Grain refinement of A356 alloy by AlTiC/AlTiB master alloys

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In both shape casting and direct chill (DC) casting of aluminum alloys, grain refinement is an important part of normal practice, bringing many processing benefits in addition to finer grains [1]. The addition of grain refiners, usually master alloys containing potent nucleant particles, promotes formation of fine equiaxed grains by deliberately suppressing the growth of columnar and twin columnar grains. The finer equiaxed grain structure ensures uniform mechanical properties, reduced ingot cracking, improved feeding to eliminate shrinkage porosity, distribution of second phases and microporosity on a fine scale, improved machinability and cosmetic features [1, 2]. Now Al—Ti—B grain refiners are widely used in the aluminum industry [3]. However, there are some problems with Al—Ti—B alloy, such as agglomeration of the borides, blockage of filters, defects during subsequent forming operations and poisoning by certain elements like Zr, V and Cr. In comparison with Al—Ti—B refiners, Al—Ti—C has been found to be much less susceptible to poisoning and to agglomeration and appears to give a more uniform grain size [4]. Therefore, 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 AlTiB refiners is inconvenient due to various reasons, and more attention has been paid to the preparation, microstructure and performance of Al—Ti—C master alloy [4–7].

Since Banerji and Reif [8] discovered that AlTiC master alloy is a better grain refiner than AlTiB, a lot of work has been done and some results have been reported [9, 10]. Some investigators found that the grains of 99.7% pure aluminum refined by AlTiC are much finer than those produced by commercial Al—5Ti—1B master alloy [11, 12]. However, little information is available on the refinement performance of AlTiC refiner on Al—Si alloy until now. A356 is a common industrial alloy widely used in aviation and mechanical fabricating industry [13]. In this paper, the refinement performance on A356 alloy with AlTiC/AlTiB refiners was studied, and their effects were compared.

The composition of A356 alloy used for refinement is listed in Table I, and the commercial Al—5Ti—0.25C and Al—5Ti—1B master alloys (all compositions are in wt. percent) were used as the grain refiners. The A356 alloy was melted in a clay-bonded graphite crucible by an electronic-resistance furnace at 720 ± 5 °C. The Al—5Ti—0.25C/Al—5Ti—1B refiner was added into the melt at the level of 0.2, 0.5, 2.0 and 5.0%, then the melt was stirred for 30 s to ensure the uniform distribution of the refiner in the melt. After 20 min of holding time, the melt was poured into an iron mold 30 mm in diameter and 20 mm in height. Samples were taken from the middle part of the castings, and the microstructures of the specimens were examined with a KH-2200 high scope optical microscope.

TABLE I Chemical composition of A356 alloy

Element (wt.%)	Si	Mg	Ti	Cu	Zn	Fe	Mn	Al
A356 alloy	6.900	0.250	0.010	0.008	0.002	0.080	0.004	Balance

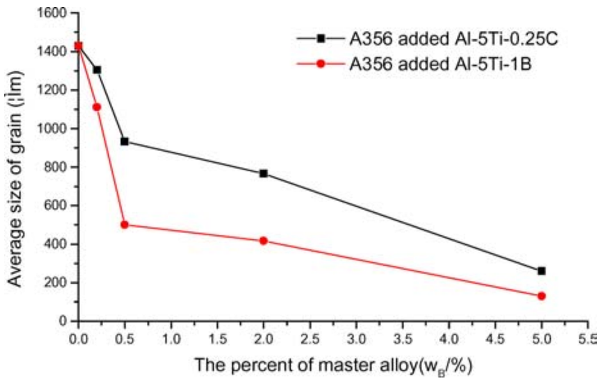

Figure 1 The refinement performances of Al—5Ti—1B and Al—5 Ti—0.25C on A356 alloy.

Ultimate tensile strength (UTS) samples were cast in a standard permanent mold. T6 heat treatment was performed to achieve optimal microstructure distributions and mechanical properties. Six tensile specimens were tested at each condition by CMT-5105 Microcomputer Controlled Election Universal Testing Machine, and the reported results are average values.

The grain refinement performances of AlTiC and AlTiB grain refiners on A356 alloy are shown in Fig. 1. On the macroscopic level, it seems that the Al—5Ti—1B master alloy has better refinement efficiency than Al—5Ti—0.25C master alloy. It is noted that the grain size decreases rapidly with the increase of AlTiC and AlTiB addition amount when the addition amount is below 0.5%, whereas the grain size decreases very slowly when the addition level exceeds 0.5%.

It is well known that the grain size can be measured in the microcosmic view only when the grain is very

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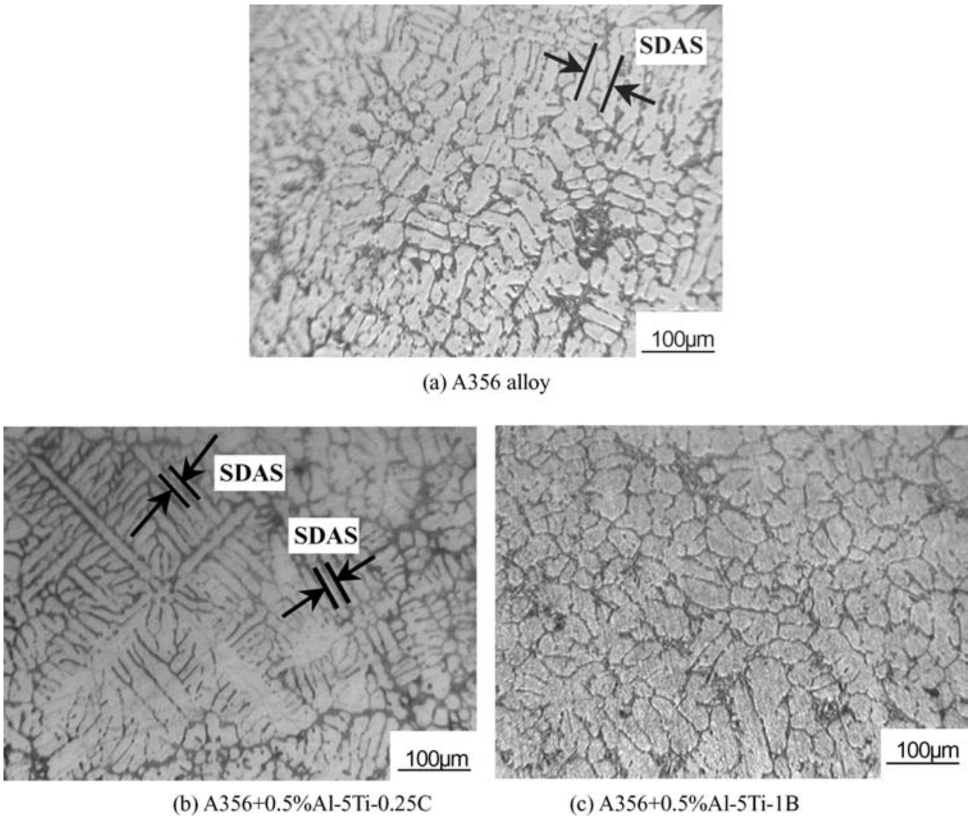

Figure 2 Micrographs of A356 alloy before and after the addition of Al—5Ti—0.25C and Al—5Ti—1B.

small, because what can be seen in the microcosmic view are mostly the primary or secondary dendrite arms or even higher order arms [14]. However, in some papers [11, 15], little dendrite branch or tip is considered as a whole grain by some researchers. In fact, the little dendrite branch or tip they measured is just a part of a whole grain. Therefore, the authors think that the correct grain size should be measured on the macroscopic level, as shown in Fig. 1.

Fig. 2 shows the micrographs of A356 alloys with and without the addition of AlTiB or AlTiC master alloys. It can be seen that the microstructure of A356 alloy greatly changed after addition of Al—5Ti—0.25C or Al—5Ti—1B master alloy.

The grain size of the A356 alloy before refinement is very large, and the grain includes many subdendrites, which intersect each other. As a result, it is difficult to find a whole grain in the microcosmic view, as shown in Fig. 2a. After addition of AlTiC refiner, the A356 alloy forms finer dendrites, that is to say, the size of dendrite grain becomes smaller. Because of this, a whole grain can be clearly found. At the same time, the Secondary Dendrite Arm Spacing (SDAS) of the alloy refined by AlTiC master alloy also becomes quite small, as shown in Fig. 2b. In comparison with the AlTiC master alloy, the refinement of A356 alloy by AlTiB master alloy is not inclined to form finer dendrites but flower-like grains. From Fig. 2c, it can be found that the grains are usually composed of several rose-like parts (the primary arms), for which the SDAS nearly disappears and the grain size is correspondingly small, in agreement with the macroscopic result shown in Fig. 1.

It is well known that Dendrite Arm Spacing is the parameter for the evaluation of the refinement degree [16]. With the decrease of Dendrite Arm Spacing, the grain boundary area increases, indicating better mechanical properties of the alloy. Further more, SDAS is quite important both for columnar dendrites and for equiaxed dendrites, thus, the decrease of SDAS can improve the metal's mechanical properties. The SDAS of the A356 alloy refined by AlTiC grain refiner obviously decreases, shown in Fig. 2b, so it can be deduced that the properties of A356 alloy will be heightened.

The mechanical properties of the A356 alloy before and after the addition of AlTiB/AlTiC master alloys are given in Table II. It is obvious that the UTS and elongation only increases a little after addition of 0.2% AlTiB, while they have been significantly improved after addition of 0.2% AlTiC; especially the elongation increased by 25%. The result not only proves the above deduction but also shows that the primary factor deciding the alloy's mechanical properties is not the grain size but the SDAS of the grain. This suggests that the AlTiC master alloy plays a more important role than AlTiB master alloy for A356 alloy.

TABLE II The mechanical properties of the A356 and the alloys refined by AlTiB/AlTiC master alloy

Properties	UTS (MPa)	Elongation (%)
A356	252.3	3.42
A356 + 0.2% AlTiC	263.8	4.27
A356 + 0.2% AlTiB	253.7	3.51

In conclusion, Al–5Ti–0.25C can obviously refine the SDAS, though the macro grain size is appreciably bigger than that refined by Al–5Ti–1B refiner. Because the main factor determining the mechanical properties is the SDAS, Al–5Ti–0.25C grain refiner is a more efficient grain refiner than Al–5Ti–1B grain refiner.

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