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Segregation of particles and its influence on the morphology of the eutectic silicon phase in Al–7 wt.% Si alloys

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Abstract

A new modification phenomenon is reported for Al–Si alloys, where the Al–Si eutectic is refined by segregated TiB_2 particles. The TiB_2 particles are pushed to the Al–Si phase boundary during solidification of the eutectic and it is believed that at high concentrations the TiB_2 particles restrict solute redistribution causing refinement of the Si.

Keywords: Casting; Solidification microstructure; Aluminium alloys; Modification

1. Introduction

The final microstructure of a casting is important as it significantly influences its mechanical properties. Large columnar grains are usually undesirable and grain refinement is undertaken to suppress the formation of columnar grains. Grain refiner is usually added via a master alloy and introduces many potent particles, which act as nucleation substrates for the primary Al (α-Al). When grain refinement is successful, fine equiaxed α-Al grains form and this leads to improved castability and mechanical properties [1]. Al–Ti–B type master alloys, which contain two types of particles, Al_3Ti and TiB_2, are commonly used for grain refining Al alloys. The Al_3Ti particles dissolve quickly providing solute Ti to assist growth restriction after the nucleation event. The TiB_2 particles remain stable in the melt and provide sites for heterogeneous nucleation. Although our understanding of grain refinement has progressed since first reported by Cibula [2], problems are still encountered in the casthouse. The ability of a grain refiner to refine a melt is dependent on several parameters and the efficiency of the refinement can vary with time.

The present work was undertaken to investigate the rate of fading of a typical Al–5%Ti–1%B (all percentages are wt.% unless otherwise stated) grain refiner in commercial purity Al and binary Al–Si alloys. Grain refined melts were sampled after different holding times and the resulting microstructures were investigated by optical and scanning electron microscopy (SEM). The settling rates are reported elsewhere [3]. In the present paper, the distribution of substrate particles in the castings, and their effect on the Al–Si eutectic morphologies in areas of high concentrations of TiB_2 particles are reported. A new phenomenon has been found, namely that the Al–Si eutectic is strongly influenced by the segregated TiB_2 particles providing a modification of the eutectic similar to that observed after Na- or Sr-additions. This phenomenon is likely associated with extensive pushing of the substrate particles during growth of the eutectic.

2. Experimental

Melts were prepared from approximately 5 kg of commercial purity Al. Al and Al–Si alloys were melted in an induction furnace. In the case of the binary alloys, high

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purity Si was placed in the bottom of a clay–graphite crucible and commercial purity Al was added to obtain a nominal composition of 7% Si. Once molten, the crucible was transferred to a resistance furnace for grain refinement and sampling. Al–5%Ti–1%B grain refiner was added to the melt and stirred for 1 min to give a nominal concentration of 0.05% Ti. After refinement, six cylindrical graphite cups (50 mm diameter, 60 mm height and 5 mm wall thickness) were preheated to 720 °C and then filled from the 5 kg melt. One cup was removed immediately after filling and the remaining five cups were held in the furnace at 720 °C. The cups were then periodically removed from the furnace after holding times of 5, 10, 20, 30 and 60 min. Insulating boards were placed on the top and bottom of the graphite cup and the samples were allowed to cool in air.

Longitudinal sample sections were taken from the bottom of the castings for microstructural examination. The samples were examined using an optical microscope and an SEM. For SEM analysis, the samples were investigated in the as polished condition and after etching for 3 min at 50 °C in a 1 vol.% NaOH aqueous solution.

3. Results

3.1. Particle pushing during growth of the primary phase (α-Al)

Fig. 1(a) and (b) shows the bottom region of the commercial purity Al castings after 5 and 60 min of holding, respectively. TiB_2 refining particles (labelled TiB_2) can be observed in the bottom region of the samples, and the amount of particle settling increases with holding time. The particles at the bottom of these castings have been confirmed as TiB_2 by chemical analysis [3]. Interestingly, the majority of the TiB_2 particles in the settled layer appear to be located on α-Al grain boundaries, an observation that is further strengthened by complimentary SEM analysis, as illustrated by the secondary electron image shown in Fig. 2. In addition to the interdendritic TiB_2 particle concentrations, individual TiB_2 particles and small agglomerates can be found located within the equiaxed grains in Fig. 2.

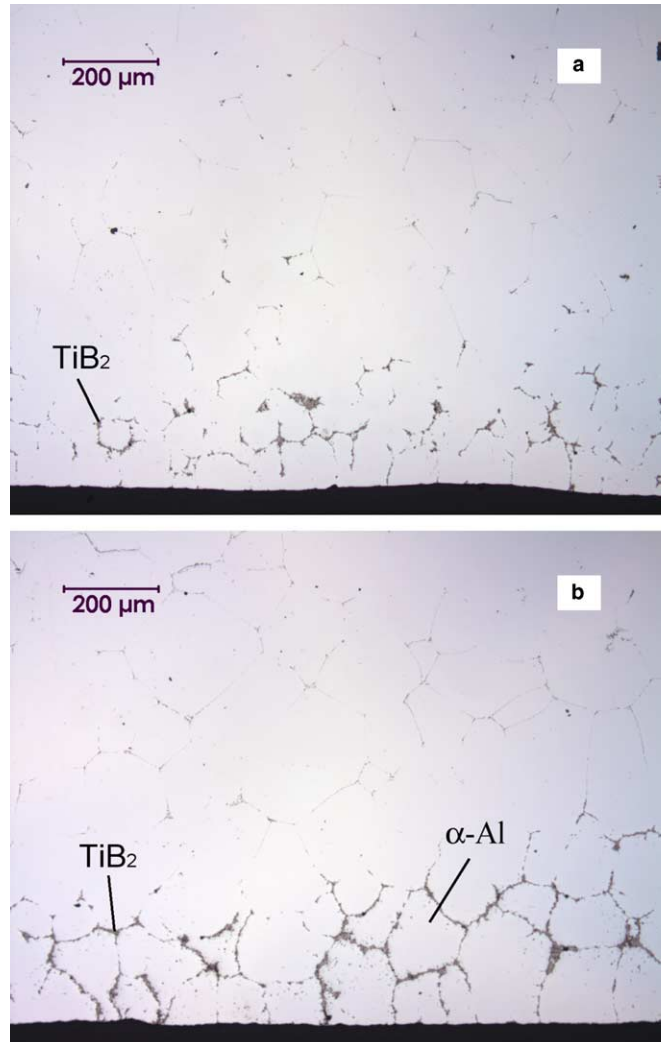

Fig. 1. The bottom region of the grain refined commercial purity Al samples after (a) 5 min and (b) 60 min of holding. TiB_2 particles can be observed as dark pixels in the interdendritic regions.

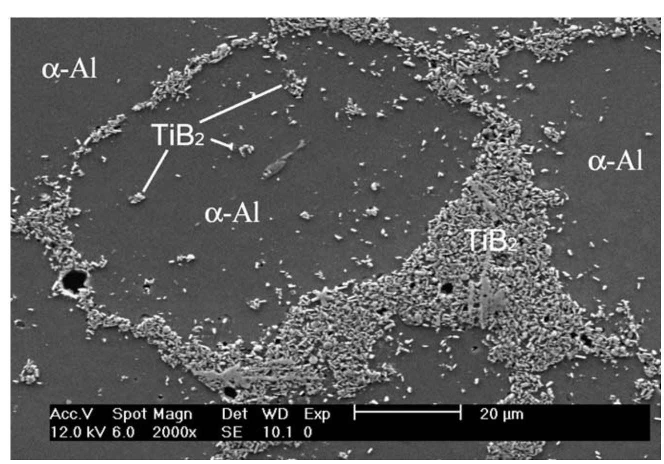

Fig. 2. A secondary electron image of the settled layer in grain refined commercial purity Al after 60 min of holding. The majority of grain refining particles have been pushed to the grain boundary. However, some TiB_2, which occurs as individual particles and small agglomerates, remain within the α-Al grains.

3.2. Particle pushing during eutectic growth

TiB_2 grain refinement of the Al–7%Si alloy gave similar results: TiB_2 particles segregated to the bottom of the melt in an amount that increased with time. The settled layer of grain refining particles in the Al–7%Si alloy after 0 and 60 min of holding are shown in Fig. 3(a) and (b), respectively. It should be noted that in the Figs. 3–6, α-Al refers to the primary Al phase and Al refers to the eutectic Al.

Fig. 4 shows a back scattered electron image of the interdendritic region in the settled layer of the Al–7%Si sample held for 60 min. In Fig. 4, the TiB_2 particles can be seen more clearly and it appears that the TiB_2 particles are relatively evenly distributed throughout the eutectic (even