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Effect of B/C ratio on the microstructure and grain refining efficiency of Al–Ti–C–B master alloy

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A series of Al–Ti–C–B master alloys with different B/C ratios were prepared in the present study. It was found that with the increase of B/C ratio, the microstructure of Al–Ti–C–B was improved firstly and then became agglomerated at a very high B/C ratio. Furthermore, the grain refining performance of Al–Ti–C–B also varied with the increase of B/C ratio. The experimental results show that Al–Ti–C–B master alloy presents both a dispersive microstructure and a high grain refining efficiency at an optimum B/C ratio about 1/1. It is supposed that the improvement of Al–5Ti–0.25C–0.25B master alloy can be attributed to the high efficiency TiC_xB_y particles and a certain amount of TiB_2 particles.

1. Introduction

Al–Ti–B master alloys have been the preferred choice for the grain refinement of wrought aluminum alloys for several decades and the insoluble TiB_2 particles are believed to be effective nucleating substrates for α-Al grains [1–3]. However, they are still suffering from some problems in certain circumstances [4–7]. For example, the coarse TiB_2 particles agglomerate easily, which not only cause porosity, streaking in foils and internal cracking in extrusion billets, but also damage the surface of the roller. They are also not suitable to be used in alloys containing Zr, Cr or V due to the poisoning effect. Afterwards, TiC particles are found to be less prone to agglomeration than TiB_2 particles, and thus Al–Ti–C master alloy is believed to be the most promising grain refiner and could have superiority in foils production except for the serious fading behavior due to the intrinsic instability of TiC particles in aluminum melt [8–10]. In recent years, many researchers have made great efforts to improve the microstructure and grain refining efficiency of Al–Ti–C master alloys [5,11,12].

In 1990s, Jiang prepared a new kind of Al–Ti–C–B master alloy which showed a better refining efficiency than Al–Ti–C and Al–Ti–B master alloys, but it was not applied in industrial production [13]. Because the addition of B or C in the Al–Ti master alloy can improve the grain refining efficiency remarkably, it is supposed that TiC and TiB_2 particles share some similarities in grain refining mechanism. In our previous work, a new kind of Al–Ti–C–B master alloy with a good refining performance has been reported and it indicates that B has a positive effect on the grain refining efficiency of Al–Ti–C master alloy [14]. It is also found that a trace addition of C can also improve the grain refining ability of Al–Ti–B master alloy [15]. The prime objective of this work is to reveal the optimum B/C mass ratio and discuss on the corresponding refining mechanism for the high efficiency Al–Ti–C–B master alloy.

2. Materials and methods

Pure Ti (99.5%, all compositions quoted in this work are in wt. % unless otherwise stated), graphite powder (99.85%, 10 μm), Al–B master alloy and commercial pure Al (99.7%) were used for experiments. Firstly, five groups of Al–Ti–C–B master alloys with a range of B/C ratio from 1/4 to 4/1 were prepared using a melt reaction method in a high frequency furnace, where the total amount of C and B in the master alloy system was fixed to be 0.5%. In addition, Al–5Ti–0.4C and Al–5Ti–0.4B master alloys were also prepared for comparison. The detailed preparation procedures have been illustrated in our previous work [14].

Metallographic specimens were taken from the center of each sample in the transverse section, then were mechanically ground and polished through standard routines. The bulk samples were dissolved in a 10 vol. % HCl–distilled water solution to remove the Al matrix and obtain the small particles in the master alloys for detection. The corresponding experimental procedures were also given in Ref. [14]. The microstructure characterization and microanalysis of the samples and collected particles were investigated by X-ray diffraction (XRD, Rigaku D/max-rB) and field emission scanning electron microscope (FESEM, SU–70).

The grain refining tests were carried out by adding 0.2% the prepared master alloys into 99.7% commercial pure Al with the same procedures [16]. The pictures of macrostructures were taken for each sample by a high scope video microscope (HSVM, KH–2200), and the average grain sizes were determined using the linear intercept method.

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3. Results and discussion

3.1. The microstructure of Al–Ti–C–B master alloy with different B/C ratio

Fig. 1 shows XRD patterns of the phase composition in three Al–Ti–C–B master alloys, i.e. Al–5Ti–0.4C–0.1B, Al–5Ti–0.25C–0.25B and Al–5Ti–0.1C–0.4B with a B/C ratio of 1/4, 1/1 and 4/1 respectively. It can be seen that three kinds of phases have formed in the alloys and the diffraction intensity of TiC are the strongest. Meanwhile, according to the diffraction intensity, it can be observed that the amount of TiB_2 increase with the addition of B ranging from 0.1% to 0.4%. It is interesting to note that the number of TiB_2 is much less than that of TiC in the Al–5Ti–0.1C–0.4B master alloy, in which the concentration of B is 0.4% and C is only 0.1%, as shown in Fig. 1c.

Fig. 2 shows the microstructure evolution with increasing B/C ratio in Al–Ti–C–B and two comparison master alloys and it can be observed that plate-like $TiAl_3$ phase and TiC or TiB_2 particles distribute in the Al matrix. Furthermore, the dispersion of particles varies with the change of B/C ratio in the Al–Ti–C–B master alloys. It is well known that, TiC and TiB_2 particles are prone to agglomeration in the Al–Ti–C or Al–Ti–B master alloy, and the

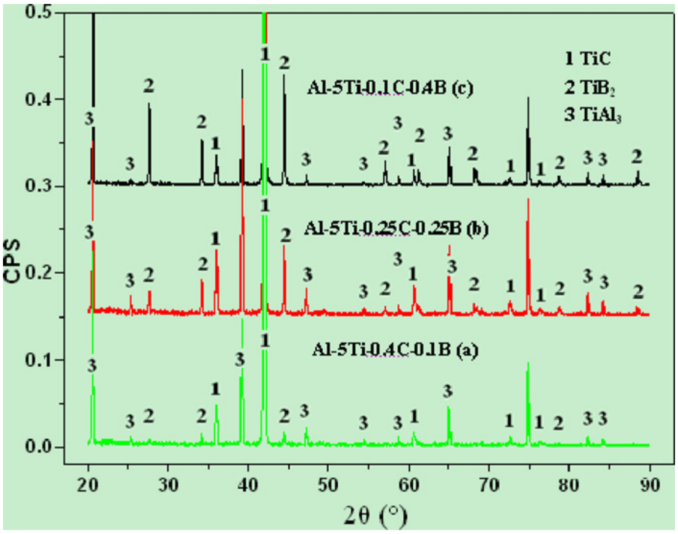

Fig. 1. XRD patterns of the prepared master alloys.

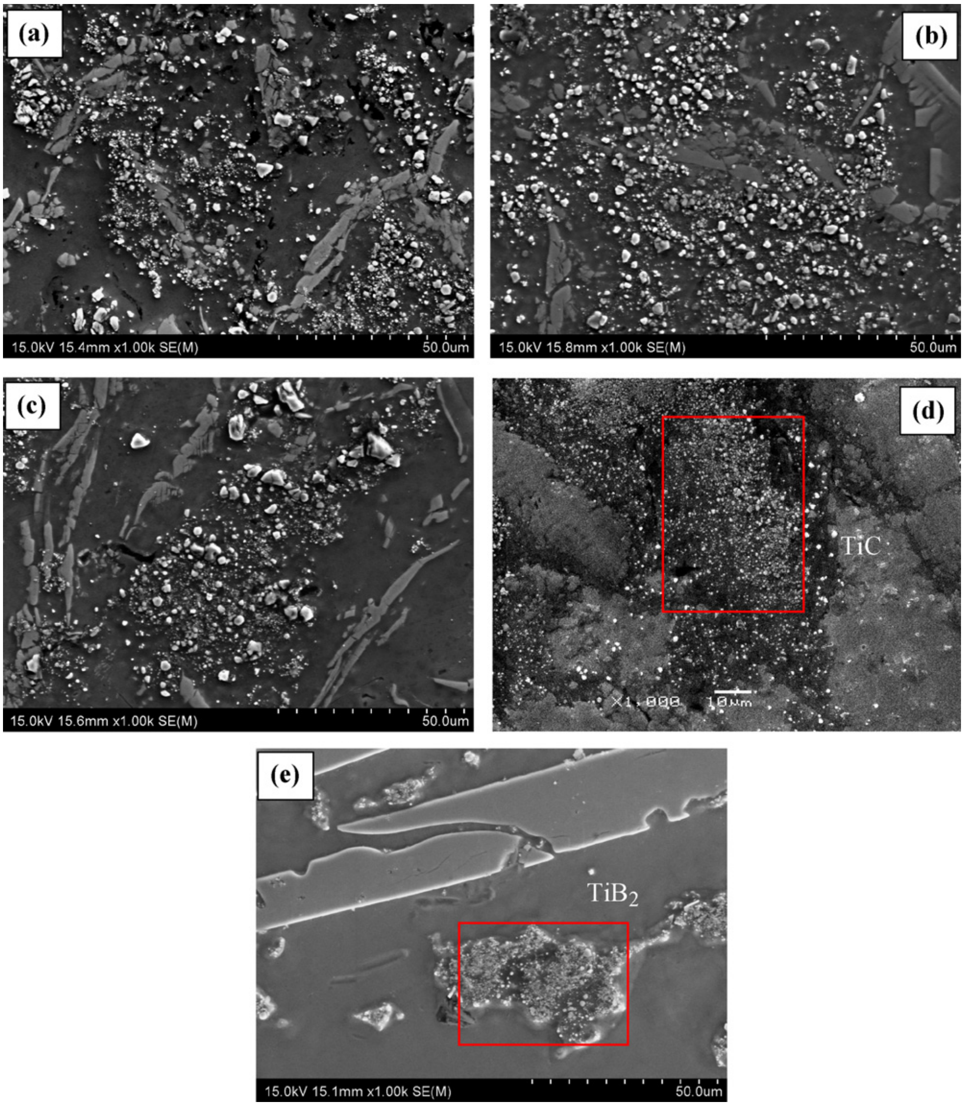

Fig. 2. The microstructure evolution of the Al–Ti–C–B master alloy: (a–c) the B/C ratio is 4/1, 1/1, 1/4, respectively; (d and e) Al–5Ti–0.4C and Al–5Ti–0.4B.