Materials Characterization 130 (2017) 237–242

Contents lists available at ScienceDirect

Materials Characterization

journal homepage: www.elsevier.com/locate/matchar

Investigation of three-dimensional morphology changes of the eutectic Si particles affected by trace P and Sr in Al-7%Si cast alloys by means of synchrotron nano-tomography

S. Furuta[a,*], M. Kobayashi[b], K. Uesugi[c], A. Takeuchi[c], T. Aoba[b], H. Miura[b]

[a] Department of Mechanical Engineering, Graduate School of Engineering, Toyohashi University of Technology, Toyohashi 441-8580, Japan
[b] Department of Mechanical Engineering, Toyohashi University of Technology, Toyohashi 441-8580, Japan
[c] Japan Synchrotron Radiation Research Institute, Hyogo 679-5198, Japan

ARTICLE INFO

Keywords:
Solidification microstructure
Eutectic solidification
Three-dimension
Tomography
Synchrotron radiation
Aluminum-silicon alloys

ABSTRACT

The difference of the three-dimensional morphology of eutectic Si particles has been investigated in Al-7mass%Si cast alloys changing trace P and Sr contents by means of synchrotron radiation nano-tomography with Zernike phase plate. Fibrous Si morphology aligning in the same direction is observed in Al-7mass%Si-2ppmP alloy. Si particles in Al-7mass%Si-8ppmP-42ppmSr are not only of a plate-like morphology but also a coral-like and a fibrous morphology. All of the Si particles have either a fibrous morphology or a coral-like morphology in Al-7mass%Si-9ppmP-277ppmSr. It is realized that a solidification sequence affected by trace P and Sr contents changes the three-dimensional morphology of Si particles.

1. Introduction

Hypoeutectic Al-Si alloy, which possess an excellent balance of mechanical properties and castability, is the most widely used material for automobile parts in order to reduce car weight. Generally, a refinement treatment of eutectic Si particles is necessary to improve the mechanical properties, because large plate-shaped Si particles degenerate elongation and ductility. A chemical modification, being the addition of trace Sr addition, is the most common method to refine eutectic Si particles in hypoeutectic Al-Si alloys [1–5]. This trace Sr addition suppresses the formation of AlP [6,7] which functions as the nuclei of the Si phase. In contrast, if impure P content is reduced, the modification of eutectic Si particles occurs naturally [8]. In fact, the mechanical properties of Sr modified and naturally modified cast alloys are slightly different.

Fig. 1 indicates stress-strain curves in Al-7mass%Si-8ppmP-42ppmSr, Al-7mass%Si-9ppmP-277ppmSr and Al-7mass%Si-2ppmP cast alloys. The tensile strength of naturally modified Al-7mass%Si-2ppmP alloy is higher than that of Sr modified Al-7mass%Si-8ppmP-42ppmSr and Al-7mass%Si-9ppmP-277ppmSr alloys. Elongation to failure in Al-7mass%Si-2ppmP alloy is also largest among them. The microstructures of these alloys look similar as can be seen in Fig. 2. Actually, the average of secondary dendrites arm spacing (SDAS) which is measured in more than fifty secondary dendrites arms in this study, is almost the same and is listed in Table 1. Furthermore, similar size of Vickers marks are confirmed in α-dendrite (i.e. α-aluminum phase) of those alloys in Fig. 2. The Vickers hardness (the average of 10 measurement points of dendrites (98 mN, 10 s)) in these alloys is listed in Table 1. Very little difference is recognized in the Vickers hardness, so no alloys have the advantage in the α-dendrites. These facts suppose that the difference of mechanical properties is caused by morphology and spatial distribution of eutectic Si particles. It is very important to understand the effects of the eutectic Si particles morphology on mechanical properties in hypoeutectic Al-Si alloys. The morphology of eutectic Si particles in Al-Si cast alloy has been investigated and characterized by a deep-etching method [9,10] and the serial sectioning of focused ion beam technique [11,12]. Furthermore, the solidification microstructures of Al-7mass%Si alloy, which is modified by trace P and Sr contents, has recently been reproduced by Eiken et al. by means of a three-dimensional phase-field simulation linked to Calphad databases [13]. Their simulation suggests slightly different Si particle morphology depending on the solidification process affected by trace P and Sr.

Meanwhile, the resolution of X-ray computed tomography (CT) utilizing synchrotron radiation has been improved in recent years. Spatial resolution of 1 μm has been achieved in projection type X-ray CT [14–20] in which a quasi-parallel beam is used for illumination. However, the size of eutectic Si particles in the sample of this study is typically smaller than 1 μm. Therefore, magnified imaging, that is nano-

* Corresponding author at: Department of Mechanical Engineering, Graduate School of Engineering, Toyohashi University of Technology, 1-1 Tempaku-cho, Toyohashi, Aichi 441-8580, Japan.
E-mail address: furuta@str.me.tut.ac.jp (S. Furuta).

http://dx.doi.org/10.1016/j.matchar.2017.06.009
Received 29 December 2016; Received in revised form 22 May 2017; Accepted 6 June 2017
Available online 07 June 2017
1044-5803/ © 2017 Published by Elsevier Inc.

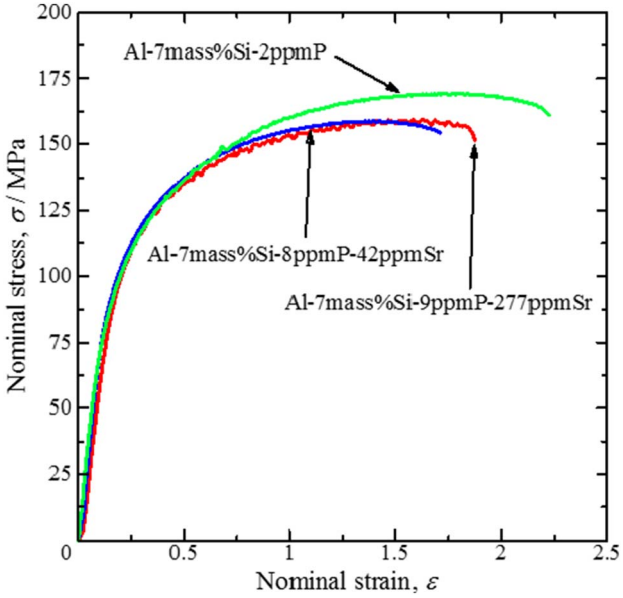

Fig. 1. Stress-strain curves in Al-7mass%Si-8ppmP-42ppmSr, Al-7mass%Si-9ppmP-277ppmSr and Al-7mass%Si-2ppmP cast alloys.

tomography [21], is necessary for improving spatial resolution. Imaging (full field) microscope CT [22–25] and holotomography [26,27] have been developed as magnified imaging techniques. We utilize the imaging microscope CT in this study. With regard to the imaging of Al-Si alloys, it is hard to distinguish silicon from aluminum using X-ray absorption, as the difference in the atomic number between aluminum and silicon is only one. In the case of quasi-parallel illumination, phase contrast imaging is available to enhance contrast on the aluminum and silicon interface [14–16] by simply adjusting the sample-to-detector distance. However, phase contrast imaging does not work in the imaging microscope CT utilizing X-ray condensing optical system. Therefore, with applying the Zernike phase plate to an imaging microscope CT, which is often utilized for imaging in the bio science field [25], the three dimensional morphology of fine eutectic Si particles was investigated in Al-7mass%Si cast alloy to clarify the effect of trace P and Sr contents on Si morphology through solidification in this study.

2. Material and Experimental Methods

Al-7mass%Si alloys with controlled P and Sr content were prepared referring to a simulation reported by Eiken et al. High purity Al (99.99%) and high purity Si (99.99%) were used as raw materials. The weighted raw materials were melted in a graphite crucible at 993 K using an electrical resistance furnace. Trace P was controlled by the addition of a Cu-8mass%P master alloy, after the raw materials of Al and Si had melted. In the case of the P less sample, a tough pitch copper was added so that the Cu content corresponds to the P controlled sample. The molten metal was held at 793 K for 1.8 ks. Sr was added by throwing Al-10mass%Sr master alloy into the molten metal. Hydrogens in the molten metal were degassed by hexachloroethane and then the molten metal was directly cast into a steel mold pre-heated at 473 K. After the casting, the chemical compositions of the cast alloys were detected by inductively coupled plasma atomic emission spectroscopy (ICP-AES). The results were Al-7mass%Si-2ppmP, Al-7mass%Si-8ppmP-42ppmSr, and Al-7mass%Si-9ppmP-277ppmSr. Note that the copper contents of the three samples were 0.31%, 0.22% and 0.23%, respectively. As mentioned in the introduction, the Vickers hardness of α-dendrites is of little difference in these alloys. The effect of trace copper content on α-dendrite strength is negligible. Small needlelike specimens with the section of about 40 μm × 40 μm for imaging type X-ray CT were prepared by manual polishing from the center of the ingots. A sample sheet, which was cut from the center of an ingot, was polished by emery papers to a thickness of 40 μm, with fixing the sheet sample on an acrylic resin plate (t = 5 mm) by glue. After polishing, the sheet

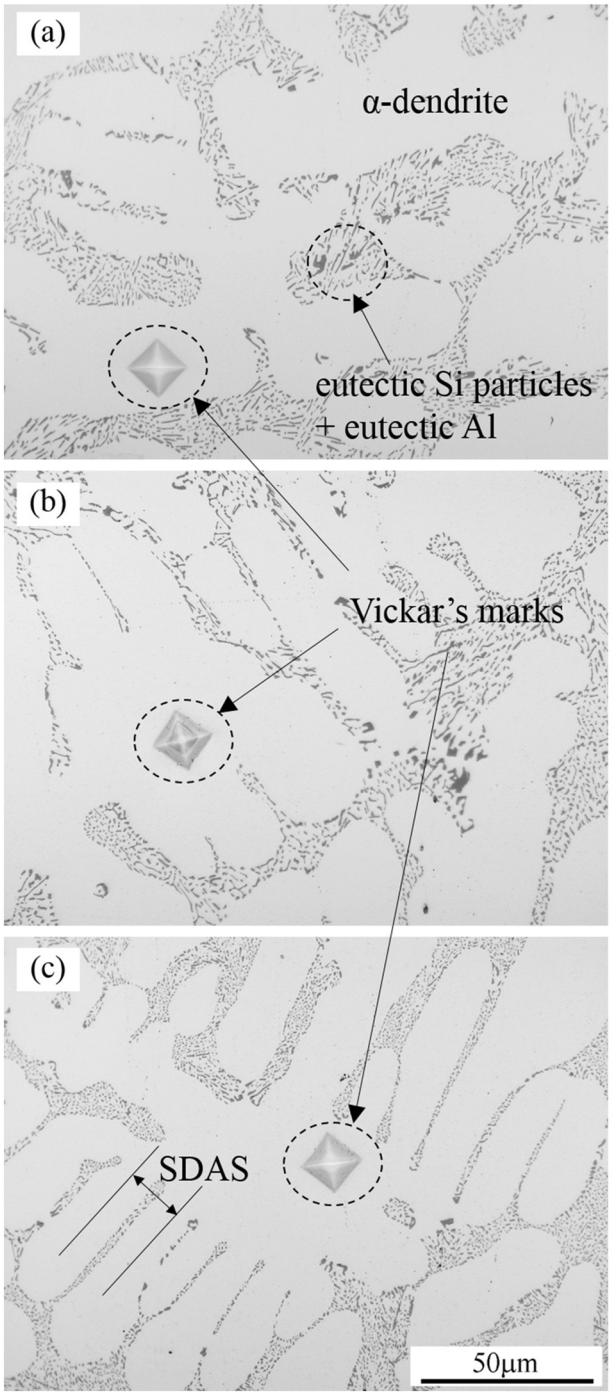

Fig. 2. Optical micrograph; (a) Al-7mass%Si-2ppmP cast alloy, (b) Al-7mass%Si-8ppmP-42ppmSr cast alloy and (c) Al-7mass%Si-9ppmP-277ppmSr cast alloy.

Table 1
Measured secondary dendrite arm spacing (SDAS) and Vickers hardness on α-aluminum phase (α-dendrite) in the cast alloys in this study.

	SDAS[μm]	HV (α-dendrite)
Al-7mass%Si-2ppmP	17.7	55.3
Al-7mass%Si-8ppmP-42ppmSr	17.9	53.8
Al-7mass%Si-9ppmP-277ppmSr	16.4	55.8

Download English Version:

https://daneshyari.com/en/article/5454711

Download Persian Version:

https://daneshyari.com/article/5454711

Daneshyari.com