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Advanced Aluminum Alloys Containing Rare-earth Erbium

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Abstract

In our research, the effects of rare-earth element erbium (Er) on microstructures and mechanical properties of some aluminum alloys are investigated. It is shown that aluminum alloys with Er additions, including Al-Mg, Al-Zn-Mg, Al-Zn-Mg-Cu, 1420 Al-Li alloys and high purity aluminum, have refined grain size, superior thermal stability, and higher hardness or tensile strength with unchanged ductility. It is concluded that, in most aluminum alloys, Er is an effective alloying element.

1. Introduction

In the last decades, the usage of rare earths, especially La, Ce, Nd, Y, Sc and mischmetall in aluminum alloys has been widely studied. These studies show that the microstructure of these alloys is modified, the mechanical properties and other properties such as electrical conductivity, optical quality and corrosion resistance are also improved.

The effects of rare earth and transition elements in aluminum alloy are evident for their special electronic structures, which have received more attention. The effects of rare-earth elements in aluminum alloys are determined by their characters. Because of their large atomic radius and tendency to lose two outermost level s-electrons and a 5d or 4f electron to become trivalent ion, rare earth metals are very active in chemical reactions.

Serving as degasifying and deslagging agent, they are apt to react with the gas, impurity and matrix in the aluminum alloys and at the same time, rare-earth compounds with stable chemical property and high melting point are formed. As strengthening phase, those compounds have the ability to change the structure and improve properties of aluminum alloys.

In the past, the research on rare-earth containing aluminum alloys was developed mainly by some specific industrial assignments, especially in China, and exploration of the application of the rare-earths in aluminum alloys has been concentrated on the effect of misch-metal in some commercial aluminum alloys.

As a matter of fact, many scientific problems are still unknown due to the complexity of aluminum alloy system and the difficulty and limitation of the characterization of the effects of rare-earths. Therefore, it is necessary to research the effects and distribution of many unitary rare-earths (Er, Y, Ce, La, Gd, Nd, Sc, ect.) in high-purity aluminum and aluminum alloy. In our previous research, we found, for the first time, that Er (erbium) is an effective alloying element in aluminum alloys [1-4].

The work on the effects of Er in Al-Mg, Al-Zn-Mg, Al-Zn-Mg-Cu, Al-Li, Al-Cu and other aluminum alloys was carried out consequently. And some new research findings were obtained.

2. Research Results

The effects of rare-earths, such as Er, Ce, La, Gd, Nd, Y and Sc, as well as their distribution in high purity aluminum was studied in our work. We found that Er was an effective alloying element in high purity aluminum. Thus the effects and acting mechanism of Er in aluminum alloys became the main focus of our research. For the purpose of comparison, the mechanism of action of Sc in aluminum alloys was also studied.

2.1 The Effect of Er in Al and Al-Mg Alloys

With the addition of Er to high purity Al and Al-Mg alloys, the as-cast grains are refined [5,6], Figure 1, and thermal stability is improved. With an increase in the content of Er, the hardness and strength are increased as well. The explanations are summarized as follows: the major existing form of Er in aluminum alloys is Al_3Er, as shown in Figure 2. The Al_3Er phase has a high melting-point, good stability, a structure that is similar to Al_3Sc and Al_3Zr, and coherent or semi-coherent with the matrix. During solidification, primary particles of Al_3Er act as heterogeneous nucleation sites of aluminium grains and thus the nucleation efficiency is improved and aluminium grains are refined. The harness and strength are increased due to the finer grain size.

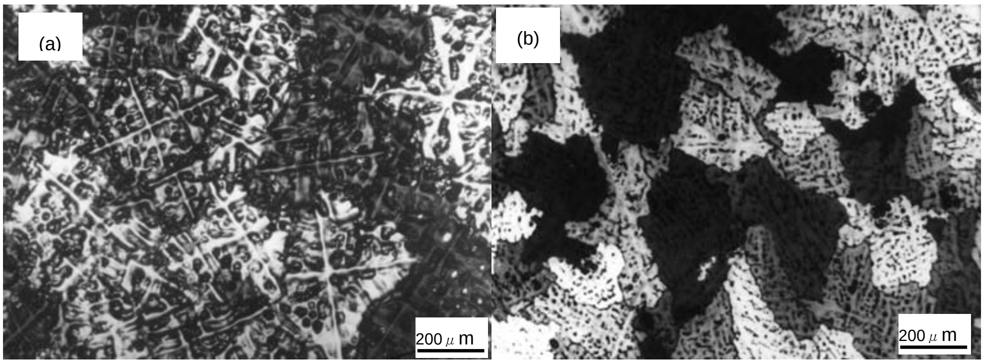

Figure 1: Micrographs of as-cast Al-Mg-(Er) alloys (wt%). (a) Al-5Mg. (b) Al-5Mg-0.5Er.

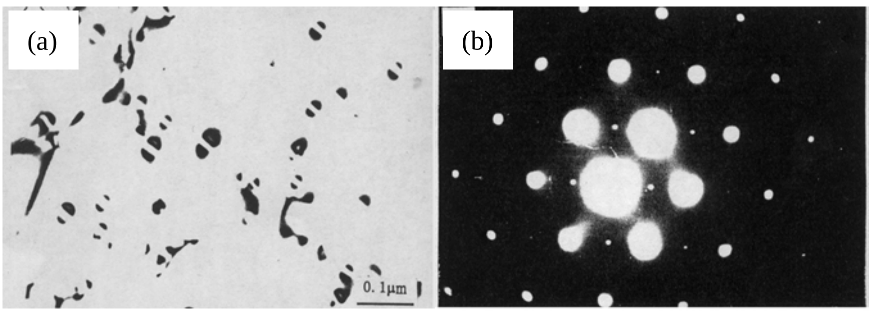

Figure 2: TEM micrograph and SAED pattern of Al-Er alloy.

2.2 Effects of Er in Al-Cu alloys

Additions of Er to an Al-4Cu alloy refine the dendritic structure [7], Figure 3. The recrystallization temperature of this alloy is also increased, despite the fact that the strength is unchanged. A low melting point phase Al_8Cu_4Er (Figure 4), instead of Al_3Er, is formed in the Al-Cu-Er alloy. In addition, the $CuAl_2$ phase, the major hardening constituent, is reduced due to the presence of Al_8Cu_4Er.

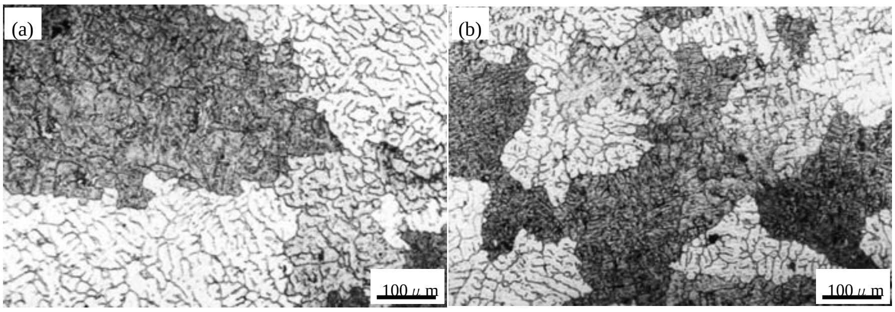

Figure 3: Micrographs of as-cast Al-Cu alloys (wt%). (a) Al-4Cu, (b) Al-4Cu-0.2Er.

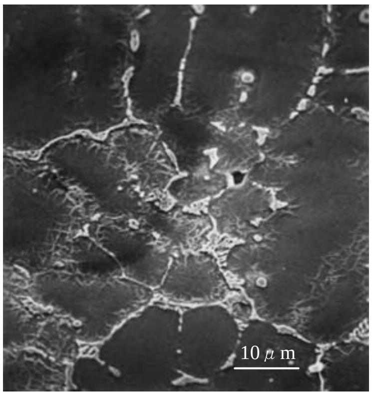

Figure 4: SEM micrograph of as-cast Al-4Cu-0.2Er alloy (wt%).

2.3 Effects of Er in Al-Zn-Mg and Al-Zn-Mg-Cu alloys

As the basis of high-strength 7000 series aluminium alloy, Al-Zn-Mg alloys have been extensively investigated due to their technological importance. The effect of Er contents on tensile properties of Al-Zn-Mg alloys at room temperature, under cold rolled and aged conditions (120℃/24h) respectively, is shown in Figure 5. It can be seen that the tensile strength σ_b and the yield strength $\sigma_{0.2}$ of the Al-Zn-Mg alloy have been increased significantly with the Er addition, yet the elongations decrease a little [8]. When the Er content is 0.1%, the increment in strength is the most significant. The strengthening increment reduces with an increase in the Er content, though the strength continues to increase compared to the Al-Zn-Mg alloy free of Er. It is notable that the elongation of the alloys decreases a little with Er additions. In the Al-Zn-Mg-Cu alloy, similar results were obtained.

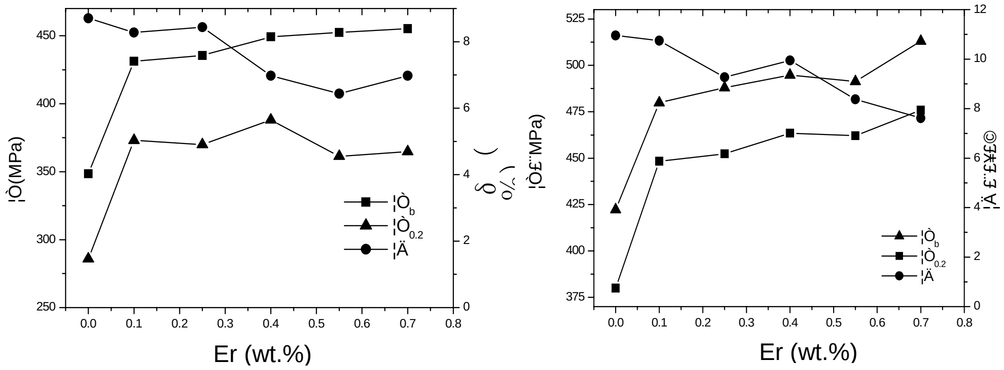

Figure 5: Relationship curves between Er content and strength of Al-Zn-Mg alloy. (a) Cold rolled (b) Aged at 120℃ for 24h

The addition of Er to the Al-Zn-Mg alloys has a significant effect on the as-cast microstructure, i.e. grains can be remarkably refined and the dentrite structure almost disappears. This probably can be interpreted that the fine primary particles Al_3Er, formed during solidification, act as nucleation sites. The recrystallization temperature of the Al-Zn-Mg alloy is also increased by about 50℃ by adding trace rare earth element Er.

2.4 Effects of Er in 1420 Al-Li alloy

The addition of small amounts of Er to the 1420 alloy has been shown to have a significant effect on mechanical properties in the under-aged condition, with the yield (YS) and ultimate tensile strength (UTS) improved by 28% and 7% respectively, while the ductility decreased a little. The higher strength is attributed mainly to the increased number density and increased volume fraction of δ’ (Al_3Li), with Er additions, as well as the formation of Al_3Er phase and Al_3Li/ Al_3Er composite particles.

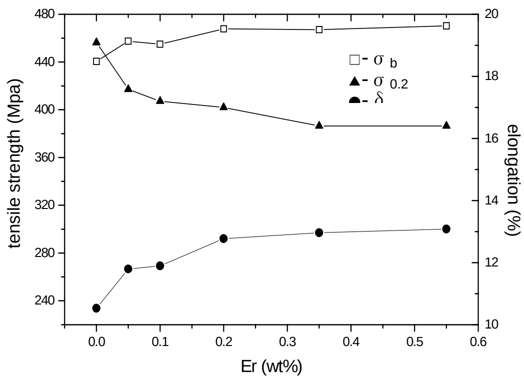

Figure 6: Relationship curves between Er content and strength of 1420 Al-Li alloy.

2.5 Effects of Sc on Microstructures and Properties of Al-Cu Alloys

It is well known that the strength and thermal stability are improved and the liability of thermal crack is reduced when rare-earth elements (La, Ce, Y ect.) are added to Al-Cu alloys. Since there is little information on the interaction between rare-earth elements and Cu, the microstructure and mechanical properties of Al-Cu alloys, with different contents of Cu and Sc were studied in our group.

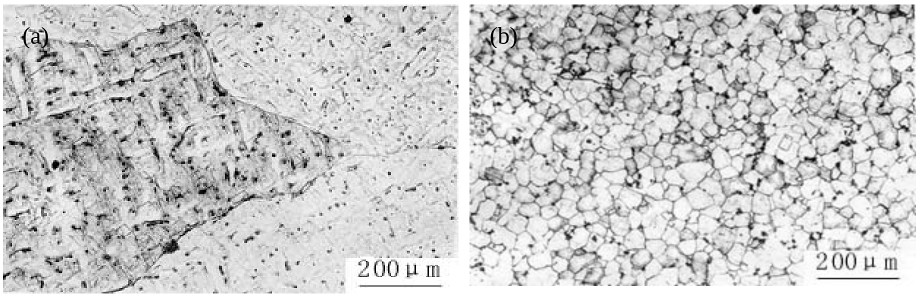

Figure 7 Micrographs (MO) of as-cast Al-Cu alloys(wt%) (a) Al-2Cu, (b) Al-2Cu-0.5Sc.

Our results are: (a) The influence of Sc on mechanical properties of Al-Cu alloys is remarkable. In either as-cast or annealed conditions, the alloy hardness is improved with an increase in the content of Sc or Cu, except an inflexion at 0.1% Sc in the annealed condition. (b) The as-cast microstructure of Al-Cu alloys is refined significantly, Figure 7. At the same content of Cu additions, the higher the concentration of Sc, the finer the grain size. The dendritic segregation is also reduced.

3. Summary

In summary, it may be concluded that Er is a favourable alloying element in aluminium alloys, such as Al-Mg, Al-Zn-Mg, Al-Zn-Mg-Cu, Al-Li and Al-Cu alloys. Moreover, due to the lower price of Er (compared to Sc), the cost of modifying aluminum alloys with Er is reduced which may lead to wider industrial applications of the Er-containing alloys. It is thus necessary to carry out further research on the mechanism of Er in refining grains and strengthening in aluminum alloys.

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