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Microstructural stability and high-temperature mechanical properties of AZ91 and AZ91 + 2RE magnesium alloys

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The effects of 2 wt.% rare earth element addition on the microstructure evolution, thermal stability and shear strength of AZ91 alloy were investigated in the as-cast and annealed conditions. The as-cast structure of AZ91 consists of α-Mg matrix and the β-$Mg_{17}Al_{12}$ intermetallic phase. Due to the low thermal stability of this phase, the strength of AZ91 significantly decreased as the temperature increased. The addition of rare earth elements refined the microstructure and improved both thermal stability and high-temperature mechanical properties of AZ91. This was documented by the retention of the initial fine microstructure and ultimate shear strength (USS) of the rare earth elements-containing material after long-term annealing at 420 °C. The improved stability and strength are attributed to the reduction in the volume fraction of β-$Mg_{17}Al_{12}$ and retention of the thermally stable $Al_{11}RE_3$ intermetallic particles which can hinder grain growth during the annealing process. This behavior is in contrast to that of the base material which developed a coarse grain structure with decreased strength caused by the dissolution of β-$Mg_{17}Al_{12}$ after exposure to high temperature.

1. Introduction

Great attention has been paid to Mg–Al alloys for their excellent combination of superior castability, good corrosion resistance and acceptable mechanical properties. The AZ91 alloy containing 9 wt.% Al and 1 wt.% Zn is the most commonly used cast magnesium alloy for low-temperature applications. The high aluminum content of this alloy results in the massive formation of β-$Mg_{17}Al_{12}$ precipitates along grain boundaries [1,2]. Due to their low melting point, these precipitates are thermally unstable and thus they can accelerate grain boundary diffusion, resulting in considerable instability of the microstructure in regions adjacent to grain boundaries [3,4]. This has been recognized as the main cause for deterioration of high-temperature mechanical properties, making the AZ91 magnesium alloy unsuitable for applications involving high temperature and load [5].

Most of the attempts for improving the high-temperature structural stability of this alloy have concentrated on suppressing discontinuous precipitation of $Mg_{17}Al_{12}$ and creating thermally stable intermetallics in the magnesium matrix. Due to the high affinity of aluminum atoms for elements such as Ca, Ti, Zr, and rare earth (RE), it is possible to reduce the amount of the $Mg_{17}Al_{12}$ by consuming the aluminum content of the alloy to form Al-containing intermetallic compounds with relatively high melting points [6–9]. The Mg–Al–RE alloys contain a mixture of RE elements, producing thermally stable $Al_{11}RE_3$ precipitates. The formation of these branch-shape compounds together with the low diffusion rate of RE elements in Mg matrix can explain the excellent mechanical resistance of the RE-containing Mg–Al alloys at elevated temperatures [10,11].

Pettersen et al. [10] studied the effect of 1 wt.% of RE on the microstructure of Mg–4Al. Two different kinds of particles, $Al_{11}RE_3$ and $Al_{10}RE_2Mn_7$, were identified at grain boundaries. Combining aluminum with RE atoms lowered the level of solute aluminum in Mg matrix in as-cast condition and consequently reduced the driving force for discontinuous precipitation of $Mg_{17}Al_{12}$ during creep. Addition of 1 and 3 wt.% RE to AZ91–0.3Ca has shown that creep resistance at 473 K had an ascending trend with increasing RE percent, the best high temperature properties being obtained for 3 wt.% RE elements [11]. Similar results have been obtained for high-temperature mechanical properties of RE-containing AM60, AZ91, and AE42 alloys [12–15]. Improvement in high temperature strength has been ascribed to the formation of the high melting point $Al_{11}RE_3$ particles as strong barriers to grain boundary sliding. However, coarsening of these particles due to increasing RE content has been introduced as the major cause for reduction of ultimate tensile strength [11–13]. Nami et al. [16] studied simultaneous addition of 1 wt.% La-rich misch-metal and 1 wt.% Ca to AZ91. They reported superior creep resistance of the RE- and Ca-containing alloy with respect to the base alloy. Effects of adding different types of RE elements (Ce, Nd and Y) on the room temperature mechanical

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