Effect of In Situ TiB_2 Particle Content on Microstructure and Properties of Cast Al–Si Alloy

Hongda Wang, Lihua Chai and He Li

Abstract Cast Al–Si alloys are widely used for their excellent casting properties, but their applications are restricted in some special fields because of their low mechanical properties. In this paper, H_3BO_3 and TiO_2 were used as raw materials to prepare TiB_2/Al–Si composites with different mass fractions by in situ generation. The effects of TiB_2 particle content on microstructure and properties of the alloy were studied. The results showed that the microstructure of the alloy was mainly composed of coarse primary α-Al dendrites and long-striped eutectic Si particles. The coarse primary α-Al particles were obviously refined and the edge of acicular eutectic Si was rounded with the addition of TiB_2 particles. When the particle content was low, the particle distribution was dispersed, and a large number of particles were located in the grain boundary. When the particle content was high, the particles were agglomerated and gathered at the grain boundary. With the increase of particle content, the mechanical properties of the material were obviously enhanced. When the content of TiB_2 particles was 5%, the tensile strength and yield strength reached 200 and 160 MPa, which were 22.8 and 34% higher than those of matrix, respectively.

1 Introduction

Aluminum and its alloys have the characteristics of low density, high specific strength, good electrical conductivity, and good thermal conductivity. They are widely used in automotive, aerospace, weapon, and equipment manufacturing [1, 2]. Among them, the casting aluminum-silicon alloy has good fluidity and filling ability. It is a common material for manufacturing automobile wheel hub and cylinder. However, the mechanical properties of Al–Si alloys are poor, which limits their further application [3]. The mechanical properties of aluminum and aluminum alloys can be improved effectively by adding smaller reinforcement particles to aluminum and aluminum alloys under the condition of ensuring elongation. However, the poor wettability of

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the interface between the reinforced particles and the matrix results in the limitation of application and development of aluminum matrix composites prepared by the traditional addition method. Particle-reinforced aluminum matrix composites prepared by in situ reaction method can effectively overcome as mentioned above [4–6].

At present, the research of particle-reinforced aluminum matrix composites is mainly focused on the preparation process. The addition of TiB_2 particles to the cast Al–Si alloy can effectively reduce the grain size and improve the strength of the material. The average size of TiB_2 particles prepared by in situ reaction method is 1 μm [7]. However, the influence of particle state, especially the content and morphology of particles on the material is still lack of systematic study. In this paper, TiB_2/Al–Si composites were prepared by self-propagating high-temperature synthesis and melt reaction. The effects of particle content on microstructure and properties of the composites were studied.

2 Materials and Methods

A Al–10 wt% Si alloy was used as the base material of the experiment, and the raw material was pure aluminum (99.9%, mass fraction) Al–20 wt% Si master alloy. Al/TiB_2 master alloy was prepared by using boric acid (H_3BO_3), titanium oxide (TiO_2), titanium powder and aluminum powder as raw materials. The raw material is mixed and dried in the mole ratio and pressed into a blank using a crucible furnace to heat aluminum ingots to 950 °C. The preform was put into molten aluminum to ignite, and the reaction was maintained by the reaction exothermic. After the reaction was finished, the pure phase Al/TiB_2 master alloy was prepared by slagging, refining and casting. Al/TiB_2 master alloy was remelted at 750 °C and TiB_2/Al–Si composites with different particle content were prepared according to the content of Al–20 Si alloy. A φ100 mm × 80 mm ingot was obtained by pouring the melt into a metal mold with preheating temperature of 200 °C. The microstructure was observed by sampling in the middle of the ingot, and the tensile specimen of φ5 mm × 25 mm was processed.

The optical microstructure of the composite was observed by OLYMPUS PMG3 optical microscope after grinding and polishing, the phase constitution was analyzed by D/MAX-3C rotating anode X-ray diffractometer, and the microstructure was analyzed by QUANTA200 scanning electron microscope. A series of tensile tests were carried out on Instron5569 electronic universal material testing machine. The tensile rate was 1 mm/min and the average value of mechanical properties was obtained.

3 Experimental Results and Discussion

3.1 Analysis of Master Alloy

Al/TiB_2 master alloys were analyzed by SEM, XRD, EDS method. Figure 1a and b show the microstructure of Al/TiB_2 master alloy. It can be seen that TiB_2 particle distribution is relatively uniform on the matrix with hexagonal and square shape, and the average size of TiB_2 particles is 1.1 µm. Due to the large surface tension of the particles, particle aggregation is inevitable in a small area. Figure 1c and d is the result of EDS and XRD analysis of Al/TiB_2 master alloy. It can be seen from the spectrum that only Al and TiB_2 phases exist in the master alloy, and no brittle hard $TiAl_3$ phase Presents which shows that the pure Al/TiB_2 master alloy can be prepared by this method.

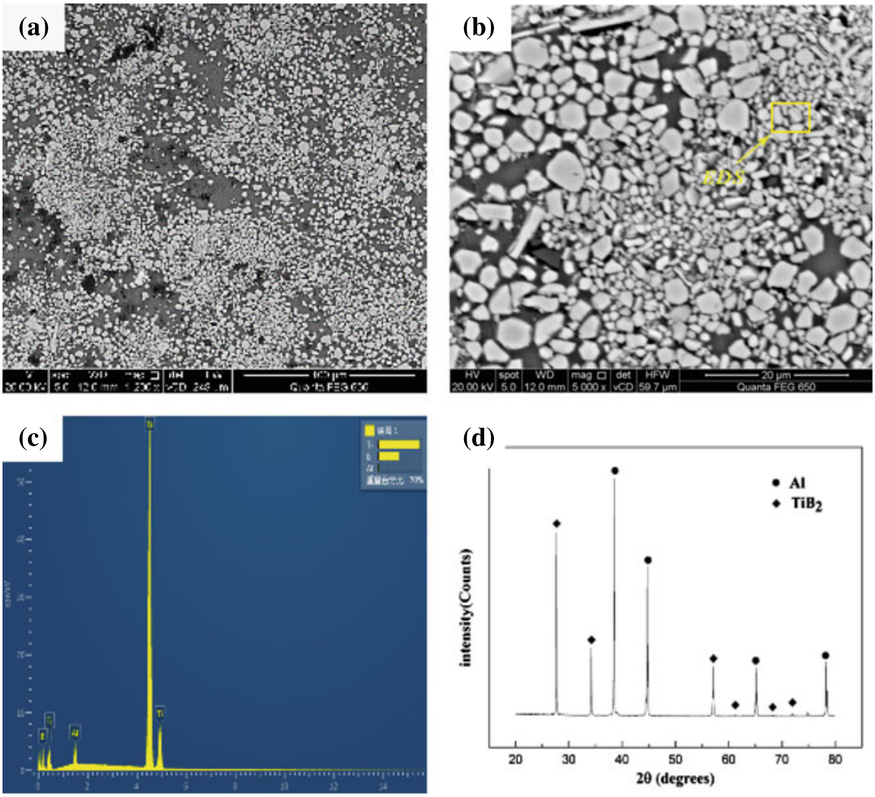

Fig. 1 Microstructure of Al/TiB_2 master alloy. **a** Microstructure (low magnification), **b** microstructure (high magnification), **c** EDS analysis and **d** XRD analysis

3.2 Microstructure of Composite Materials

Figure 2 shows the composite microstructure with different particle content (0, 1, 3 and 5 wt%). As shown in Fig. 2a, the matrix alloy mainly consists of dendritic primary α-Al phase and acicular eutectic Si. The white region is the primary α-Al phase and the grey precipitates in coarse dendritic formed during solidification. Some black needle-like structure distributes at the adjacent parts of primary α-Al, which is Si-enriched phase in eutectic structure. With the addition of TiB_2 particles, the primary α-Al changes from coarse dendritic to rose-shaped, and the existence of primary α-Al particles increased the growth resistance of α-Al, hindered the grain growth and dendritic formation, and made the needle-shaped Si edges rounded. When the particle content is low, the particles distribute dispersedly in the matrix, and with the increase of the particle content, a small range of segregation occurs at the grain boundary, as shown in Fig. 3. The reason is that during solidification process, it is difficult for the particles to be swallowed and moved to the grain boundary with the

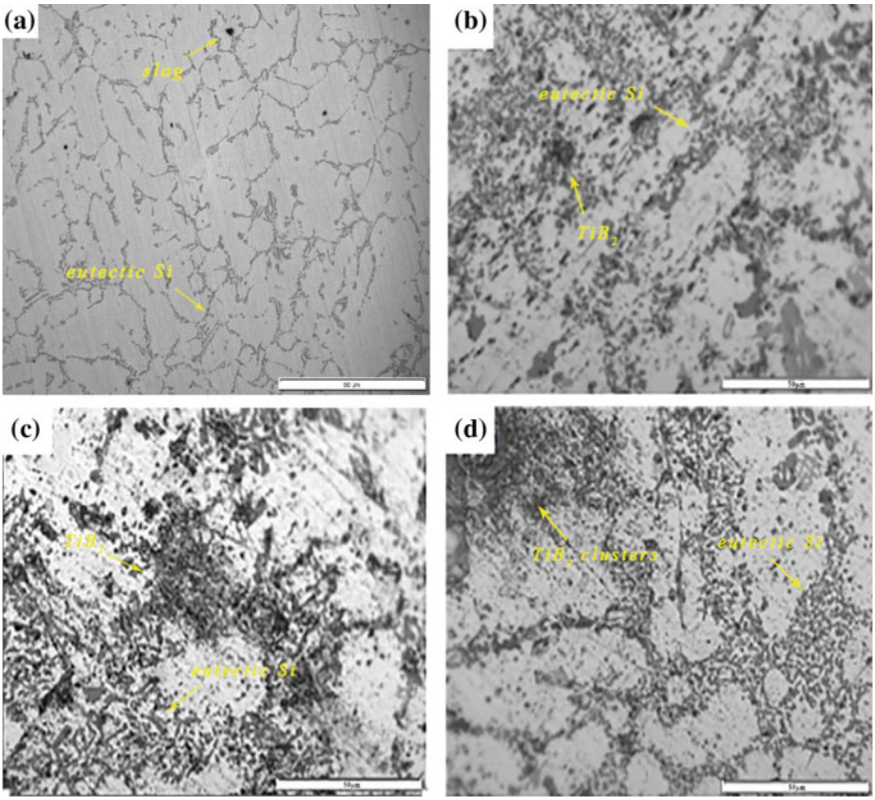

Fig. 2 Composite microstructure under different particle content **a** 0 wt%, **b** 1 wt%, **c** 3 wt% and **d** 5 wt%

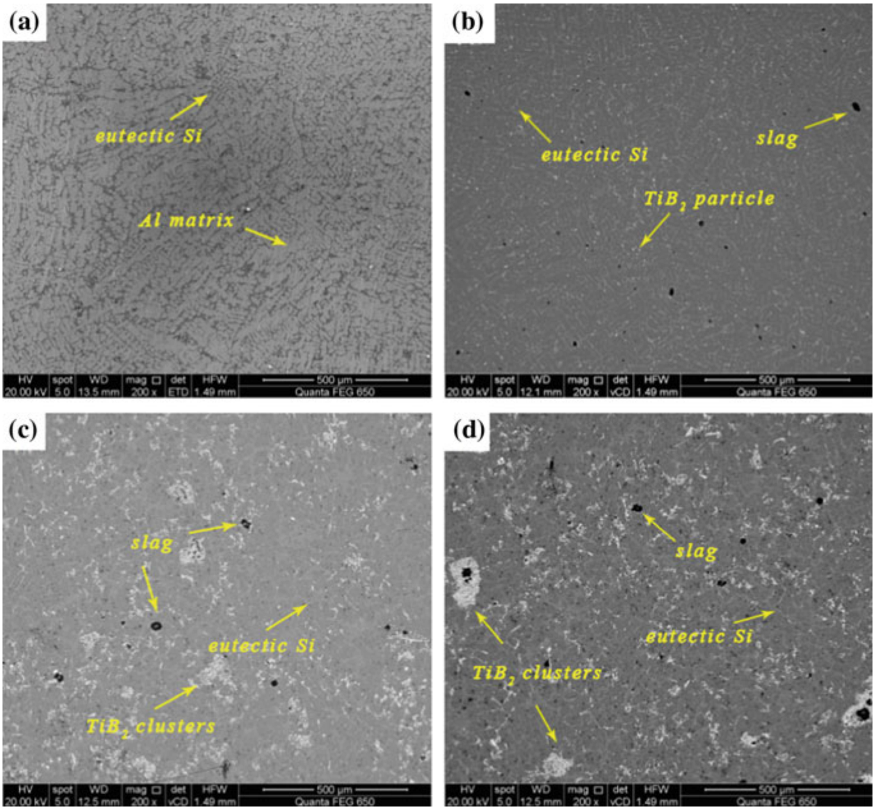

Fig. 3 TiB_2 particles distribution under different particle content **a** 0 wt%, **b** 1 wt%, **c** 3 wt% and **d** 5 wt%

migration of the solid–liquid interface, and it is easy to reduce the surface energy by agglomeration under casting conditions, so the phenomenon of local agglomeration occurs.

3.3 Mechanical Properties of Composites

Figure 4 shows the Brinell hardness. It can be seen from the chart that the hardness of the composites increases with the increase of particle content. When the particle content is 5%, the hardness of the composites is 41.7 HB, which is 8.3% higher than that of the matrix. Table 1 shows the tensile properties of composites with different particle contents (0, 1, 3, and 5 wt%). It can be seen from the table that with the increase of TiB_2 particle content, the mechanical properties of the composites are improved gradually. When the particle content is 5%, the tensile strength and yield

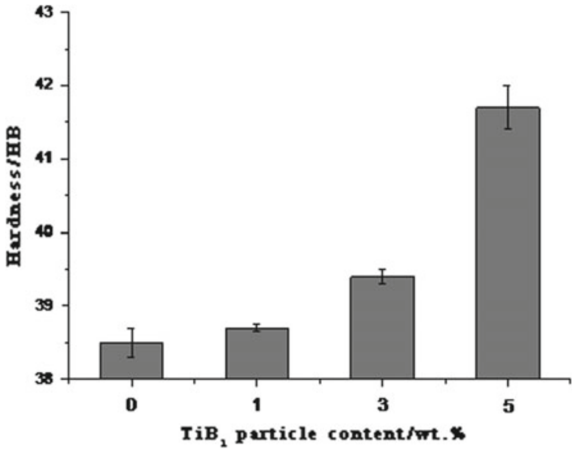

Fig. 4 Brinell hardness of the composites with different particle content (0, 1, 3 and 5 wt%)

Table 1 Tensile properties of the composites with different particle content

TiB_2 particle content (wt%)	0	1	3	5
Tensile strength (MPa)	166.82	169.79	188.48	205.78
Yield strength (MPa)	110.51	125.97	139.42	154.77
Elongation (%)	4.94	2.83	3.07	2.55

strength of the composites reach 205.78 and 154.77 MPa respectively, compared with the matrix, the tensile strength and yield strength of the composites are increased by 23.4 and 40.1%, respectively. The addition of TiB_2 particles leads to a decrease in the elongation of the composites. The reason is that stress concentration occurs near some large particle and leads to cracking under stress state. As the particles increased, the elongation rate deceased.

For composites, the strengthening effect mainly refers to the improvement of tensile strength and yield strength. The main causes of composite strengthening are the synergistic effect of load transfer mechanism, Orowan reinforcement mechanism and grain refinement mechanism [8]. When the composite material receives the external force, the matrix and the reinforced particle bear the load together. Because of the coordinated deformation, the stress of the matrix is small, and the strength and the bearing capacity of composite are improved. When the TiB_2 particles are small dispersive particles, the reinforcement of the material will also be enhanced by the dislocation movement caused by the addition of reinforcing phase, thus forming the Orowan strengthening [9, 10]. For the composite materials, the smaller TiB_2 particles are difficult to be shearing because of their high strength, and the dislocation lines bypass the particles by the Orowan mechanism. The combination of matrix strength and particle will further enhance the strength of composites. The small-sized TiB_2 particles prevent grain growth, produce grain boundary pinning, and greatly reduce

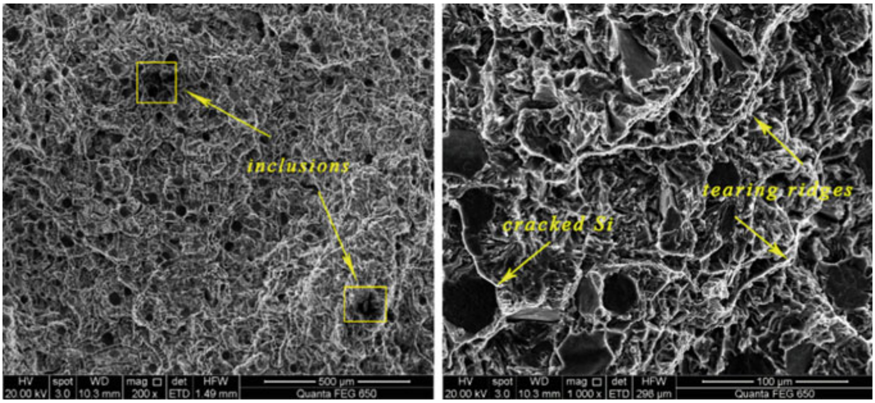

Fig. 5 Fractographies of TiB_2/Al–Si composites

the stress concentration inside the composite material. The mechanical properties of the composites are greatly improved by the combined action of many factors.

Figure 5 shows the tensile fracture morphologies of the composite, the fracture surface is flat, perpendicular to the tensile axis, indicating that the material is brittle fracture. The EDS analysis of the yellow line area for casting defects shows that the inclusions are Al_2O_3. It can be seen from the morphology of high magnification fracture that there are many silicon fracture surfaces and tearing ridges, showing the characteristics of quasi-cleavage fracture. The cracks mainly originate from the fracture of Si phase and the bond between Si phase and matrix. Due to the large stress concentration near Si phase, the brittle cracking of Si phase occurs. There are a large number of submicron TiB_2 particles at the bottom of the dimple, which indicates that the TiB_2 particles are mainly distributed at the interface between the particles and the matrix. This is due to the smaller size and higher strength of the TiB_2 particles with a regular shape, which is not easy to crack due to the stress concentration. However, due to the difference of thermal expansion coefficient between the matrix and the particles, the interface between the reinforced particles and the matrix is in a loaded state. Finally, under the action of the external force, the particles appeared the phenomenon of destaining.

4 Conclusions

The results are listed as follows:

(1) TiB_2/Al–Si composites without brittle and hard $TiAl_3$ phase can be prepared by a new in situ reaction method, and the TiB_2 particle content is high.
(2) The grain size of TiB_2 particles is refined, and the primary Al changes from coarse dendrite to rose shape, and the edge of the eutectic Si is rounded.

(3) When the particle content is low, the distribution in the matrix is more uniform. When the particle content is high, a local area of agglomeration occurs at the grain boundaries. With the increase of TiB_2 particle content, the mechanical properties of the composite are improved. When the content of TiB_2 particles is 5%, the tensile strength and yield strength reached 200 and 160 MPa, which are 22.8 and 34.8% higher than those of matrix, respectively.

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