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A new technique to refine pure aluminum by Al–Ti–C mold

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Abstract

A new technique to refine commercially pure aluminum was presented, in which the pure Al melt was cast into an Al–Ti–C mold after flowing through an Al–Ti–C launder in the presence of electromagnetic field, and the refinement effect was also investigated. The experimental results indicate that the chill surface of the ingots can be more effectively refined by Al–5Ti–0.4C mold than by Al–7Si mold. In the presence of electromagnetic field, the forced convection significantly modifies the flow pattern and temperature field, which leads to a substantial amelioration of the surface quality and a marked reduction of the grain size. A uniform and fine equiaxed as-cast structure was obtained when the melt flows through an Al–5Ti–0.4C launder before casting into the Al–5Ti–0.4C mold with electromagnetic vibration, and the main reason for this is that the launder wall and the mold wall become permanent and continuous nucleation substrates from which α-Al grains come forth and depart because of the presence of substantial TiC particles and electromagnetic vibration.
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Keywords: Grain refinement; Aluminum; Al–Ti–C master alloy; Mold

1. Introduction

Grain refinement has been extensively studied in recent years because as-cast structures of alloys have a significant influence on the mechanical and physical properties of finished products. Among several techniques, the application of grain refiner is the most prevalent technique in the metallurgical industry. The addition of grain refiners, usually master alloys containing potent nucleant particles, promotes formation of a uniform equiaxed macrostructure by deliberately suppressing the growth of columnar and twin columnar grains. The finer grain size reduces the size of defects such as microporosity and second-phase particles, producing improved mechanical properties [1–4]. The Al–Ti–B master alloys containing soluble $TiAl_3$ and insoluble TiB_2 particles have been dominant in Al industry for 20 years or so and cover a wide range of chemical compositions [5]. However, problems with Al–Ti–B master alloys can be agglomeration of the borides, blockage of filters, defects during subsequent forming operations and poisoning by certain elements like Zr, V and Cr [6,7]. Al–Ti–C grain refiners containing soluble $TiAl_3$ and insoluble TiC particles are not affected by poisoning by Zr, etc. The process of grain refinement by means of Al–Ti–C is of special importance in some Al alloys for plastic working where the application of Al–Ti–B refiners is inconvenient due to various reasons. Therefore, more attention has been paid to the preparation, microstructure, and performance of Al–Ti–C master alloys [3,8,9].

Besides the application of grain refiner, the application of an electromagnetic field is of great interest in the metallurgical industry [10,11]. In the presence of electromagnetic field, the melt is subject to Lorentz force, so the resultant forced convection significantly modifies the flow pattern and temperature field in the sump and these effects lead to a substantial amelioration of the surface quality and a marked reduction of the grain size. In fact, the presence of forced convection is followed by a decrease in the height of the initial solidified shell and the depth of the sump, which, in turn, must result in a significant decrease in the macrosegregation and the possibility of hot cracking in the production of large size ingot [12]. Therefore, this technique is very important in improving the quality of as-cast ingot.

The objective of the present work is to describe a new technique to refine pure aluminum by using Al–Ti–C mold in the presence of electromagnetic field, and investigate its re-

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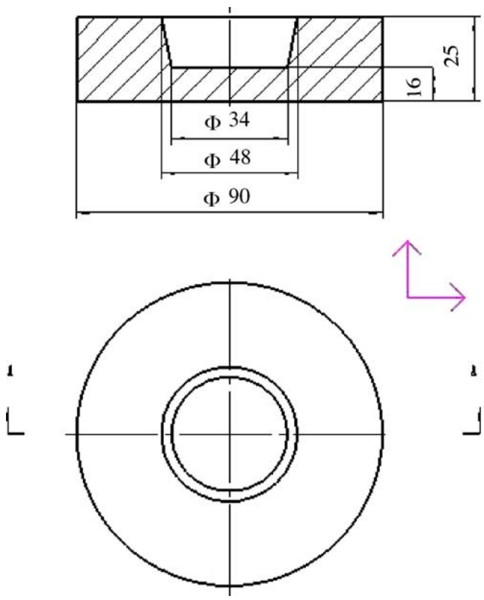

Fig. 1. The mold made of Al–5Ti–0.4C (or Al–7Si) alloy (mm).

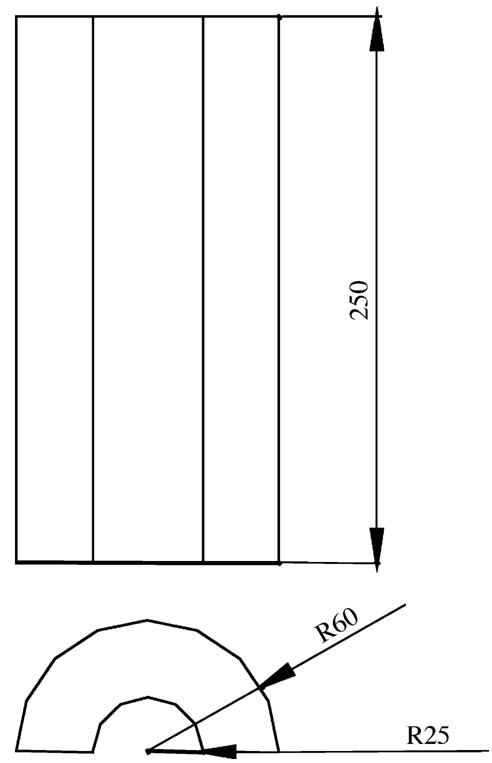

Fig. 2. The launder made of Al–5Ti–0.4C (or Al–7Si) alloy (mm).

finement effect. This innovative technique, which is different from the conventional idea of refinement of Al by using the master alloys, would greatly decrease the amount of master alloys used.

2. Experimental procedures

The master alloy used in this work, Al–5Ti–0.4C (all compositions in wt.%) was prepared using a novel and economic method reported in the literature [13]. Two kinds of cast molds (shown in Fig. 1) were used, and one was made of Al–5Ti–0.4C master alloy, the other was made of Al–7Si alloy. The size of the mold was calculated to ensure that the heat released by the solidification of pure Al melt poured into the mold is not enough for the Al–5Ti–0.4C/Al–7Si mold to melt. Two kinds of launder were also made of Al–5Ti–0.4C master alloy and Al–7Si alloy with the size shown in Fig. 2. It is half of a hollow cylinder, through which the pure Al melt flows to the mold. The casting process is schematically shown in Fig. 3, which consists of a ladle, the Al–5Ti–0.4C (or Al–7Si) launder, the Al–5Ti–0.4C (or Al–7Si) mold, and a 50 Hz electromagnetic field outside both the launder and the mold.

The pure Al was melted in a clay-bonded graphite crucible heated by an electronic resistance furnace at $720 \pm 5\,^{\circ}C$, holding 20 min at the temperature, then part of the melt was directly cast into the Al–5Ti–0.4C (or Al–7Si) mold with or without electromagnetic vibration, while the rest was poured into the mold through the Al–5Ti–0.4C launder. The chill surface and the section of the castings were etched using 0.5% HF solution, and the macrostructures were observed using a KH-2200 high scope optical microscope. All the experiments have been repeated for three times to ensure the reproducibility. The weight of the launder and the mold has been measured to be equal before and after casting, and the surface of them has also been investigated to be same to the interior (Fig. 4), which proves that the launder and the mold have no change before and after casting.

3. Results

Fig. 5 shows the chill surfaces of the pure aluminum ingots directly cast into the Al–5Ti–0.4C (or Al–7Si) mold. Fine grains are uniformly distributed in the chill surface of the ingot poured into the Al–5Ti–0.4C mold, as shown in Fig. 5(b), which is much finer than that cast into the Al–7Si

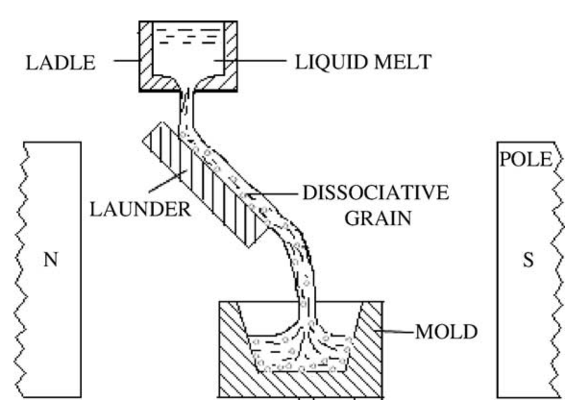

Fig. 3. Schematic illustration of the casting process.

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