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The effects of mischmetal, cooling rate and heat treatment on the eutectic Si particle characteristics of A319.1, A356.2 and A413.1 Al–Si casting alloys

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Abstract

The effects of mischmetal, cooling rate and heat treatment on the eutectic Si particle characteristics of A319.1, A356.2 and A413.1 Al–Si casting alloys were investigated and recorded for this study. Mischmetal was added to the alloys in the form of Al–20% mischmetal master alloy to produce four levels of mischmetal addition (0, 2, 4 and 6 wt%). The alloys were also modified with strontium (∼250 ppm) to study the combined modification effect of Sr and mischmetal at both high and low cooling rates corresponding to dendrite arm spacings of ∼40 and 120 μm, respectively. The alloys were subjected to solution heat treatment (495 °C/8 h for A319.1 and A413.1 alloys, and 540 °C/8 h for A356.2 alloy) to investigate its effect on the eutectic Si particle morphology.

An optical microscope-image analyzer system was used to measure the characteristics of eutectic Si particles such as area, length, roundness ratio and aspect ratio, in order to monitor the modifying effect of mischmetal, as well as the combined modification effect of mischmetal and Sr. For each alloy sample examined, the Si particle characteristics were measured over an area of 50 fields and the average particle characteristics were thus determined.

The eutectic Si particle measurements revealed that partial modification was obtained with the addition of mischmetal while full modification was achieved with the addition of Sr in the as-cast condition, at both high and low cooling rates. The interaction between Sr and mischmetal was observed to weaken the effectiveness of Sr as a Si particle-modifying agent. This effect was particularly evident at the low cooling rate.

During solution heat treatment, the eutectic Si particles in the non-modified alloys underwent rapid coarsening, otherwise known as Ostwald ripening, whereas those in the Sr-modified alloys exhibited a high spheroidization rate. The coarsening was evidenced by an increase in the thickness of the Si particles, clearly observed in the A356.2 alloy at both cooling rates. In the alloys containing mischmetal, the presence of this mixture of rare earth elements reduced the coarsening of the Si particles slightly.

Keywords: Al–Si cast alloys; Sr modification; Mischmetal addition; Cooling rate; Heat treatment; Eutectic Si particle characteristics

1. Introduction

Aluminum–silicon (Al–Si) cast alloys are fast becoming the most popular commercial aluminum alloys being used in the automotive industry mainly because of their high strength-to-weight ratio, high castabililty, high corrosion and wear resistance, as well as for their high tensile, impact and fatigue properties after an adequate heat treatment process.

The mechanical properties attainable in Al–Si alloys are controlled by the chemical composition of the alloy, i.e. by its Si, Mg, and Cu content, by the presence of impurities such as iron, and by the presence of such casting defects as porosity, inclusions, etc. The solidification conditions (or cooling rate) and heat treatment applied are also significant contributing factors [1,2].

The mechanical properties of the Al–Si alloys depend to a great extent on the size and morphology of the eutectic Si particles. Under normal cooling conditions, Si particles are present as coarse acicular needles. The needles act as crack initiators and weaken the mechanical properties significantly. The addition of controlled amounts of such elements as Sr, Na, Ca or mischmetal (a mixture of rare earth metals) to the melt prior to casting alters

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Table 1
Chemical compositions of commercial grade 319, 356 and 413 Al–Si casting alloys used for this study

Alloy	Element (wt %)								
	Si	Fe	Cu	Mg	Mn	Ti	Ni	Zn	Al
A319.1	5.57	0.151	3.45	0.02	0.001	0.138	0.004	0.008	Balance
A356.2	6.99	0.139	0.071	0.352	<.0005	0.148	0.0061	0.006	Balance
A413.1	12.36	0.705	0.276	0.074	0.260	0.127	0.0877	0.11	Balance

the morphology of the Si particles from a brittle acicular form to a fine fibrous form, providing a well-modified eutectic structure through a melt treatment process termed "modification". As a result, a considerable improvement in the tensile properties of the alloy may be obtained [3].

An adequate solution heat treatment process, if applied to Al–Si alloys, could lead to a significant improvement in the eutectic Si particle morphology. During solution treatment, the eutectic Si particles undergo shape perturbations. The particles are fragmented into small segments, then begin to spheroidize and finally coarsen, the high solution temperature and/or prolonged solution time providing assistance for the dissolution of smaller Si particles into the larger ones due to the Ostwald ripening phenomenon. In recent years, chemical and thermal modifications have been used together to produce the desired casting properties [4–6].

The use of Na and Sr as modifying agents for Al–Si alloys is well-established. Recently, however, considerable interest was focused on the use of mischmetal as a modifier for these alloys [7–10]. Mischmetal (MM) is a combination of rare earth metals (Ce, La, Pr and Nd), and has been reported to act as a Si particle modifier in Al–Si alloys [11]. Sharan and his co-workers [7,12–14] made a study of the modification effect of rare earth additions in hypoeutectic and hypereutectic Al–Si alloys. They observed that the addition of rare earth metals to hypoeutectic Al–Si alloys in amounts of up to 0.2% led to the refinement of the primary α-aluminum and the eutectic structure. Ye et al. [8] reported that a reliable and persistent eutectic modification effect may be obtained with the addition of rare earths. Chang et al. [15] investigated the refinement of the cast microstructure of hypereutectic Al–Si alloys through the addition of rare earth metals in the form of mischmetal. They observed that a simultaneous refinement of both primary silicon and eutectic silicon was obtained. In addition, mischmetal is known to have the capacity for overcoming problems such as hydrogen pick-up and fading associated with the use of strontium [8,16].

This study was carried out in order to investigate (a) the effect of mischmetal as a modifier, (b) the combined effect of Sr and mischmetal, and (c) the effect of cooling rate and solution heat treatment on the size and morphology of eutectic Si particles in Al–Si alloys. Three commercially popular casting alloys were selected, namely, A319.1, A356.2 and A413.1 alloys, where the effects of Sr, mischmetal and cooling rate on the eutectic Si particle characteristics were incorporated by using non-modified and Sr-modified alloys containing a range of mischmetal additions (0, 2, 4 and 6 wt%), and employing two cooling rates which provided dendrite arm spacing (DAS) values of 40 and 120 μm, corresponding to high and low cooling rate conditions, respectively. The silicon particle characteristics were measured in both as-cast and solution heat-treated samples of castings corresponding to the various A319.1, A356.2 and A413.1 alloy melt compositions.

2. Experimental procedures

Alloys A319.1, A356.2 and A413.1, received in the form of 12.5 kg ingots, were used for the present study. The chemical compositions of the alloys are shown in Table 1. The ingots were cut into smaller pieces, cleaned, dried and melted in a silicon carbide crucible of 30-kg capacity, using an electrical resistance furnace. The melting temperature was held at 730 ± 5 °C. The molten metal was degassed using pure dry argon injected into the molten metal by means of a graphite rotary degassing impeller. The degassing time/speed was kept constant at 30 min/150 rpm. After degassing, all melts were grain refined using Al–5% Ti–1% B master alloy.

Mischmetal additions were made to these base alloys using Al–20% mischmetal master alloy, the chemical composition of which is shown in Table 2. Additions were made using a graphite bell immersed into the melt, to obtain four mischmetal levels of 0, 2, 4 and 6 wt%, in order to investigate its effect as a modifier individually, as well as in combination with Sr in the Sr-modified alloys. In the latter case, Sr (∼250 ppm) was added in the form of Al–10% Sr master alloy to the degassed melt using the graphite bell, following which degassing was carried out for 15 min before pouring. Rotation of the degassing impeller ensured a thorough mixing of the additions in the melt, while the duration of degassing provided the necessary dwell time in the melt. A sampling for chemical analysis was also taken for each melt composition that was prepared and poured.

Table 2
Average chemical composition of the Al–20% mischmetal master alloy used for this study

Element	wt%
Ce	10
La	7
Nd	1
Pr	1
Others	1
Al	Balance