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Short Communication

Precipitation hardening of cast Zr-containing A356 aluminium alloy

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ABSTRACT

The effect of small additions of zirconium on the hardness, grain size, precipitate type and size of cast A356 aluminium alloy was investigated. The cast alloys were solution treated and then artificially aged for different periods of time. Hardness tests and scanning electron microscope (SEM), energy dispersive X-ray (EDX) and X-ray diffraction (XRD) studies were carried out on the as-cast, as-solutionised and age-hardened specimens. Incoherent, coarse Al_3Zr particles formed in the microstructure during the solidification of the alloy and caused grain refinement in the as-cast structure. These particles dissolved and reprecipitated as smaller-size particles during the solution treatment, causing the hardness of the alloy to remain constant at high temperatures for long periods of time due to the slow diffusion of Zr in the α-Al.

1. Introduction

Al–7 wt.% Si–0.3 wt.% Mg alloys, which are extensively used in automotive, aerospace, and other weight sensitive industries, are one of the most well-developed aluminium alloys and have excellent specific strength, castability and corrosion resistance [1]. The yield strength and hardness of these alloys are usually improved by solution treatment and artificial aging through the formation of fine Mg_2Si precipitates [2,3]. However, the strength of these alloys degrades quickly above working temperatures of 130–150 °C because of rapid coarsening of the precipitates.

To improve the mechanical properties and thermal stability of Al-based alloys, dispersoid-forming elements such as Zr, Mn and Cr can be added to the alloy. Of these elements, Zr is the most effective [4–6]. In the Al–Zr binary system, an ordered Al_3Zr trialuminide may be precipitated from a super saturated solid solution during post-solidification aging [5,7–9]. These nano-scale, metastable cubic ($L1_2$) precipitates exhibit excellent resistance to coarsening at high temperatures [7].

A number of researchers have studied the effect of Zr on several wrought aluminium alloys [10–12]. All of these studies have shown that Zr improves the resistance to recrystallisation of the alloys due to the formation of fine, metastable $L1_2$–Al_3Zr precipitates.

Srinivasan and Chattopadhyay [13] studied the non-equilibrium effects of $L1_2$–Al_3Zr in the as-cast and heat-treated ternary Al–Cu–Zr and Al–Ni–Zr alloys. They observed that the solidification sequence began with the formation of the $L1_2$–Al_3Zr (cubic) phase. These metastable particles exhibit a small lattice parameter mismatch with the α-Al solid solution and therefore act as efficient heterogeneous nucleants during solidification of α-Al [7]. In two different studies, Seyed Ebrahimi et al. [14,15] found a considerable decrease in the grain size of an Al–Zn–Mg–Cu alloy by the addition of Zr.

Mahmudi et al. [5] studied the effects of 0.15 wt.% Zr addition on the mechanical properties and wear resistance of an A319 Al casting alloy. They found no evidence of Al_3Zr particles in the as-cast structure. Because of the similarity of the hardnesses of the alloys with and without the Zr addition, they concluded that no Zr-rich precipitates formed during the solidification of the alloy. They found a 15% difference between the hardnesses of the two alloys after a 24 h solution treatment at 503 °C and attributed this difference to the formation of Al_3Zr particles. However, they offered no other evidences for this conclusion.

The behaviour of Zr in some of the commercial wrought aluminium alloys has been studied [6–8], but few studies focus on the commercial cast alloys. In this study, the influence of small additions of Zr on the microstructure and mechanical properties of as-cast and heat-treated A356 aluminium cast alloy is investigated.

2. Experimental

One kg of A356 Al alloy containing (in wt.%) 7.0 Si, 0.6 Fe, 0.3 Mg, 0.25 Cu, 0.35 Zn and 0.02 Ti was melted in an electric furnace to a temperature of 740 °C. The Zr level in the melt was then increased to four different nominal concentrations of 0, 0.1, 0.2 and 0.3 wt.% by adding Al-7.5% Zr master alloy. The exact Zr concentrations of these alloys were measured (for at least three different

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