Effect of In Situ TiB2 Particles on the Microstructure and Mechanical Properties of Spray deposited Zn-30Al-1Cu Alloy

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Abstract. In this study, the Zn-30Al-1Cu (wt%) alloy and TiB2/Zn-30Al-1Cu composite were synthesized by the spray atomization and deposition technique. The microstructures and mechanical properties of the spray deposited alloy and composite were studied using scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray diffraction (XRD), and tensile tests. The results have shown that the TiB2 particulates are formed in the microstructure. It was found that the in situ TiB2 particles can refine effectively the grain of the matrix and restrain the grain growth. The tensile test results indicate that the spray-deposited TiB2/Zn-30Al-1Cu composite has better strength than the Zn-30Al-1Cu alloy at room and elevated temperature (150°C) due to the presence of in situ TiB2 particles.

Introduction

In the past several decades, considerable commercial interest has been shown in the development of high specific strength eutectoid Zn-Al aluminum alloys. The Zn-Al alloys have been found to be a promising energy and cost effective substitute to conventional bearing bronzes under heavy load and slow-to-medium speed applications[1,2]. In addition, these alloys have found increasing use for many applications and compete effectively against copper, cast irons, steel fabrications and aluminum alloys[3]. The eutectoid Zn-Al alloys have been modified by the addition of many elements in order to improve the mechanical and tribological properties and corrosion resistance[4]. The addition of 1-3% Cu to the eutectoid Zn-Al alloys improves its mechanical properties and corrosion behavior[5,6]. However, the eutectoid Zn-Al alloy has some disadvantages such as inferior dimensional instability and lower tensile strengths at high temperature. Efforts have been made towards improving the elevated temperature properties of the alloy by means of dispersing second phase[7]. An important solution to improve this is to reinforce the alloy with ceramic particle, such as titanium boride(TiB_2) with high elastic modulus and hardness.

In order to improve the mechanical properties of the Zn-Al alloys, various advanced metallurgical processes, such as continuous casting, thermal evaporation and spray deposition etc. are developed[8,9]. It has been recognized generally that the spray-deposited process is an innovative technique of rapid solidification. Investigations over the past five decades have shown that spray-deposition can be readily utilized to synthesize discontinuously reinforced metal matrix composites (MMCs)[10]. In this process, the matrix material is first melted, then the reinforcements are in situ formed in the molten alloy by chemical reactions between elements or between the elements and the ceramic compounds. The in situ synthesis of particles in this technique differs from the injection of particles in the conventional spray-deposition process.

In view of the above, an innovative spray deposition technique has been applied to produce in situ TiB_2/Zn-30Al-1Cu composites, the objective of the present investigation was to analyze the effect of in situ TiB_2 particles on the microstructure and mechanical properties of spray deposited Zn-30Al-1Cu alloy.

Experimental

The nominal composition of the master alloy was: 30%Al, 1% Cu (wt%) and balance Zinc. TiB_2 particles added by in situ reaction with the alloy melt, the powder bulk's (with Ti, B, Al) composition, purity and size were shown in Table 1. The prepared Ti, B and Al powders were mixed about 30min by mixing machine and then the mixed powder were preformed Φ50*5mm bulk by press machine.

Table 1 Composition, purity and size of the powder package

Composition (powder)	purity	Size (μm)
Ti	99%	45
B	95%	1.25
Al	99.3%	45

The spray-deposition experiments were conducted in a SF-200 type chamber (manufactured by General Research Institute for Nonferrous Metals, Beijing, China). During spray-deposition process, the molten metal was atomized by N_2 at 720°C, the distance of atomizing deposition was kept constant at 500 mm. The bulk Al was superheated to 850 °C a period time and then put Cu into the melt. When the Cu was melt, the 5 wt% mixed powder packages were put into the melt in batches. A small graphite stir propeller which rotated in the melt was used to achieve better distributions of TiB_2 particles. After the in situ reaction, the temperature was dropped to 700°C and the Zn was put into the melt. After pouring out the slag, the melt temperature was kept to 720°C and the melt transferred to the middle package of spray deposition equipment to obtain the deposits. The melt was atomized using nitrogen gas at 0.6-0.8 MPa. The perform, after being cut into cylindrical billets was extruded at a temperature of 250°C with a reduction ratio of 10:1 and a ram speed of 3 mm/s. After extrusion, the material was cooled in air. In this study, a commercially used scheme of heat treatment for the alloy, which involved solution treating at 350°C for 6h followed by water quenching, and artificial ageing at 120°C for 6h.

The microstructures of the composite were characterized using scanning electron microscope (SEM), transmission electron microscope(TEM) and X-ray diffraction. A JEOL JSM-7001F type scanning electron microscopy working at 15 kV attached with energy dispersive X-ray was used to observe the microstructures. The TEM studies were conducted on a JEM-2010 transmission electron microscope operated at an acceleration voltage of 200kV. The disc for TEM was mechanically thinned down to ~70μm then electropolished using a twinjet machine with a 10% nitric acid solution in methanol at -30°C and 15 ~ 25V. The X-ray diffraction experiments were performed on a Japanese Rigaku diffractometer using Cu K_α radiation. The room and elevated temperature tensile tests were conducted with an Instron tensile testing machine at an initial strain rate of 0.5 s-1. The elevated temperature tensile tests were conducted at 150°C at the same initial strain rate. In the tests at 150°C, the specimens were held at the temperature for 10 min before loading.

Results and Discussion

Microstructure

Fig.1 (a) and (b) shows typical scanning electron microscope (SEM) micrographs of spray deposited Zn-30Al-1Cu alloy and 5 wt% TiB_2/Zn-30Al-1Cu composite, respectively. It was found that the lamella eutectoid structure (α-Al and η-Zn) was primary phases in the alloy and composite. However, the size of the grains for the composite was effectively refined by adding 5 wt% TiB_2. Obviously, the presence of the TiB_2 particles increased the density of nuclei in the melt, which was beneficial to the formation of fine matrix grains. Moreover, the surface active TiB_2 particles were pushed onto the solid/liquid interface front and enriched at the grain boundaries during solidification, which obstructed solute redistribution and refined the grains. Higher magnification by SEM of spray-deposited TiB_2/Zn-30Al-1Cu composites, Fig.2(a), revealed some particle-like compounds in the microstructure. Energy dispersive X-ray analysis showed that the compounds contain Ti and B elements , as can be seen in Fig,2(b). Obviously, In situ TiB_2 particles were presented in the microstructure. The TiB_2 particles in the composites are fine with the size of less than 2μm.

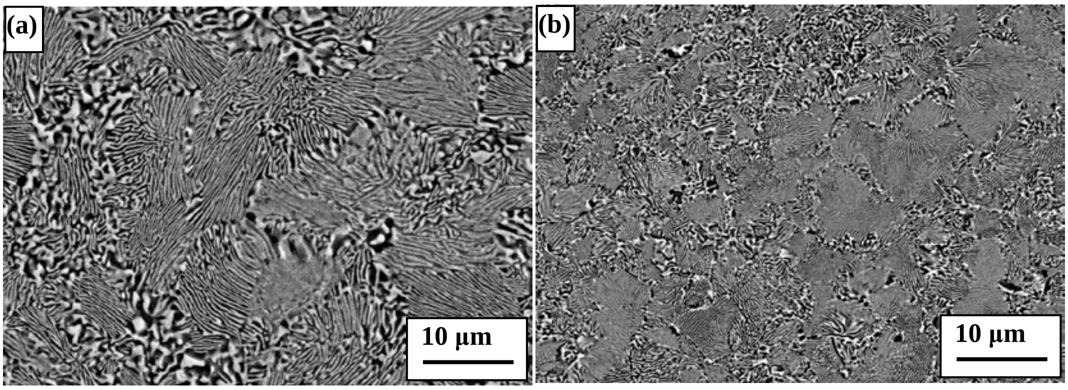

Fig.1 SEM micrographs of spray deposited Zn-Al-Cu alloy and composite, (a) Zn-30Al-1Cu alloy, (b) 5 wt% TiB2/Zn-30Al-1Cu composite

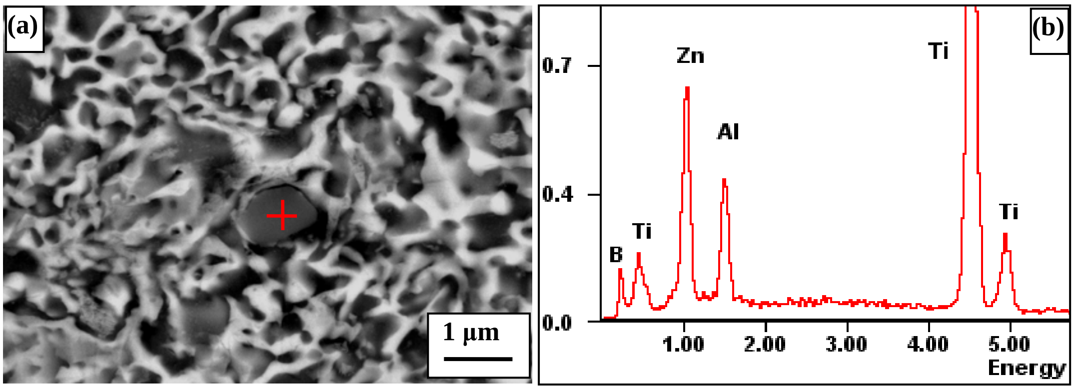

Fig.2 SEM micrographs of spray-deposited TiB2/Zn-30Al-1Cu composites, (a) SEM micrograph, (b) EDS analysis result

Fig. 3 shows the TEM micrographs of the particle-like compound phase on the grain boundaries. Indexing of the selected area diffraction patterns indicates that the phase is TiB_2 compounds with hexagonal parameters of a = 0.3028 nm and c = 0.3228 nm using electron diffraction, as can be seen in Fig. 3(b).

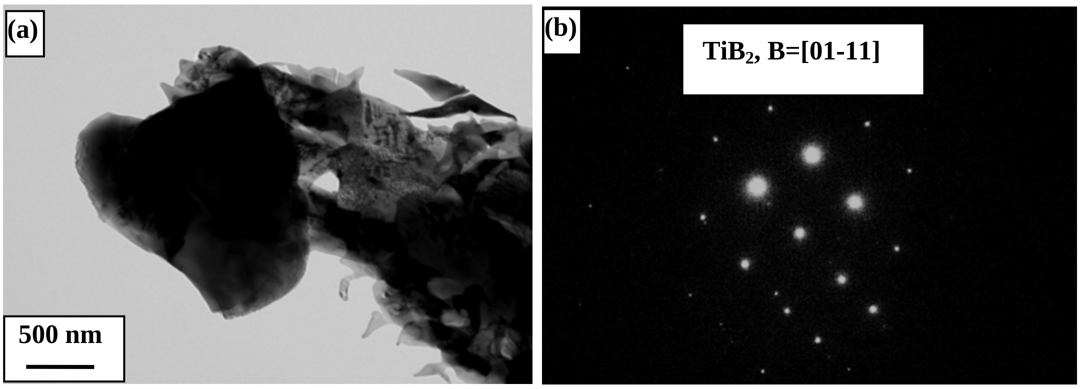

Fig.3 TEM micrographs of spray-deposited TiB2/Zn-30Al-1Cu composites, showing the particle-like TiB2 compounds observed in the microstructure: (a) BF image; (b) selected area diffraction pattern.

Fig.4 shows the X-ray diffraction(XRD) patterns of spray-deposited Zn-30Al-1Cu alloy and TiB2/Zn-30Al-1Cu composite. XRD was performed to identify second phases, and the compounds that can be identified in the microstructure of the composite are ε-CuZn4 and TiB2 phases. Analysis of the diffraction patterns shows that the microstructure of the alloy and composite is mainly composed of the α-Al and η-Zn phases.

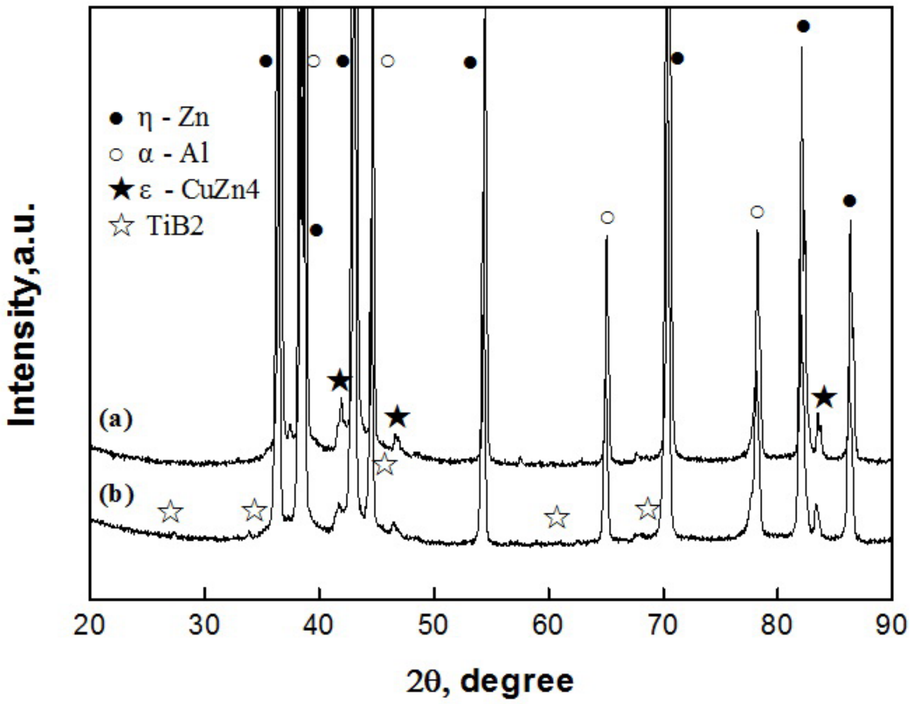

Fig.4 X-ray diffraction patterns of spray-deposited Zn-Al-Cu alloy and composite, (a) Zn-30Al-1Cu alloy, (b) 5 wt% TiB2/Zn-30Al-1Cu composite

Mechanical Properties

The spray-deposited Zn-30Al-1Cu alloy and TiB_2/Zn-30Al-1Cu composite were subjected to tensile testing at room and elevated temperature (150°C) after hot extrusion and T6 temper. Table 2 summarizes the tensile test results. It is worth noting that the tensile strengths of the composite both at room and elevated temperature displayed superior strength. Obviously, in situ TiB_2 particle leads to a distinct improvement of the tensile strengths both at room and elevated temperatures. The dispersion-strengthened TiB_2 particles distributed in the matrix can prevent dislocation moving, and enhance strength of the composite at room temperature. Moreover, the dispersion of the thermally stable TiB_2 particles, in combination with their inhibition to growth of the grains occurring at elevated temperature, is considered to be the key to the enhanced hot strength of the composite.

Table 2 Tensile properties of spray-deposited Zn-30Al-1Cu alloy and TiB_2/Zn-30Al-1Cu composite

Materials	Processing	Temperature (°C)	Yield strength (MPa)	Ultimate tensile strength (MPa)	Elongation (%)
Zn-Al-Cu	SD+Extr.	25	418	471	14
	+T6 temper	150	136	151	32
TiB_2/Zn-Al-Cu	SD+Extr.	25	431	494	12.3
	+T6 temper	150	169	209	30.8

SD: spray deposition; Extr.: extrusion

Conclusions

(1) The microstructure of the spray-deposited TiB_2/Zn-30Al-1Cu composite is composed of the Zn/Al eutectoids, ε-$CuZn_4$ and TiB_2 particles. The grains of the matrix in the spray deposited Zn-30Al-1Cu alloy can be refined significantly by adding 5 wt% TiB_2 particles to the alloy.

(2) The tensile test results indicate that the spray-deposited TiB_2/Zn-30Al-1Cu composite has better strength than the Zn-30Al-1Cu alloy at room and elevated temperature(150°C) due to the presence of in situ TiB_2 particles.

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