Available online at www.sciencedirect.com
ScienceDirect
Acta Materialia 58 (2010) 6773–6783
Acta MATERIALIA
www.elsevier.com/locate/actamat

The effect of Gd on the recrystallisation, texture and deformation behaviour of magnesium-based alloys

Nicole Stanford *, Dale Atwell, Matthew R. Barnett

Institute for Technology Research and Innovation, Deakin University, Pigdons Road, Geelong, Victoria 3217, Australia

Received 14 May 2010; received in revised form 6 August 2010; accepted 2 September 2010

Abstract

A series of binary magnesium-based alloys have been prepared with Gd concentrations between 0.22 and 4.65 wt.% Gd. These alloys were processed by hot rolling in order to refine the microstructure and examine the recrystallisation behaviour. The addition of small amounts of Gd was found to significantly decrease the recrystallised grain size and at higher alloy concentrations nucleation of recrystallisation became more strongly inhibited, but the growth rate remained largely unchanged. The effect of Gd concentration on solute strengthening was quantified and it was found that strengthening of the prismatic slip system above 100 MPa could be achieved through alloying with Gd. A fivefold increase in ductility also resulted from Gd addition, and this was attributed to changes in the recrystallisation texture.

Keywords: Magnesium; Ductility; Recrystallisation; Texture; Rare earth elements

1. Introduction

Texture development in magnesium alloys has received considerable attention because it has a significant impact on the room temperature ductility of this alloy system [1,2]. The most notable way of modifying the texture of wrought products is by the addition of certain alloying elements that alter the recrystallisation texture [3–11]. As a secondary effect, many of these alloying additions also refine the grain size of the alloy, which, in the case of magnesium, adds an additional ductility benefit [12]. In the present study we chose to examine the effect of a known texture modifier, Gd [11], on the behaviour of a hot rolled sheet. Gd is soluble in magnesium to ~4 wt.% at 200 °C [13], and this enabled examination of a wide range of alloy concentrations without the complicating effects of precipitation that are encountered with other texture modifiers such as Ce.

Although the addition of rare earth elements offers the possibility of greatly improved mechanical properties, we still lack fairly basic knowledge about the behaviour of these alloying elements. How much do you need to modify the texture? How will this refine the grain size? Will it improve the ductility? How will this affect the strength of the alloy?

Ultimately, the desired outcome is improved room temperature ductility. But ductility is affected by a number of factors. For magnesium, grain size and texture are the two dominant factors, and any investigation on ductility must address both. There are other factors that may help rare earth additions improve ductility. Sheet forming research has long established that increasing both the work hardening rate and the strain rate sensitivity of alloys leads to an improvement in the ductility [14]. We therefore chose to carry out a full study of the effect of rare earth additions on ductility, which encompassed each of the factors that we know can affect the measured elongation.

In addition to ductility, we had the opportunity to evaluate the solute strengthening that results from rare earth elements in magnesium. This parameter too is strongly

* Corresponding author.
E-mail address: stanford@deakin.edu.au (N. Stanford).

1359-6454/$36.00 Crown Copyright © 2010 Published by Elsevier Ltd. on behalf of Acta Materialia Inc. All rights reserved.
doi:10.1016/j.actamat.2010.09.003

affected by grain size and texture, so we chose here to normalise for both of these parameters in order to accurately determine the solute strengthening effect of Gd.

2. Experimental methodology

Four alloy compositions have been prepared, containing 0.22, 0.75, 2.75 and 4.65 wt.% Gd. These compositions were chosen to be in the range of Gd solid solubility. A sample of pure magnesium was also included to be used as a basis for comparison. Each alloy was prepared in 400 g lots by diluting a Mg–1.5%Gd or Mg–10%Gd master alloy in an induction furnace under an argon atmosphere at 20 kPa positive pressure and chill cast into a 135 × 65 × 24 mm ingot.

The as-cast ingots were sectioned into plates measuring 65 × 24 × 5 mm in preparation for refinement of the microstructure by hot rolling. The rolling schedule entailed preheating all samples to 400 °C for 2 h, followed by an initial 50% reduction in one pass at 400 °C. All samples were subsequently annealed at 400 °C for 0.5 h. Samples of these intermediate specimens were collected before the material was subject to a second 50% reduction pass at either 400 or 300 °C. The alloy containing 4.65% Gd was the only material to show edge cracking (minor) after the first pass, which became more significant, but not catastrophic, after the second pass.

The recrystallisation behaviour of the hot rolled sheets was carried out on coupons measuring 15 × 15 × 1.25 mm cut from the rolled plates. The temperatures employed included 200, 250, 300, 350, 400 and 450 °C for a constant time of 1 h. Samples were metallographically prepared using standard techniques and then etched in acetic picral. The grain size was determined using the linear intercept method.

After studying the recrystallisation behaviour, an annealing treatment was chosen for each alloy such that it produced a fully recrystallised microstructure with a grain size of 10 ± 2 μm. The mechanical behaviour of each of the alloys was measured in this grain size normalised condition. Tensile tests were carried out at room temperature and strain rates of 0.001, 0.0005 and 0.01 s^{-1}. All tensile tests were carried out with the tensile direction parallel to the rolling direction of the sheet. Specimens had a starting gage length of 60 mm and gage width of 12 mm, with the longest axis of the specimen cut parallel to the rolling direction. Because there was significant edge cracking in the 4.65 wt.% Gd after the second rolling pass the dimensions of these specimens were reduced to a length of 30 mm and width of 5 mm. The tension tests were carried out in a screw driven Instron tensile tester equipped with a non-contact video extensometer.

The strain hardening behaviour was examined using the standard approach, $\sigma = K\varepsilon^n$, where σ and ε are the true stress and strain, K is the strength coefficient and n is the strain hardening exponent. The rate sensitivity parameter m was determined in the usual manner: $m = (\Delta\log\sigma)/(\Delta\log\dot{\varepsilon})$ where σ and $\dot{\varepsilon}$ are the true stress and true strain rates [15].

The texture of the fully recrystallised sheet prepared for tensile testing was measured using a Panalytical X-ray diffractometer with Cu Kα radiation on the basal peak. The pole figures were corrected for background and defocusing using LaboTex 3.0 software.

3. Results

3.1. As-cast microstructure

The alloys were cast into a steel chill mould in an attempt to solidify the microstructure as quickly as possible. Despite having a large amount of alloying addition in some cases, the as-cast grain size was relatively large, 300–500 μm across all of the alloys. The pure Mg and the leanest two alloys showed little evidence of segregation in the as-cast microstructure, but did show some inclusions (see Fig. 1). The two alloys with the highest Gd contents both showed dendritic segregation in the as-cast microstructure (Fig. 1b). The pure magnesium showed the largest number of casting twins, while the two alloys of highest concentration did not show any evidence of casting twins.

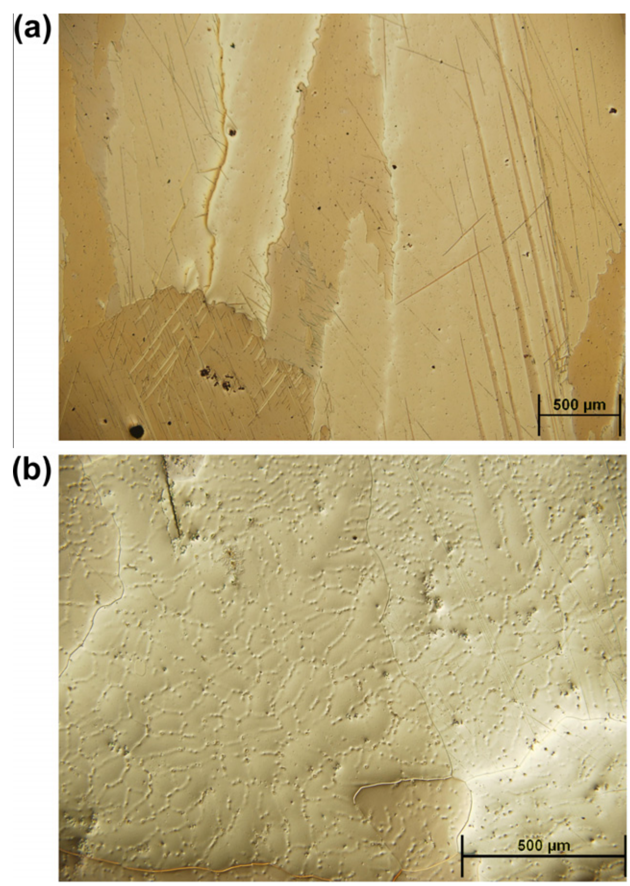

Fig. 1. Optical micrographs of the as-cast microstructure of (a) Mg–0.22%Gd and (b) Mg–2.75%Gd. Note the higher magnification in (b). Scale bar 500 μm.