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ScienceDirect

Trans. Nonferrous Met. Soc. China 26(2016) 2304−2312

Transactions of Nonferrous Metals Society of China

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Fabrication and characterization of stir casting AA6061−31%B_4C composite

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Received 6 September 2015; accepted 6 January 2016

Abstract: A sophisticated stir casting route to fabricate large scale AA6061−31%B_4C composite was developed. Key process parameters were studied, microstructure and mechanical properties of the composite were investigated. The results indicated that vacuum stirring/casting, B_4C/Mg feeding and ingots cooling were essential to the successful fabrication of AA6061−31%B_4C composite. Chemical erosion examination verified the designed B_4C content; X-ray fluorescence spectrometer (XFS) showed the chemical composition of Mg and Si in the matrix conformed to industry standards; scanning electronic microscope (SEM) and X-ray diffraction (XRD) revealed that B_4C particles were evenly distributed in the composites with well dispersed Mg_2Si precipitates. Tensile testing results showed that the AA6061−31%B_4C composite had a tensile strength of 340 MPa, improved by 112.5% compared with AA1100−31%B_4C composite, which is attributed to the enhanced strength of the matrix alloy.

Key words: Al−B_4C alloy; metal matrix composite; stir casting; microstructure; mechanical properties

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1 Introduction

Al−B_4C metal matrix composites (MMCs) combine the desirable attributes of aluminum and boron carbide. Al matrix has low density, resists corrosion and provides a wide range of strength levels by adding various alloy elements with their subsequent aging hardening [1]. As the reinforcing phase, B_4C is a hard material (surpassed only by diamond and cubic boron nitride) with excellent thermal stability, high wear resistance and large neutron absorption cross section [2,3]. Therefore, Al−B_4C composites are widely used in automotive, aerospace, military industry, especially in nuclear industry for storage and transportation of spent fuels [4−7], and the application is expected to increase with the development of low-cost processing methods.

Among the available manufacturing processes, stir casting is appealing for its flexibility in selecting raw materials and processing conditions, through which composites with various matrixes and reinforcing phases have been successfully fabricated [8−12]. It is also attractive for being economical, allowing large scale composites to be fabricated [13]. However, major challenges lie in wetting and chemical reactions between the ceramic particles and the matrix, homogeneous distribution of reinforcement materials, fluidity of the composites and porosity in the cast metal matrix composites [14], and wide adoption of stir casting method depends on a satisfactory resolution of these technical difficulties.

In fabricating Al−B_4C stir casting composites, Ti was found to be an effective alloy element for promoting the wetting between B_4C and molten aluminum, as well as limiting the degradation of B_4C particles [15,16]. Ti-rich layer was formed around B_4C particle surfaces and this layer was identified to be TiB_2 at a reaction temperature of 750 °C [17]. Based on this, extensive researches have been conducted on Al−B_4C [18], Al−Si−B_4C [19], Al−Mg−B_4C [20], Al−Mg−Si−B_4C [9,10] composites concerning interface, particle distribution, fluidity and mechanical strength of the composites. However, B_4C content in these composites was low, typically with mass fractions less than 15%. For both functional and structural purposes, it is desirable to fabricate Al−B_4C composite with high B_4C content and high strength matrix [6,21−23]. In this work, AA6061−31%B_4C composite was fabricated. On the one hand, it is an endeavor to develop competitive stir casting Al/B_4C composites where their powder metallurgy counterparts

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DOI: 10.1016/S1003-6326(16)64322-4

have been prevalent in nuclear industry for storage and transportation of spent fuels [4,21]; on the other hand, the successful processing of composites with high B_4C content and high strength matrix would indicate sophisticated handle of stir casting method which would further expand its applications. As anticipated, difficulties associated are exacerbated. Major challenges involve incorporation and dispersion of lots of B_4C particles, fluidity deterioration during stirring and casting, and chemical composition control of the matrix.

Based on these considerations, a sophisticated stir casting technique was developed to fabricate large scale (about 12 kg per batch) AA6061−31%B_4C (mass fraction) composite. Key process parameters were studied, the microstructure and mechanical properties of the composite were investigated.

2 Experimental

2.1 Composites preparation and rolling

Figure 1 shows the schematic of the designed equipment used in the experiment. A graphite crucible was placed at the center of the furnace with induction heating coil around. Two thermocouples were set outside and inside of the crucible respectively for heating control. At the bottom of crucible there was a hole with tightly matched stopper, which was designed to pour the composite slurry into the mold consecutively at the end of the mechanical stirring. The mechanical stirrer system was along the axis of the crucible which was able to rotate and adjust its height consecutively. The feeding tank was designed to add ceramic powders and alloy elements at proper time during the stir casting. The vacuum valve provided the whole system with a vacuum limit about 10 Pa, while argon gas was used to balance the atmosphere pressure in cases that the mold separated from the furnace to cool in air. The shape and size of the impeller blade are also shown in Fig. 1. It is a simplified version of a typical three-blade propeller. It has two blades to gain better strength considering the paramount resistance encountered during stir casting. The edge-lengths of the cut parts (two parts are symmetric) are 60, 30 and 30 mm, respectively.

Initially, calculated commercial pure Al (99.7%), Al−20%Si master alloy, Al−10%Ti (mass fraction) master alloy were melted in the graphite crucible and maintained at 750 °C, and B_4C powders were preheated at 400 °C for 2 h. Then, the furnace was open to remove the slag of the melt. Meanwhile, calculated commercial pure Mg (99.99%) and preheated B_4C particles with an average size of 23 μm were placed in the feeding tank. After the system approached its vacuum limits, B_4C powders were added into the melt approximately at the speed of 1000 g/min. The melt was stirred after incorporation of particles in the melt at gradually increasing speed and hold at 550 r/min after all the B_4C powders were added. The stable vortex lasted for 15 min, and Mg granules were added into the melt in the final 1 min. Finally, the stirrer was turned off, the stopper was pulled down, and the composite slurry was poured in a preheated rectangular heat-resistant steel mold (450 °C) which was then separated from the furnace for cooling. Table 1 lists key processes studied. With optimized process, two experimental composites namely

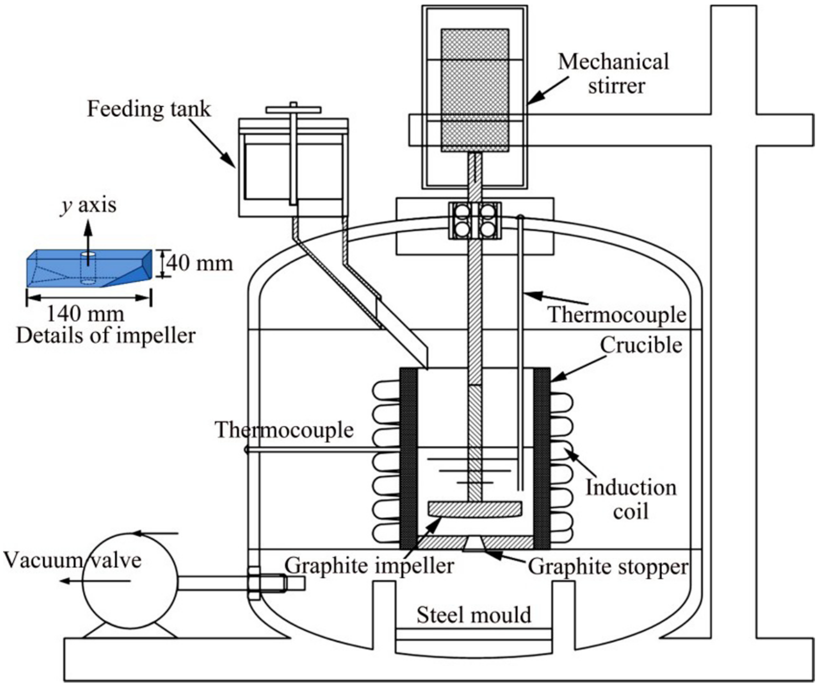

Fig. 1 Schematic of designed equipment