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Function of modification and refinement of rapidly solidified master alloy Al–Ti–Sr

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The function of modification and refinement of a master alloy Al–Ti–Sr solidified at cooling rates of 10 $K s^{-1}$ or less and 10^3 $K s^{-1}$ or greater for a hypoeutectic Al–10 wt% Si alloy has been studied. The master alloy Al–Ti–Sr solidified at a cooling rate of 10^3 $K s^{-1}$ or greater presents a more marked function of modification and refinement than that solidified at a cooling rate of 10 $K s^{-1}$ or less, both under the casting condition of a sand mould and a permanent mould. The addition amount of the master alloy is reduced by rapid solidification technology, keeping the same degree of modification and refinement.

1. Introduction

Hypoeutectic Al–Si alloys that exhibit good castability and a high strength-to-weight ratio have been widely applied in the automotive and machinery industries. The mechanical properties of the hypoeutectic Al–Si alloys are strongly dependent on the size, the morphology and the distribution of the eutectic silicon and the primary α-Al present in the microstructures. Modification is one of the most common ways to change the morphology of eutectic silicon from a flake form to a fibrous form. Refinement is one of the most common technologies to refine the dendrite cell and secondary dendrite arm spacing of the primary α-Al.

The modification treatment was first done by Pacz [1] in 1921 using Na and it is used widely in the commercial applications. However, owing to the limited solid solubility of Na in aluminium and a very high vapour pressure, Na is readily volatilized during the modification processes. As a results, the Na recoveries are rather low and sometimes unpredictable, and also the treated melt is subjected to rapid fading [2–4]. Like Na, the addition of Sr promotes the formation of fibrous silicon by retarding the growth rate of silicon [5–7]. The Sr modifier is usually added into molten aluminium alloys using the master alloy Al–Sr.

Ti is one of the most common elements for the refinement of α-Al in aluminium alloys, using the master alloy Al–Ti or Al–Ti–B. It has been found that the master alloy Al–5 wt% Ti–1 wt% B with different structures possesses a different grain refinement efficiency [8].

The subject of this work is to investigate the modification and refinement function of a master alloy Al–Ti–Sr rapidly solidified.

2. Experimental procedure

The hypoeutectic Al–10 wt% Si alloy used in this work was prepared from commercial pure Al and Si using an electric resistance furnace with a graphite crucible. The master alloy Al–Ti–Sr manufactured at different cooling rates was added to molten Al–10 wt% Si alloy at temperatures ranging from 730 to 740 °C. Maintaining the temperature for 10 min, the molten alloy was poured into a permanent mould, and a sand mould for the observation of microstructure.

The master alloy Al–Ti–Sr was made by the following technology: the sponge titanium was added to the molten aluminium in the temperature range 900 °C–920 °C. Maintaining the temperature for 1 h the pure strontium was added to the molten alloy. Keeping the temperature for 20 min the molten alloy was poured into an ingot in the permanent mould and into ribbons in a single-roll melt-spinning apparatus. The cooling rates were 10 $K s^{-1}$ or less and 10^3 $K s^{-1}$ or greater respectively. The Ti and Sr contents in the master alloy were 4.14 wt% and 1.97 wt%, respectively, according to a chemical analysis report. This master alloy is called the Al–4 wt% Ti–2 wt% Sr alloy in this work. The evaluation of the modification rating was on the basis of [9].

3. Results

The microstructures of the master alloy Al–4 wt% Ti–2 wt% Sr made at cooling rates of 10 $K s^{-1}$ or less and 10^3 $K s^{-1}$ or greater are shown in Fig. 1. Fig. 2 shows the relationship between the amount of Sr addition and the modification rate of the Al–10 wt% Si alloy in a sand mould modified with an ingot and a ribbon with the composition Al–4 wt% Ti–2 wt% Sr. Fig. 3 gives the relationship between the amount of Ti addition and the secondary dendrite arm spacing of the alloy in a sand mould modified with an ingot and a ribbon of the master alloy. The microstructures of the alloy in the sand mould modified with 0.05 wt% Sr added in the form of an ingot and 0.03 wt% Sr in the form of a ribbon are shown in Fig. 4. Fig. 5 shows the relationship between the amount of Sr addition and the modification rating of the alloy in the permanent mould added by a different form master alloy

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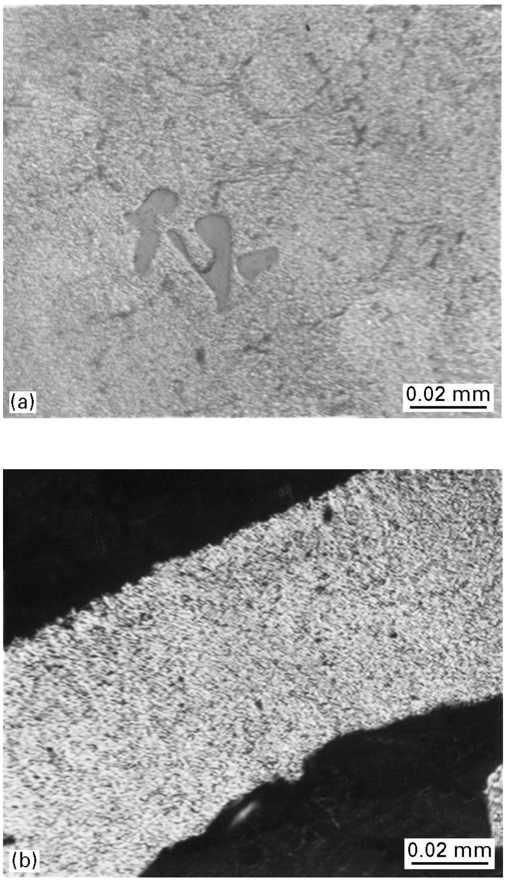

Figure 1 Microstructure of the master alloy Al–4 wt% Ti–2 wt% Sr: (a) cooling rate of 10 K s^{-1} or less; (b) cooling rate of 10^3 K s$^-$ or greater.

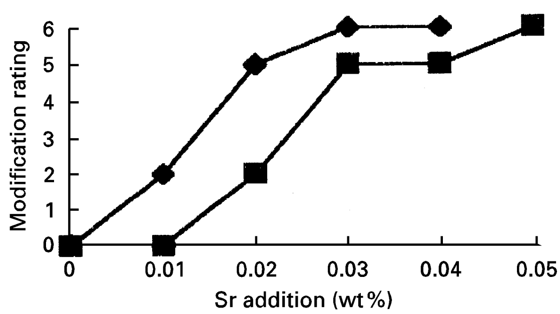

Figure 2 The Sr addition versus the modification rating in the sand mould. (◆), ribbon form; (■), ingot form.

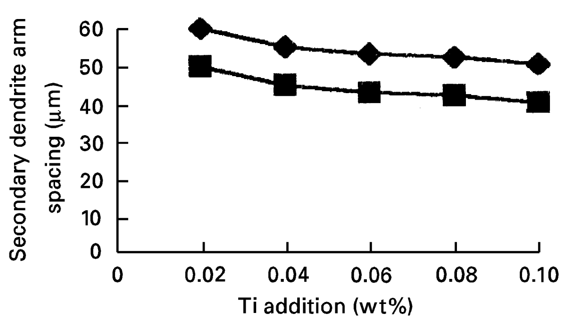

Figure 3 Ti addition versus the secondary dendrite arm spacing. (◆), ingot form; (■), ribbon form.

Al–4 wt% Ti–2 wt% Sr. The relationship between the amount of Ti addition and the secondary dendrite arm spacing of the α-Al in the permanent mould is presented in Fig. 6. Fig. 7 shows the microstructure of the

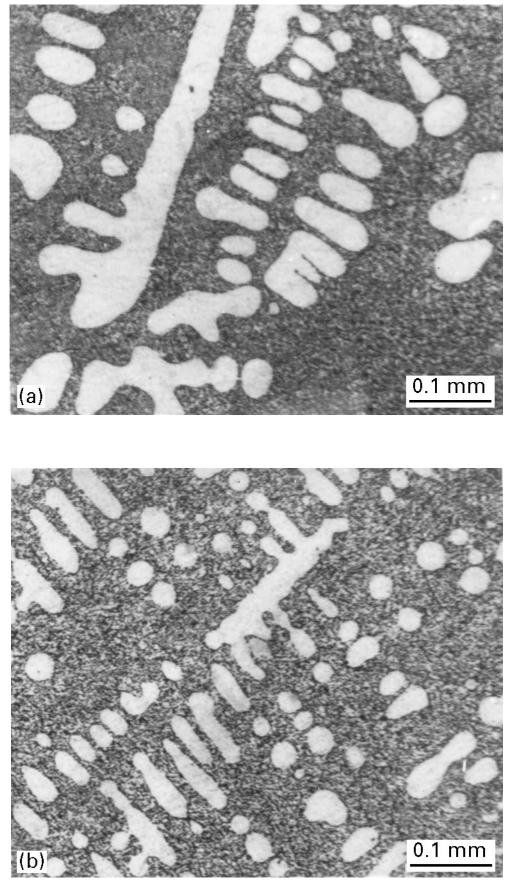

Figure 4 Microstructures of the alloy Al–10 wt% Si in the sand mould: (a) with 0.05 wt % Sr added in the form of ingots; (b) with 0.03 wt% Sr added in the form of ribbons.

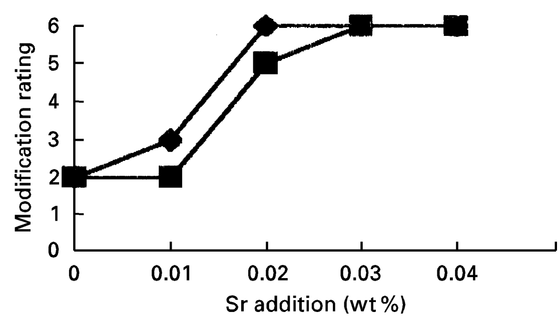

Figure 5 Sr addition versus modification rating in the permanent mould. (◆), ribbon form; (■), ingot form.

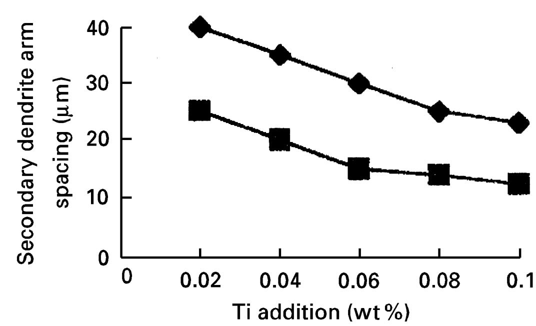

Figure 6 Ti addition versus secondary dendrite arm spacing of α-Al in the permanent mould. (◆), ribbon form; (■), ingot form.

alloy Al–10 wt% Si in the permanent mould. The transmission electron micrograph of the master alloy Al–4 wt% Ti and Al–2 wt% Sr in the form of a ribbon are shown in Fig. 8 and Fig. 9, respectively.

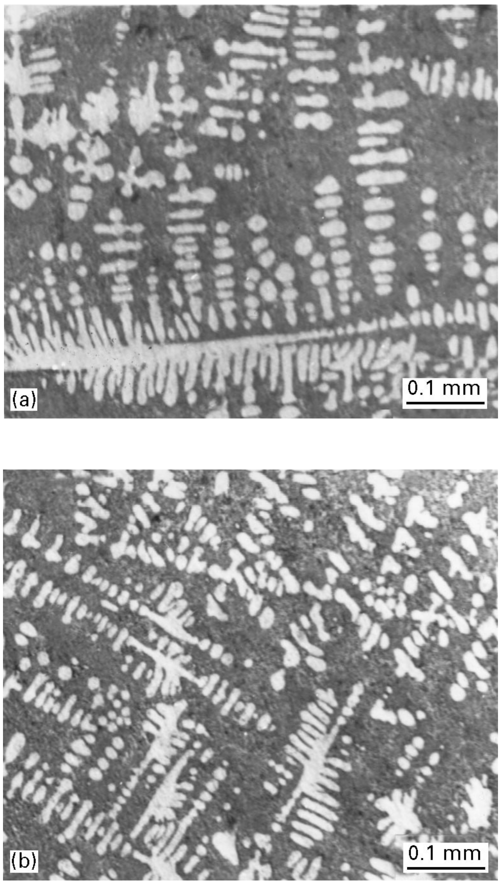

Figure 7 Microstructure of Al–10 wt% Si in the permanent mould; (a) with 0.03 wt% Sr added in the form of ingots; (b) with 0.015 wt% Sr added in the form of ribbons.

Figure 8 Transmission electron micrograph of master alloy Al–4 wt% Ti ribbon.

4. Discussion

The equilibrium Al_3Ti and Al_4Sr phase particles, usually in the form of flakes, are major components in this master alloy Al–4 wt% Ti–2 wt% Sr when the cooling rates is 10 $K\,s^{-1}$ or less, as shown in Fig. 1a. A number of finer compound particles appear in the master alloy at a cooling rate of 10^3 $K\,s^{-1}$ or greater, as shown in Fig. 1b.

Figure 9 Transmission electron micrograph of master alloy Al–2 wt% Sr ribbon.

When the sand mould was used, the modification rate of the 0.03 wt% Sr addition in the form of ribbons is equal to that of the 0.05 wt% Sr addition in the form of ingots. Under the same modification condition, the amount of Sr addition in the master alloy ribbon could be reduced by 40 wt%, compared with that in the ingot, based on Fig. 2 and Fig. 4. It is clear from Fig. 3 and Fig. 4 that the refinement function of the master alloy Al–4 wt% Ti–2 wt% Sr for α-Al has been increased by the rapid solidification technology.

When the permanent mould was used, the refinement function of the 0.02 wt% Ti addition in the form of ribbons is equal to that of 0.08 wt% Ti addition in the form of ingots, as shown in Fig. 6 and Fig. 7. It is clear from Fig. 5 and Fig. 7 that the modification function of the master alloy Al–4 wt% Ti–2 wt% Sr has been increased by the rapid solidification technology.

In order to investigate the modification and refinement function of the master alloy Al–4 wt% Ti–2 wt% Sr, ribbons of the master alloys Al–4 wt% and Al–2 wt% Sr were made at a cooling rate of 10^3 $K\,s^{-1}$ or greater. Fig. 8 shows the metastable intermetallic particles of Ti and Al, similar to the result in [10], found in the master alloy Al–4 wt% Ti. The metastable intermetallic particles are attributed to the increase in the refinement function.

Fig. 9 shows the linear dislocation in the intermetallic compounds of Al and Sr in master alloy Al–2 wt% Sr. As the dislocation density increases, the activation energy increases. When this kind of the master alloy is added to the melt, the activity and diffusion rate of Sr increase, which benefits the absorption of Sr by the silicon crystal. Therefore the modification function of the master alloy ribbon is increased greatly.

5. Conclusions

1. Under the sand-mould casting condition, the addition amount of Sr in the form of ribbons is reduced by 40 wt% compared with that in the form of ingots.

2. Under the permanent-mould casting condition, the refinement function of 0.02 wt% Ti added into the melt in the form of ribbons is equal to that of 0.08 wt% Ti added in the form of ingots.

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