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Enhancement of mechanical properties of duplex Mg−9Li−3Al alloy by Sn and Y addition

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Abstract: For enhancement of mechanical properties in Mg−9Li−3Al alloys, Mg−9Li−3Al duplex alloys were alloyed by addition of Sn and Y. Microstructure evolution and mechanical property response of as-cast Mg−9Li−3Al alloys by alloying with Sn and Y were investigated by optical microscopy, scanning electron microscopy, X-ray diffractometry and tensile tests. The results indicate that considerable blocky dendrites of primary α phase in Mg−9Li−3Al alloys become lath-like due to the addition of Sn. With addition of Y, Mg−9Li−3Al alloy consists of both block-like and lath-like α-Mg dendrites. The as-cast Mg−9Li−3Al−1Sn−1Y alloy shows a yield strength of 118 MPa, ultimate tensile strength of 148 MPa and the elongation to failure of 21%. Improvement in both strength and elongation of Mg−9Li−3Al alloys with Sn and Y addition is attributed to the combined action of $MgLi_2Sn$ and Al_2Y intermetallic compounds.

Key words: Mg−Li alloys; grain structure; tensile properties; precipitation strengthening

1 Introduction

Magnesium alloys, with low density and high specific strength, have been widely used in automobile, aerospace and military industries [1−3]. However, conventional Mg alloys usually show poor ductility for lack of slip systems with a hexagonal-closed-packed (HCP) crystal structure. By addition of Li, the density of magnesium alloys can be reduced to 1.35−1.65 g/cm^3, which is only the half that of aluminum alloys [4]. Moreover, magnesium alloys with Li addition have a good formability by transforming the crystal structure from HCP to body-centered-cubic (BCC) with more slip systems and reducing the axial ratio of the HCP Mg [5−7]. According to the Mg−Li phase diagram, when the mass fraction of Li is in the range of 5.7%−10.3%, β-Li with BCC crystal structure forms in hexagonal α-Mg, leading to a duplex structure containing both α and β phases. When the content of Li is lower than 5.7% or higher than 10.3% (mass fraction), the Mg−Li alloy is composed of either α phase or β phase. Although the Mg−Li alloys have comparative advantages over other magnesium alloys, for a wider application in engineering applications, they still have some shortcomings needed to be overcome, such as low strength, stable high temperature properties, and poor corrosion resistance.

For the enhancement of strength of materials, alloying is considered to be an effective approach to improve the strength of Mg−Li alloys by both solution hardening and precipitation hardening [8,9]. For example, Al, Sn and Zn are added into Mg−Li based alloys for improvement in strength [10−13]. Among them, Al is the most widely used alloying element in strengthening of Mg−Li alloys and WU et al [14] reported that the strength of Mg−Li alloys increased with the increase of Al content until the Al content reached 3% (mass fraction). Although solution hardening and precipitation hardening lead to the improvement of strengths of metal and alloys, simultaneous improvements in strength and ductility for most engineering materials can be achieved effectively by grain refinement [15,16]. Sn was added into Mg−9Li alloys to form $MgLi_2Sn$ for grain refinement during casting, and $MgLi_2Sn$ compounds also act as heterogeneous nucleation sites for dynamic recrystallization during the following plastic deformation

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process [17]. Recently, it has been reported that the addition of rare earth (RE) elements into Mg−Li alloys is quite effective to improve mechanical properties of magnesium alloys [18−21]. According to ZHU et al [22], by adding Y into Mg−Li alloys, mechanical strength of Mg−Li alloys can be increased due to the formation of Al_2Y. PENG et al [23] reported that Al and Y addition into Mg−8Li alloy ensured good mechanical properties after a homogenization treatment at 300 °C for 12 h.

In the present work, a series of duplex Mg−9Li−3Al alloys with Sn and Y addition were fabricated using vacuum melting and microstructure evolutions with different alloying elements were explored. Simultaneously, the corresponding tensile properties were examined and the strengthening mechanisms were discussed in detail.

2 Experimental

Commercial pure (CP) magnesium ingot, CP aluminum, and Mg−Li−Al and Mg−Y master alloys were melted in a steel crucible in vacuum induce furnace at the temperature of 720 °C and poured into a cylinder steel mold with a diameter of 55 mm and height of 100 mm preheated to 200 °C. After solidification, samples were homogenized at 300 °C for 12 h to be prepared for the tensile tests.

Optical microscope (OM), scanning electron microscope (SEM), energy dispersive spectrometer (EDS) and X-ray diffractometer (XRD) were used to characterize the microstructure and phase compositions of alloys. Samples for OM/SEM observation and XRD characterization were ground, polished and then etched with 4% (volume fraction) nital solution. Tensile tests were conducted on a WDW−200E testing machine on flat samples 1 mm thick and 3 mm wide with a gauge length of 15 mm at a constant strain of 1×10^{-3} s^{-1} and the loading direction was parallel to the axial direction of the cylindrical ingot.

3 Results and discussion

3.1 Microstructure analysis of Mg−9Li−3Al alloys with Sn and Y addition

Figure 1 shows the optical microstructures of as-cast Mg−9Li−3Al based alloys. It is found that Mg−9Li−3Al alloys have two-phase structure, which is identical to the Mg−Li phase diagram. On optical microscope, the two phases are presented to be different colors, i.e. α phase shows to be white while β phase is dark. Meanwhile, abundant black points are observed inside β phase. Further investigation of Fig. 1 indicates that shapes and sizes of α and β phases are directly dependent on the addition of alloying elements. As seen in Fig. 1(a), blocky α phase distributes evenly inside β-Li matrix and second phases (black points) scatter inside β phases in the Mg−9Li−3Al alloy. With the addition of

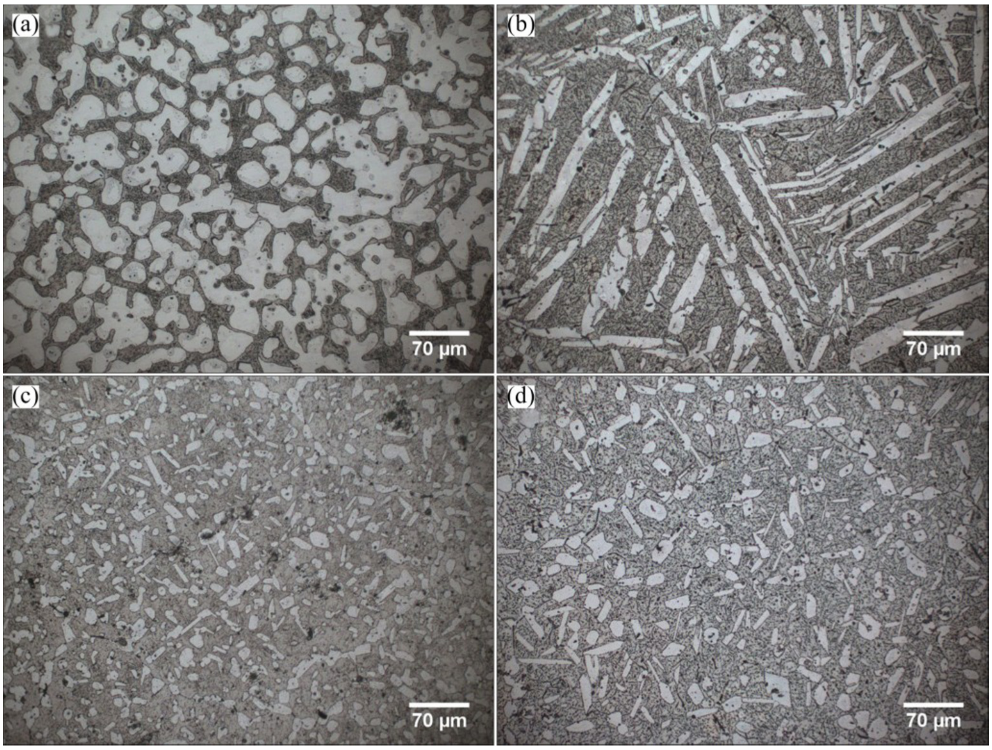

Fig. 1 Optical microstructures of Mg−9Li−3Al based alloys: (a) Mg−9Li−3Al; (b) Mg−9Li−3Al−2Sn; (c) Mg−9Li−3Al−2Y; (d) Mg−9Li−3Al−1Sn−1Y