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Effect of Co-Modification of Ba and Bi on Microstructure of Al-20%Mg_2Si in Situ Composite and Mechanism

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Abstract – *Al-20%Mg2Si composite was in situ synthesized and modified by the addition of Ba and Bi; the microstructure of the resulting composites will be investigated. It is expected that the co-modification with Ba and Bi effectively refined the morphology of Mg_2Si which is attributed to the formation of fine Ba_2Bi particles that acted as the heterogeneous nucleation sites for the primary Mg_2Si particles, resulting in a refined distribution of these precipitates. Therefore, the addition of Ba and Bi can provide a better effect than only the addition of Bi or Ba separately.*

Keywords: Metal Matrix Composite, Mg_2Si, Modification, Microstructure, Heterogeneous Nucleation

1.0 INTRODUCTION

During the last decades considerable efforts have been devoted to the development of novel, lightweight materials in automobile and other industries. Aluminum metal matrix composite is one of the competitive lightweight automobile materials. Hypereutectic Al-Si alloys with high Mg content are in fact an in situ aluminum matrix composite containing a large amount of hard Mg_2Si particles. The Al/Mg_2Si composite has a potential as candidates to replace Al-Si alloys used in the aerospace and automotive applications because the intermetallic compound of Mg_2Si exhibits high melting temperature, low density, appropriate hardness, low thermal expansion coefficient and reasonably high elastic modulus [1-4]. In addition, an in situ process of fabricating Al/Mg_2Si composite possesses some merits, such as even distribution of reinforcement, well matched matrix-reinforcement interface, thermodynamically stable system and much lower costs of production compared with their counterparts from ex situ processes [5-7]. However, conventional casting of Al-Mg_2Si in situ composite could cause formation of an undesirable coarse skeleton shape of intermetallic Mg_2Si, besides being bigger in size [8, 9]. That would result in deterioration of mechanical properties, demonstrating low ductility and fracture toughness of the composite [10] because of high crack propagation at sharp edges and corners of the coarse structure. Therefore, control of the microstructure is crucial during the casting procedure in order to improve the morphology and obtain the desired mechanical properties as well as the required casting quality. Various approaches have been used to modify Mg_2Si phase to obtain interesting refining effects on the final microstructures, such as hot extrusion, mechanical alloying, heat treatment and vibration [11, 12]; however, conventional gravity casting with addition of inoculant agent is a more practical method because it is simpler, cost effective and suitable for general engineering applications [9, 13, 14]. It has been claimed that refinement of primary Mg_2Si particles could be achieved by addition of Sr [9, 15, 16], P [3, 6], Si [2] and Sb [8], whereby the coarse dendritic structure of Mg_2Si particles has been changed to fine polygonal shapes. Similarly, the pseudo-eutectic Al-Mg_2Si phase has been altered from flake-like to a fibre form [2, 3]. Better modifiers are still needed because finer reinforcements usually afford better properties. It is found that Bi transformed coarse Mg_2Si into equiaxed particles by increasing the number of heterogeneous nucleation sites [9, 13]; in addition, Ba was shown as an effective modifier for Mg_2Si in Mg_2Si/Mg–Zn–Si composite in the study which is carried out by K et al [17]. Therefore, a combined effect of Ba and Bi will be highly expected and desired. In this study, Ba and Bi were used in the Al-20%Mg_2Si composite, and their effects and co-modification mechanism were investigated.

2.0 EXPERIMENTAL PROCEDURE

Industrially pure metals (Al, Mg) and Si were used as starting materials to prepare Al–20% Mg_2Si composite ingots. All materials were heated in an electrical resistance furnace using a 10 kg SiC crucible. Table 1 shows the chemical composition of this Al–20%Mg_2Si composite. The parent ingots were cut in small pieces, with the approximate dimensions of 40mm×30mm×20mm, appropriate for a 2 kg SiC crucible then the composite was remelted in another electrical resistance furnace. When the temperature reached 750 °C, Appropriate amounts of pure Ba (>98 wt. %) and Bi (>99 wt. %) were added to the remelted ingot. After stirring and deslagging, the melts were cast into a preheated cylindrical ceramic mould (outer diameter 40 mm, height 40 mm and wall thickness of 7 mm) and preheated at 750 °C for 15 min. The Ba and Bi contents of the ingots are listed in Table 2. The samples were cut from the middle of the ingots, and then prepared by standard grinding procedures. The ground specimens were then subjected to a final polishing with colloidal silica suspension. Microstructures were analysed using an optical microscope (Nikon-MICROPHOT-FXL) and field emission scanning electron microscope (FESEM Supra- 35VP, Carl Zeiss) equipped with an energy dispersive spectrometer (EDS).

Table 1: Chemical composition of Al–20%Mg_2Si (wt. %)

Material	Si	Mg	Fe	Ni	Zn	Mn	Cu	Ti	Cr
Al–20% Mg_2Si	7.50	12.80	0.16	0.01	0.01	0.01	0.01	0.01	0.01

Table 2: Alloy number and nominal Ba/Bi contents

Alloy no.	0	1	2	3	4	5
Ba content (wt. %)	0	0.2	0.2	0.2	0.2	0.2
Bi content (wt. %)	0	0	0.05	0.1	0.15	0.2

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3.0 EXPECTED RESULTS

The modification mechanisms and refinement of the Mg_2Si precipitate by adding various elements have been discussed in the previous studies. For example, Ba and Bi mainly increased the amount of nucleation sites, thus decreasing the Mg_2Si particle size. Bi formed Mg_3Bi_2 particles [13], which acted as the nucleation sites for Mg_2Si. Although $BaMg_2Si_2$ can play a similar role when Ba was added to the alloy [17], in the case of the simultaneous addition of Bi and Ba, as performs in this study, no Mg_3Bi_2 or $BaMg_2Si_2$ particles is observed. Instead, several fine Ba_2Bi particles are detected inside the Mg_2Si precipitate. This could be explained by the electronegativity of the different atoms. Electronegativity is a chemical property that describes the tendency of an atom to attract the shared pair of electrons (or electron density) toward itself. In general, the larger the difference between electronegativities of the two atoms, the higher is the tendency of their combination leading to compound formation. The electronegativities of Ba, Bi, Mg, and Si are 0.89, 2.02, 1.31, and 1.98, respectively. Apparently, the electronegativity difference between Ba and Bi is much larger than that between Ba and Mg, or that between Bi and Mg. Therefore, Ba and Bi combined to form Ba_2Bi rather than Mg_3Bi_2 or $BaMg_2Si_2$ particles. The face-centered tetragonal Ba_2Bi (lattice parameters: a =b= 5.26 Å, c = 18.70 Å) and belongs to 14/mmm space group with melting point of 1350 °C [18]. Mg_2Si has a face-centered cubic structure with a lattice constant of a = 6.39 and belongs to Fm-3 m (225) space group with the Pearson symbol cF12 with melting point of 1085 °C [19]. Note that there were significant coincident relationships between lattice constants of Ba_2Bi and Mg2Si, i.e. a (Ba_2Bi) ≈ a (Mg_2Si) and c (Ba_2Bi) ≈ 3a (Mg_2Si). Furthermore, the melting point of Ba_2Bi is higher than Mg_2Si; Therefore, Ba_2Bi can be as an effective heterogeneous nucleation substrate for the primary Mg_2Si particles. The formation of large amounts of tiny Ba_2Bi particles increased the nucleation rate of the primary Mg_2Si particles. Therefore, the growth of primary Mg_2Si nuclei to dendrite structure was hindered before the completion of solidification, i.e., the primary Mg_2Si phase could be refined. So it is expected that with addition of Bi to Ba-modified composite, the primary and Mg_2Si particles becomes much smaller with the concomitant reduction in the Chinese-script eutectic Mg_2Si compared to Ba-modified composite.

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