Effect of Trace La on Microstructure and Mechanical Properties of Al-Si-Mg alloy

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Abstract： The effects of La elements (0, 0.02, 0.04, 0.08 wt.%) on the microstructure and mechanical properties of Al-Si-Mg sand casting alloy were studied by means of optical microscopy(OM), X-ray diffractometry (XRD) and scanning electron microscopy (SEM), the mechanical properties test. The results show that the size of coarse eutectic silicon and secondary dendrites in the as-cast alloy can be significantly refined by the addition of trace La element. The as-cast alloy without La element is mainly composed of Al phase, Si phase, and a small amount of Mg2Si phase, Al3Ti phase and AlFeSi phase. When the content of La element exceeds 0.08%, Al3La phase appears in the alloy. With the increase of La content, the tensile strength of the alloy increases gradually, the elongation increases first and then decreases. The alloy containing 0.04%La has the best mechanical properties, the tensile strength and elongation of the alloy are 160 MPa, 4.52% and 350 MPa, 2.35%, respectively, in the as-cast and aged states. Continue to increase La content, the tensile strength and elongation of alloy decreased rapidly. The re-coarsening of eutectic silicon and secondary dendrites, and the appearance of Al3La phase results in rapidly decreased in tensile strength and elongation of alloy.

Keywords: Al-Si alloy; La; microstructure; mechanical properties,

1 Introduction

A357 alloy is a hypoeutectic Al-Si alloy with excellent casting and mechanical properties, which is suitable for casting high-strength parts with complex shapes[1,2]. It has been widely used in aviation, aerospace, military, automotive and other industrial fields[3,4]. At home and abroad, the tensile strength of the sand mold casting alloy is usually required to be more than 320 MPa and the elongation is more than 5%, but in the traditional sand mold casting alloy production process, it has the large grain size and precipitated Si-phase size due to the slow cooling rate, which is difficult to achieve the required performance indicators[5]. Modifying Si is the most effective way to increase tensile strength, especially elongation. The commonly modification method is strontium modification because it has a high absorption rate and a long effective period, however, the burn-off rate is high and the absorbs gas in alloying solution is serious during the holding process, which affect the quality and mechanical properties of the castings[6]. Due to the fact that rare earth elements not only have good deoxidation and slag removal effects, but also have long-term modification of mono-silicon and refinement of grain size, they have become a research hot spot for alloying elements of aluminum alloy. Many studies have shown that adding La, Ce, Sc and Y elements to the Al-Si alloy can refine the α-Al grains and modify the eutectic Si, thereby improving the mechanical properties of the alloy[7-10]. However, addition of a single rare earth element needs a relatively high content to achieve a better modification effect, and the modification mechanism is different from that of the commonly used industrial modification agents, resulting in a large gap in modification effect. Therefore, the present study takes the Al-7Si-0.5Mg alloy (A357) as the research object and studies the effects of trace Sr (0.015 wt%) and La (0-0.08 wt%) elements on the microstructure and mechanical properties of the alloy. It aims to find the optimal addition level of rare earth metal, provide experimental basis for the development of new low-cost Al-Si alloys with better performance.

2 Experimental procedure

Gravity casting is performed in Al-7Si-0.5Mg-0.2Ti-0.015Sr-xLa (x=0, 0.02, 0.04, 0.06, 0.08wt.%, mass fraction, the same below) alloys. The main experimental raw materials are industrial pure aluminum ingot (99.95wt.%), pure Mg ingot (99.95wt.%), Al-10wt.%Si intermediate alloy, Al-10wt.%Sr intermediate alloy, Al-10wt.%La intermediate alloy and Al-5wt.%Ti intermediate alloy. The alloy is smelted by resistance furnace. After melting, the alloy is refined and degassed at 730 °C and kept for 15 minutes before casting into a gravity sand mold at 720 °C. The solid solution treatment of alloys were conducted at 535 °C for 12h, and then the alloys containing different La contents were aged at 170℃ for 10h. The alloy samples were etched with 0.5% hydrofluoric acid solution, and the microstructure was observed on OLYMPUS microscope. Phase analysis was carried out by DPMax 2500 X-ray diffractometer. The microstructure and energy spectrum were analyzed by Sirion-200 scanning electron microscope. The tensile test was carried out on the CSS-44100 universal electronic experimental machine.

3 Result and discussion

1. Influence of trace La on microstructure of A357 alloy

The X-ray diffraction patterns, the SEM microstructure and EDS analysis show that the as-cast A357 alloy without La mainly consists of Al phase, Si phase, a small amount of Mg_2Si phase and AlFeSi phase. After adding 0.08%La, a small peak of Al_3La phase appears in the alloy. The optical microstructures of the as-cast A357-xLa (x=0, 0.02, 0.04, 0.08 wt.%) alloys shows that the content of long bar-shaped silicon phase gradually decreases and it transforms into cubic and short rod-shaped phases. The size of eutectic Al dendrite also gradually decreases, with the La content increases to 0.04%. However, when the content of La increases further, the eutectic Si phase appears with more long bar-shaped particles and rapidly coarsens, and the eutectic Al dendrite also re-coarsens.

2. Effect of trace La on the mechanical properties of A357 alloy

It can be seen that the tensile strength and elongation of the cast alloy without La element were 157 MPa and 4.38%, respectively. As the La content increases, the tensile strength of the cast alloy gradually increases, while the elongation first increased and then decreased. The tensile strength and elongation of the alloy with 0.04% La element were improved to 160 MPa and 4.52%, respectively. Continuing to increase the La content, the elongation rapidly decreased. After aging, the tensile strength of the alloy was significantly improved, but the elongation sharply decreased. The tensile strength and elongation of the peak-age alloy without La element were 334 MPa and 2.18%, respectively. With the increase of La content, the tensile strength and elongation of the peak-age alloy were improved. The tensile strength and elongation of the alloy with 0.04% La element were improved to 350 MPa and 2.35%, respectively. The tensile strength and elongation decrease rapidly with further increase of La content.

4 Conclusion

1. With the addition of La element, the coarse, long rod-shaped and square-shaped eutectic silicon at the grain boundary of the cast alloy is significantly refined, and the secondary dendrite arm spacing also gradually decreases. When the addition of La exceeds 0.04%, the eutectic silicon and secondary dendrite arm spacing become coarse again.

2. The cast alloy without La mainly consists of Al phase, Si phase, and a small amount of Mg_2Si phase, Al_3Ti phase, and AlFeSi phase. After the addition of La exceeds 0.08%, the alloy contains Al_3La phase.

3. With the increase of La content, the tensile strength of the alloy gradually increases, while the elongation first increases and then decreases. The alloy with 0.04% La content has the best mechanical properties, with a tensile strength of 160 MPa and an elongation of 4.52% in the cast state and 350 MPa and 2.35% in the aged state. Continuing to increase the La content results in the re-coarsening of the eutectic silicon and the secondary dendrite arm spacing, as well as the appearance of the Al_3La phase, which lead to a rapidly decrease in tensile strength and elongation.

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