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Solid-state composite technology for B_4C_p reinforced magnesium-lithium alloy

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Abstract: B_4C_p/Mg-8Li-1Zn and B_4C_p/Mg-8Li-1Al-1Y composites were prepared with hot-extrusion solid-state composite processing. The microstructures and mechanical properties of the composites were studied. With the optimized parameters, the deformation effects and the migration of α phase are improved, and the amount and size of foil gaps are decreased. The bonding force between foils is improved, and the oxidation of foils is lowered. The results of tensile test show that the strengths of the B_4C_p/Mg-8Li-1Zn and B_4C_p/Mg-8Li-1Al-1Y composites are increased obviously after hot-extrusion solid-state composite processing (238 MPa and 257.23 MPa, respectively). The specific strength of B_4C_p/Mg-8Li-1Al-1Y composite is the highest (169.23×10^3 cm).

Key words: Mg-Li base composites; B_4C; microstructures; mechanical properties

1 Introduction

The ultra-lightweight property makes magnesium-lithium base alloys attract more and more interest from researchers. Magnesium-lithium base alloys have many potential applications in the fields of aerospace, automobile and military equipments[1−3]. However, the strength of magnesium-lithium alloys is often dissatisfied for these applications.

Therefore, many researchers focus on the alloying for magnesium-lithium base alloys. The alloying elements include Al, Zn, Mn, Y, Ce, etc[4−5]. Thermomechanical work, such as hot-extrusion, hot-rolling and ECAP, is another way to improve the mechanical properties of magnesium-lithium alloys[6−9]. Composite technology is also effective means to improve the strength of the alloys[10−11].

There are many reports about the magnesium-lithium base composites. Al_2Y_p, Al_2O_{3f}, B_4C_p, C_f, B_p, etc, have been used to reinforce magnesium-lithium base alloys with stir casting, foil metallurgy process, pressure infiltration process, etc[12−16]. Recently, WANG et al[12] studied the Al_2Y_p/Mg-Li composites and obtained a good composite effect with a large increased strength. To avoid the oxidation of melt during the process at high temperature, a solid composite technology was used in this work, and the B_4C_p reinforced magnesium-lithium alloys were prepared with this technology. Mg-8Li-1Zn and Mg-8Li-1Al-1Y alloys were prepared with vacuum melting method under the argon atmosphere. B_4C_p/Mg-8Li-1Zn and B_4C_p/Mg- 8Li-1Al-1Y composites were prepared with hot-extrusion solid-state composite processing. The microstructures and mechanical properties of composites were also investigated and discussed.

2 Experimental

Pure magnesium ingot (99.95%, mass fraction), pure lithium ingot (99.90%), pure aluminum ingot (99.95%), magnesium-yttrium master alloy (containing 25.67% Y), and B_4C particles (<10 μm) were used in this experiment. The as-cast materials were melted in a vacuum induction melting furnace under the protection of argon atmosphere. The furnace chamber pressure was pumped to 1×10^{-2} Pa, then pure argon was input as protective gas before melting. The as-cast materials were

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homogenized at 280 °C for 24 h, and were rolled at 230 °C. The as-rolled materials (2 mm in thickness) were cut into foils (40 mm×45 mm). B_4C particles were soaked in ethanol to remove any surface contamination. The B_4C particles were then suspended in an ethanol to form suspension liquid. The suspension liquid was painted on Mg-Li foils. The amount of B_4C was determined by the mass change of the foils before and after using the B_4C powder. The compositions of the composites are listed in Table 1. The foils were stacked together and press bonded at 230 °C. Then, they were extruded at 280 °C.

Table 1 Composition of composites (mass fraction, %)

Matrix alloy	Composite
Mg-8Li-1Zn	Mg-8Li-1Zn-2.4B_4C_p
Mg-8Li-1Al-1Y	Mg-8Li-1Al-1Y-2.34B_4C_p

The microstructures of samples were measured with optical microscope (OM) after being etched with an etchant of 3% (volume fraction) nital. The tensile test was performed using a universal tensile testing machine with a tensile speed of 2 mm/min.

3 Results and discussion

3.1 Microstructures and phase analysis

Microstructures of the as-cast and B_4C_p/Mg-8Li-1Zn composite are shown in Fig.1. In as-cast Mg-8Li-1Zn alloy, there are two phases (*α* and *β*). The *α* phase is block-like shape. The recrystallization microstructure can be observed in B_4C_p/Mg-8Li-1Zn composite after hot-extrusion solid-state processing. The zigzag interface of foils is shown in Fig.1(c), and on the edge of the foils there is a continuous film of *α* phase. The presence of this continuous film is caused by the phase motion. *α* phase is more difficult to be deformed than *β* phase. Therefore, *α* phase is squeezed into the edge of the foils.

Microstructures of the as-cast and B_4C_p/Mg-8Li-1Al-1Y composite are shown in Fig.2. In as-cast Mg-8Li-1Al-1Y alloy, there are two phases (*α* and *β*). *α* phase is spherical-like shape. The recrystallization microstructure can also be observed in B_4C_p/Mg-8Li-1Zn composite after hot-extrusion solid-state processing. After hot-extrusion solid-state processing, the foil gap size is decreased. Therefore, the binding extent of interface in foils is improved.

3.2 Mechanical properties

Figures 3 and 4 show the strength and elongation of the matrix alloys and corresponding composites. Figure 5 shows the specific strength of the matrix alloys and corresponding composites. Compared with the

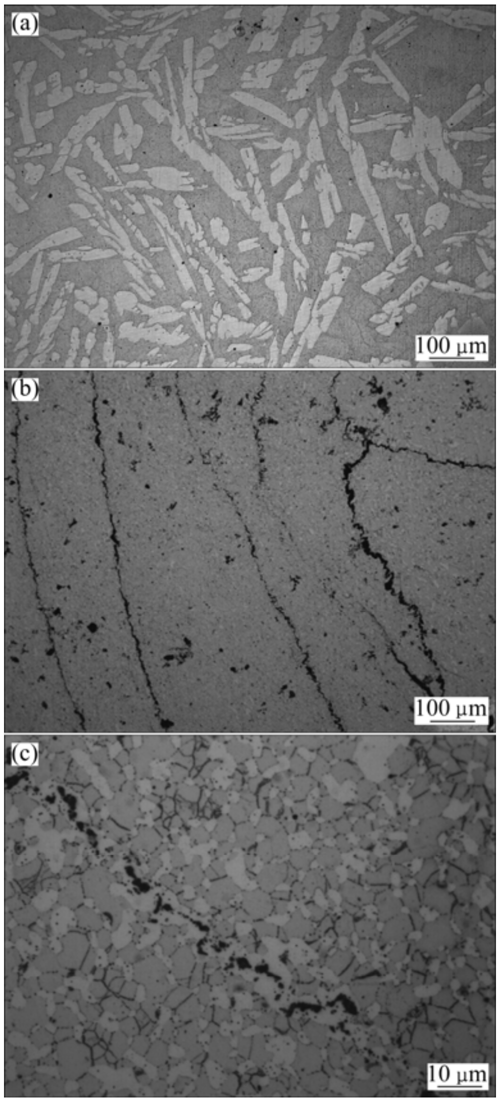

Fig.1 Microstructures of Mg-8Li-1Zn alloys: (a) As-cast; (b) B_4C_p/Mg-8Li-1Zn composite (low magnification); (c) B_4C_p/Mg-8Li-1Zn composite (high magnification)

mechanical properties of as-cast alloy, the strengths of the as-rolled alloys and composites increase, the elongations of the as-rolled alloys and composites are reduced. B_4C_p/Mg-8Li-1Al-1Y composite possesses peak strength (257.23 MPa).

The strength increase of the as-rolled alloys can be attributed to the following reasons. Firstly, the amount of defects is decreased after rolling, such as shrinkage porosity and gas porosity. Secondly, the grains are refined after rolling. Thirdly, the most significant effect for the increase of strength is the work hardening. Besides, the dislocation density also increases significantly due to the deformation process. Thus the above factors cause lots of dislocation tangles. Finally, the motion of dislocations becomes more difficult and the strength of alloy is improved accordingly. Then the work hardening is the mainly factor for the reduction of

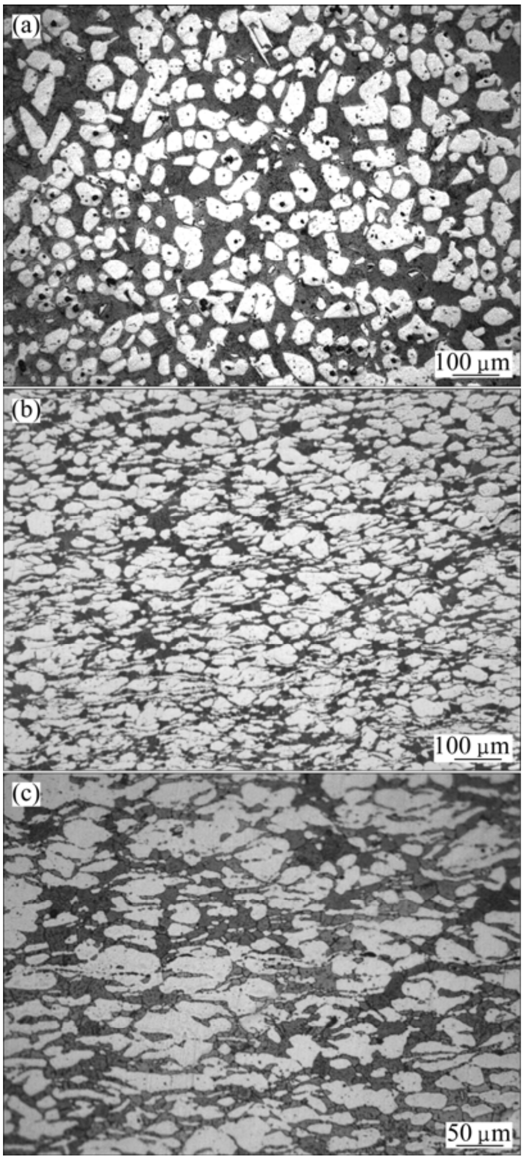

Fig.2 Microstructures of Mg-8Li-1Al-1Y alloys: (a) As-cast; (b) B_4C_p/Mg-8Li-1Al-1Y composite (low magnification); (c) B_4C_p/Mg-8Li-1Al-1Y composite (high magnification)

elongation of as-rolled Mg-8Li-1Zn and Mg-8Li-1Al-1Y alloys.

There are three aspects for the strength increase of composites. Firstly, the extent of work hardening is increased further after extrusion. Secondly, the zigzag interface and B_4C_p can increase friction between foils. The slip of grain boundary and dislocation can be restrained. Then, the bonding extent of interface between foils is mainly factor for the strength of composites. Thirdly, the grains are refined after rolling and annealing, especially the fine equiaxed grains. While the amount of dislocation tangles is increased, and the elongation of composites is reduced.

The density of alloy is increased after the B_4C_p is added into the alloys. The strength of alloys is increased obviously. Therefore, the specific strength of composites is higher than that of as-cast alloys. The specific strength of B_4C_p/Mg-8Li-1Al-1Y composite is the highest (169.23×10^3 cm).

4 Conclusions

1) The alloys are composed of α phase (white) and β phase (gray). In as-cast Mg-8Li-1Zn alloy, α phase is block-like shape. In as-cast Mg-8Li-1Al-1Y alloy, α phase is spherical-like shape.

2) The work hardening is mainly factor for strength increase of alloys after rolling. The recrystallization microstructure of composites can be observed after hot-extrusion solid-state processing. The bonding extent of interface between foils is the mainly factor for the strength increase of composites.

3) Compared with the mechanical properties of as-cast alloy, the strengths of the as-rolled alloys and composites increase, the elongations of the as-rolled alloys and composites are reduced. B_4C_p/Mg-8Li-1Al-1Y composite possesses peak strength (257.23 MPa). The specific strength of B_4C_p/Mg-8Li-1Al-1Y composites is the highest (169.23×10^3 cm).

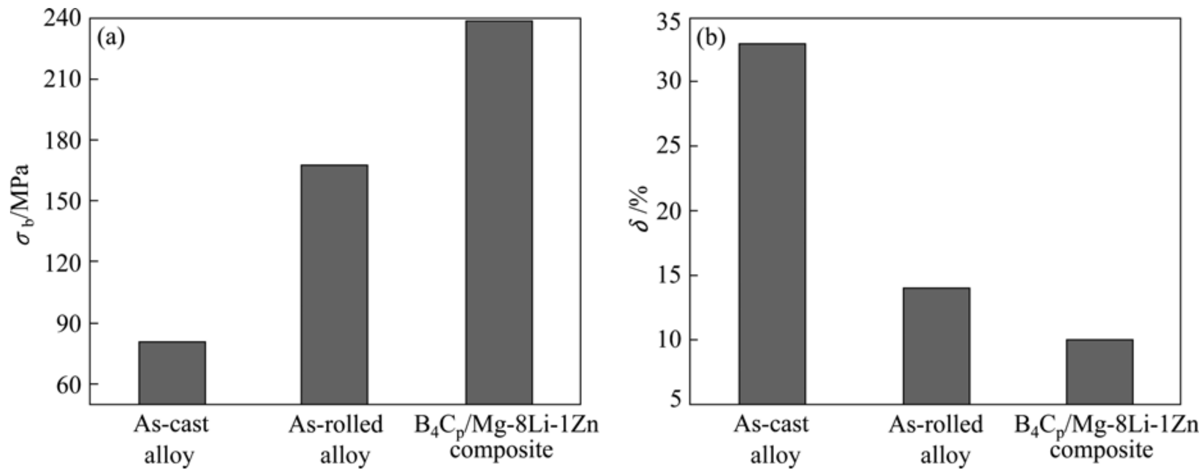

Fig.3 Strength (a) and elongation (b) of Mg-8Li-1Zn alloys

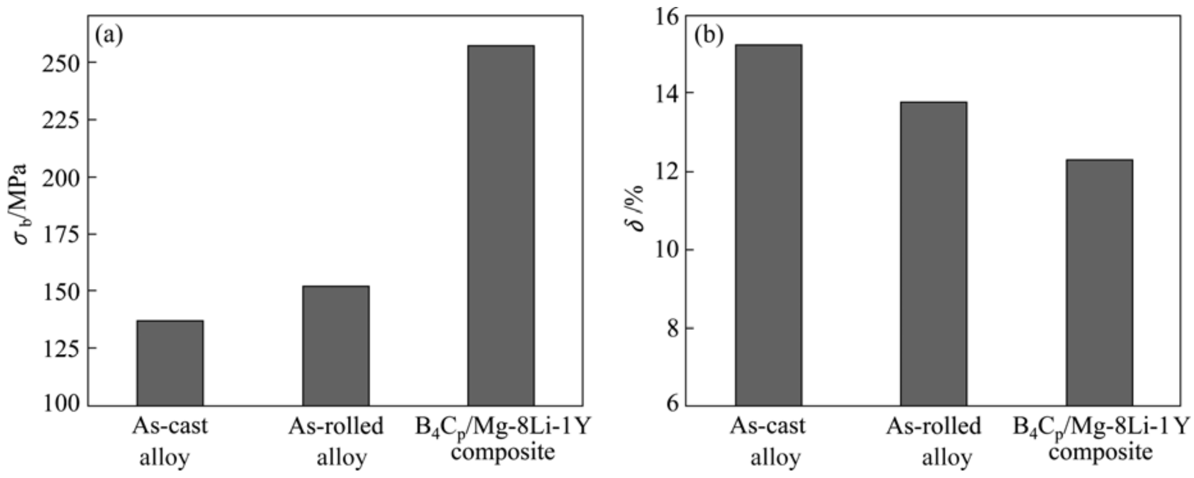

Fig.4 Strength (a) and elongation (b) of Mg-8Li-1Al-1Y alloys

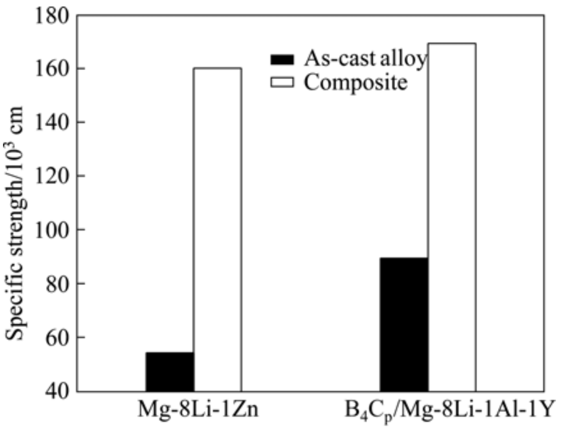

Fig.5 Specific strength of alloys

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B_4C_p 增强镁锂基合金的固态复合技术

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摘　要：采用热挤压固态复合技术制备 B_4C_p/Mg-8Li-1Zn 和 B_4C_p/Mg-8Li-1Al-1Y 复合材料，研究复合材料的显微组织和力学性能。结果表明：随着参数的优化，材料的变形效果和 α 相的移动性得到提高, 而复合薄层的数量和间距尺寸减小；界面结合力得到提高的同时降低了界面的氧化程度。拉伸测试结果表明，通过固态热挤压复合强化, B_4C_p/Mg-8Li-1Zn 和 B_4C_p/Mg-8Li-1Al-1Y 复合材料的强度得到明显提高，分别为 238 MPa 和 257.23 MPa；B_4C_p/Mg-8Li-1Al-1Y 复合材料的比强度最高 (169.23×10^3 cm).

关键词：镁锂基复合材料；B_4C；显微组织；力学性能

(Edited by LI Xiang-qun)