence of microstructure of the AlSi10Mg alloy fabricated by selective laser melting (SLM) combined with a powder bed technique, plate-shaped AlSi10Mg alloy samples with various widths (ranging from approximately 10 mm to 0.3 mm) were produced in this study. All the fabricated samples exhibited characteristic microstructural morphologies consisting of melt pools with columnar α-Al grains surrounded by fine eutectic Si particles, whereas their sample sizes had a relatively small effect on the texture and average grain size of the α-Al matrix. However, the formation of fine Si precipitates inside the columnar α-Al grains was observed more often for the smaller-sized samples, which could be a possible dominant contributor to the observed softening of the sample by reducing sample size. The obtained results were utilized for discussing the size dependence of the strength of the SLM-manufactured porous alloy samples.

1. Introduction

Artificial cellular metals and alloys are often called "porous metals (metal foams)". They exhibit various unique physical properties such as low apparent density, high impact-energy absorption, low thermal conductivity, high gas permeability, and high specific stiffness [1–5]. Thus, these materials can be potentially used in many areas, which include lightweight structures, shock damping/absorption, thermal insulation, catalyst support, and biomedical implants. In particular, lightweight porous Al alloys are characterized by compressive absorption properties, high deformability, relatively low density, and simple processing routes [6,7]. Therefore, they can be considered promising candidates for the structural parts of the crumple zones of automobiles [3]. The energy absorption capacity of these porous metals can be optimized by varying the shape, size, and distribution of their pores.

Additive manufacturing [8] is one of the promising routes of manufacturing open-cell porous materials with a controlled structure. In particular, various powder bed fusion (PBF) processes utilize either laser or electron beams to melt and fuse powder metals or alloys and thus represent the most widely used additive manufacturing technique for fabricating metal components with complex shapes. These processes include the commonly used selective laser melting (SLM), selective laser sintering, direct metal laser sintering, electron beam melting, and selective heat sintering methods [9,10]. In particular, the SLM process [9,10] allows fabrication of porous metals with cellular lattice structures [11]. However, porous Al alloys fabricated by SLM process exhibit the unstable compressive stress characterized by a series of peaks and troughs [12,13]. Hence, the compressive properties of the SLM-manufactured porous Al alloys cannot satisfy the requirements for the structural parts of crumple zones since the stable and highly reliable compressive strength (plateau stress) must be required to achieve high energy absorption [7]. In order to improve the mechanical performance of porous Al alloys, many researchers have intensively studied the mechanical properties and microstructures of bulk Al alloys produced by SLM [10,14–16]. While applying the results obtained in these works to the SLM-fabricated porous Al alloys might be considered a valid approach, limited studies on the microstructure of the walls of porous Al alloys with cellular lattice structures were reported in the literature [12,17]. In particular, no microstructural differences (related to their mechanical properties) between the relatively large bulk (centimeter-sized) and lattice-structured (submillimeter-sized) samples were observed. Therefore, it is necessary to elucidate the role of the resulting sample surface in the microstructural evolution of porous Al alloys during the SLM process (which includes local melting and rapid solidification via laser beam irradiation).

In the present study, plate-shaped samples of AlSi10Mg alloy with various widths ranging from 0.1 mm to 10 mm were fabricated by SLM process. In order to identify the effect of sample size on the microstructure of the SLM-fabricated AlSi10Mg alloy, their microstructural characteristics were investigated and compared with the constitute

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Table 1
A chemical composition of the studied AlSi10Mg alloy (wt%).

		Si	Fe	Cu	Mn	Mg	Ni	Zn	Pb	Sn	Ti
Nominal		9.0–11.0	≤ 0.55	≤ 0.05	≤ 0.45	0.20–0.45	≤ 0.05	≤ 0.10	≤ 0.05	≤ 0.05	≤ 0.15
ICP analyzed	Powder	10.73	0.42	–	–	0.17	–	–	–	–	–
	As-built	10.77	0.40	–	–	0.18	–	–	–	–	–

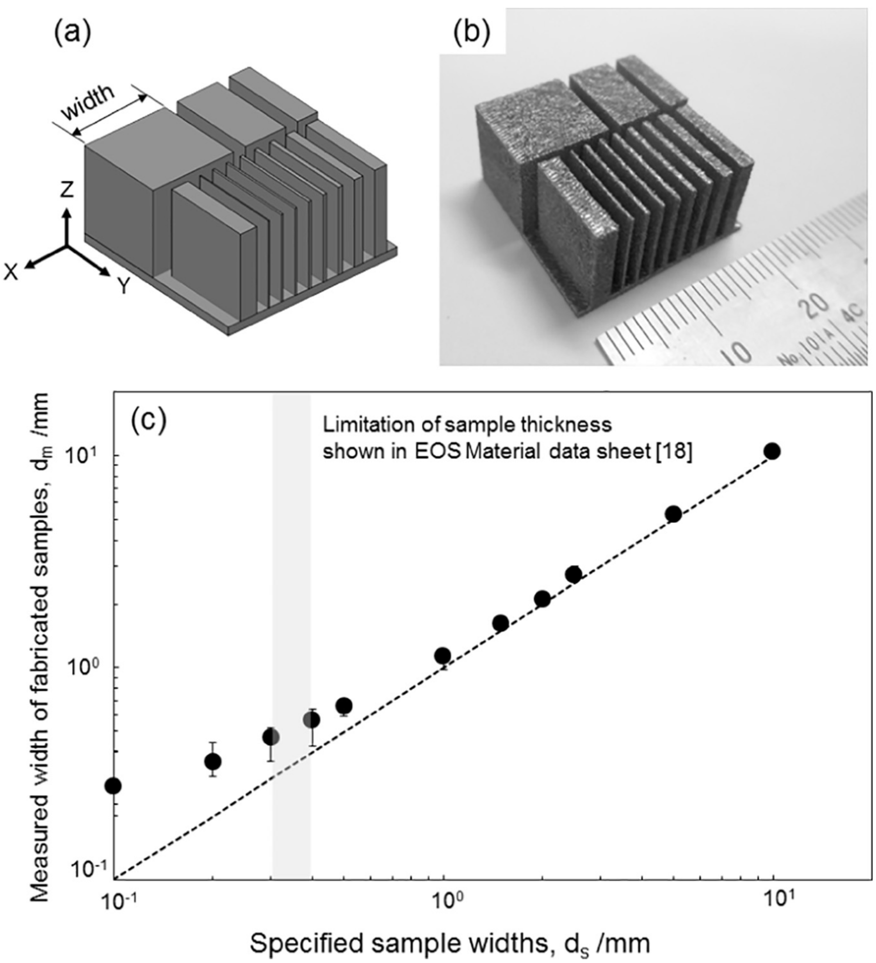

Fig. 1. (a) Schematic and (b) actual photograph of the alloy sample fabricated in this study. (c) A relationship between the specified (d_s) and measured widths (d_m) of the plate-shaped samples.

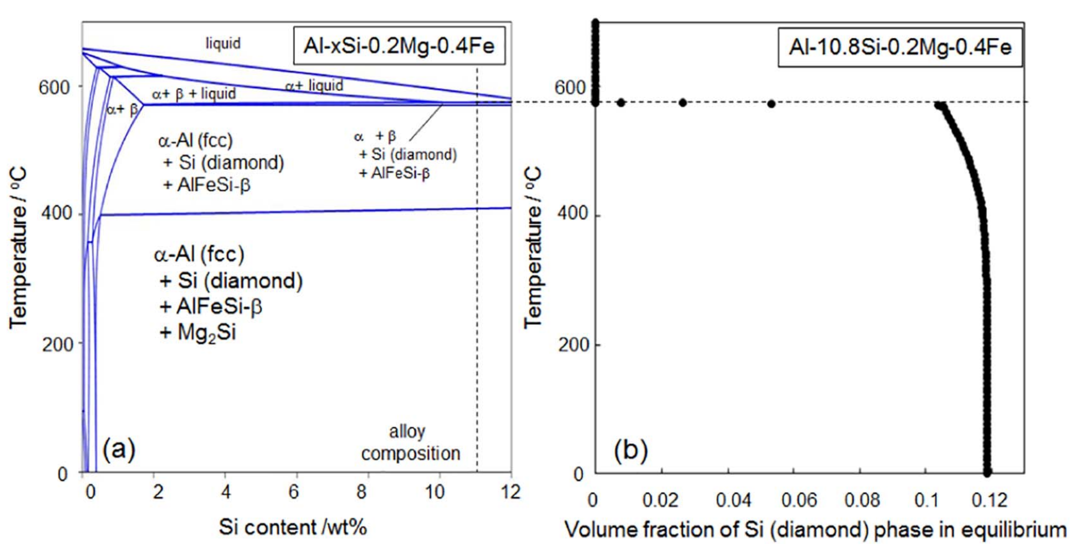

Fig. 2. (a) Vertical section of Al-0.2 Mg-0.4Fe (wt%) in Al-Si-Mg-Fe quaternary phase diagram and (b) calculated volume fraction (in equilibrium) of Si (diamond) phases in Al-10.8Si-0.2 Mg-0.4Fe alloy at various temperatures.