MECHANICAL PROPERTIES OF MG-RE ALLOYS STUDIED BY ACOUSTIC EMISSION

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Abstract

In this paper the effect of grain size and gadolinium content on mechanical properties was studied. The Mg-Gd binary alloy with broad range of Gd concentrations (0.4 to 4.2 wt.%) and grain size (15 to 500 μm) were used. Concurrent measurement of acoustic emission was used to better understand deformation mechanisms. The Hall-Petch parameters for Mg15Gd alloy were measured. Significant differences between the alloys were observed. The twin growth is most pronounced in Mg04Gd alloy, Mg15Gd exhibits generally lower twinning activity and Mg42Gd alloy exhibits limited twin growth and nucleation of many thin twins.

Keywords: Magnesium, acoustic emission, mechanical testing, twinning

1. INTRODUCTION

Pure magnesium has very low yield stress and it is not suitable for engineering applications. However, it properties can be significantly improved by alloying. Improvement of strength, elastic modulus, ductility, corrosion resistance or creep resistance was reported in [1]. The influence of solute atoms on plastic deformation is caused by their interaction with the dislocations and twins. It is well known that the $(0001)\langle 11\bar{2}0\rangle$ basal slip and $\{10\bar{1}2\}$ extension twinning requires the lowest activation stress at room temperature. The further deformation systems, as $\{10\bar{1}0\}\langle 11\bar{2}0\rangle$ prismatic and $\{11\bar{2}2\}\langle 11\bar{2}3\rangle$ second-order pyramidal slip or $\{10\bar{1}1\}$ compression twinning generally requires either higher applied stress and/or elevated temperatures to be activated.

The addition of alloying elements influences each deformation mechanism separately, for example there is a general agreement that addition of Al and Zn increases the critical resolved shear stress (CRSS) for basal slip and concurrently decreases that for prismatic slip [2, 3]. The influence of alloying elements on twinning nucleation and growth vary a lot as well. The experimental work suggests that Zn has no effect on the stress required to propagate a twin [4] while Al increases the CRSS for twin nucleation and growth [5]. The change of active twinning systems was also reported as a result of alloying [6]. In last few years the alloying by rare-earth elements has been studied since they improve the mechanical properties of magnesium alloys significantly.

The acoustic emission (AE) has been found as a powerful non-destructive technique for study of deformation mechanisms. It gives information from entire volume about the dynamic processes during plastic deformation. The signal can be divided into two types - burst and continuous emission. Burst emission has the characteristics of the individual pulses, which can be detected from the background noise and separated from each other. If there are no characteristic individual pulses, it is called continuous emission. AE response during the mechanical loading of magnesium alloys usually consist of the combination of continuous (e.g. from dislocation movement) and burst emission (e.g. twinning) [7, 8]

The main sources of AE in magnesium is twin nucleation and dislocation slip. The released energy during the twin nucleation is generally higher than for the dislocation slip. The classic approach of measurement and evaluation of AE data, so called hit-based processing, is based on setting parameters, which define the AE event (threshold level, hit definition time, …). The system saves the parameters of the AE event (amplitude, duration, counts, energy, frequency, …) (**Figure 1**). In materials science, this approach can be successfully applied for general characterization, when the main goal is the investigation of the influence of the experimental and material parameters on the deformation behavior (e.g. [9, 10]). Another possibility is to record the whole AE dataset and do the signal post processing. Advantage of this approach is that it is possible to evaluate the data with different threshold levels and separate to strong signals.

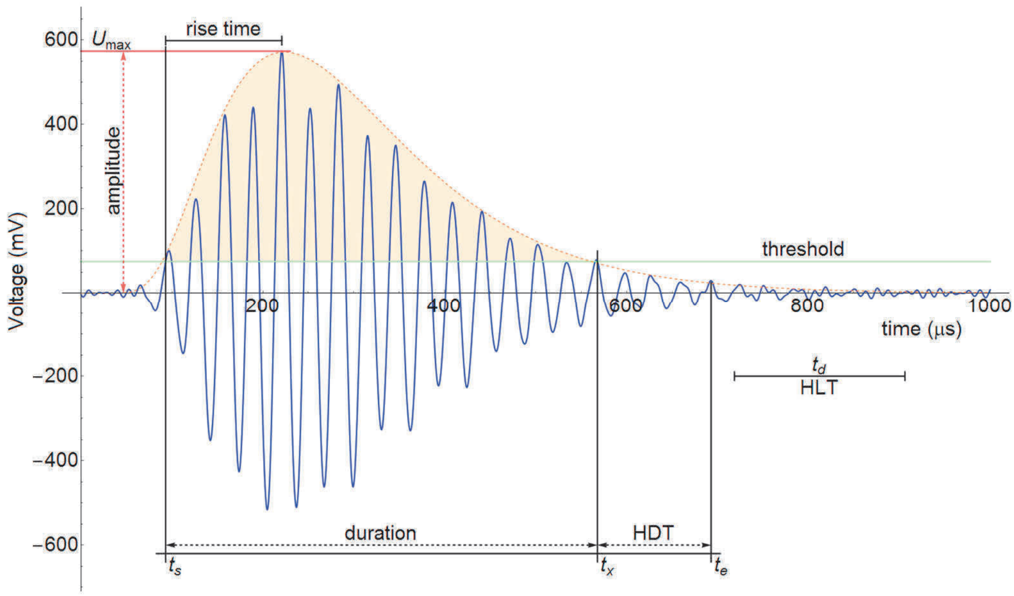

Figure 1 Parametrization of AE signal

2. MATERIAL AND EXPERIMENTAL METHODS

Binary Mg-0.4 at.% Gd, Mg-1.5 at.% Gd, and Mg-4.2 at.% Al (further referred as Mg04Gd, Mg15Gd and Mg42Gd) were used for the experiments. The samples were prepared with various grain size from 15 µm to 500 µm (**Figure 2**). The microstructure of the samples was examined by the optical microscopy and scanning electron microscopy using the Quanta FEG microscope. The samples were polished by standard methods down to 0.25 µm.

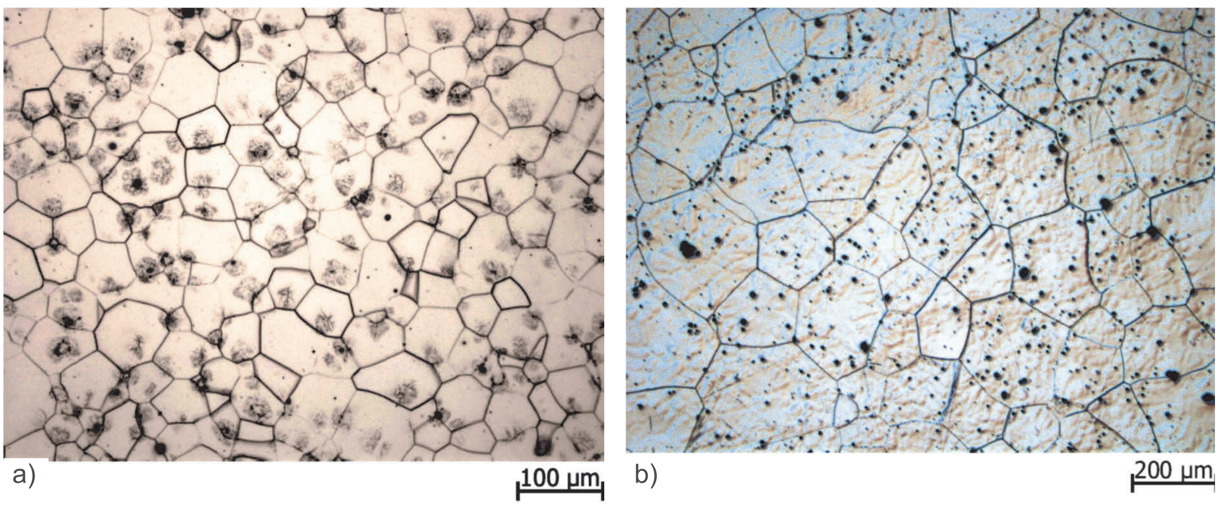

Figure 2/1 Examples of the initial microstructure a,b) Mg04Gd, c)Mg15Gd, d)Mg42Gd with various grain size

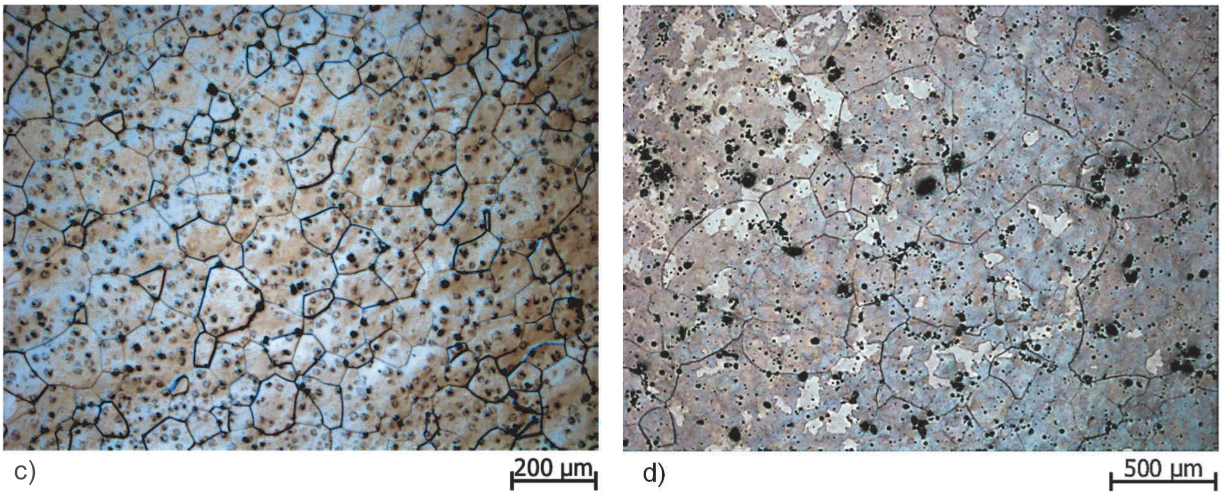

Figure 2/2 Examples of the initial microstructure a,b) Mg04Gd, c)Mg15Gd, d)Mg42Gd with various grain size

Mechanical properties were investigated by compression deformation tests performed by INSTRON 5882 deformation machine with concurrent acquisition of acoustic emission (AE). The samples had a rectangular profile 6x6x10mm^3 and the strain rate was 10^{-3} s^{-1}. The AE was monitored using a computer controlled PCI-2 device (Physical Acoustic Corporation). The threshold level of detection was set as 24 dB, just above the background noise. A PICO piezoelectric transducer, manufactured by Physical Acoustic Corporation, with a flat response between 50 and 650 kHz was mounted on the outside gauge length.

3. RESULTS

3.1. Grain size

The Mg15Gd alloy was selected to compare the samples with different grain sizes. The deformation curves of Mg15Gd alloys with AE response are shown at the **Figure 3** and the yield stresses and maximal stresses are in **Table 1**. The yield stress is increasing with decreasing grain size fulfilling the Hall-Petch equation:

$\sigma_{0.2} = \sigma_o + k/\sqrt{d}$ with parameters σ_o = 76±6 MPa and k = 0.26±0.05 MPa m$^{-½}$. Similar trend is observed with the shift of the maximum of AE amplitude to the higher stresses. Another effect is the decrease of the AE amplitude with decreasing grain size. AE energy released during the nucleation of twins is proportional to the size of nucleated twin [11] and the higher grain size allows to form larger twins.

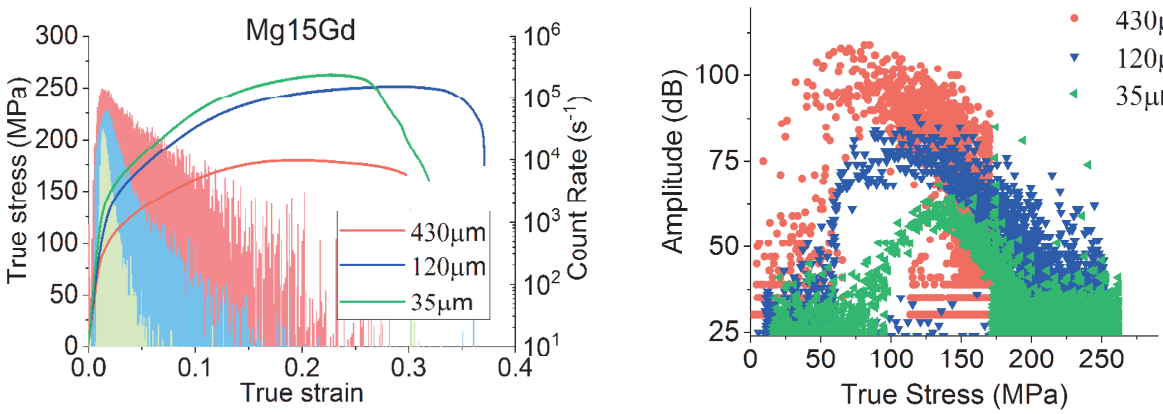

Figure 3 Deformation curves with the AE count rate and amplitude

Table 1 Yield stress and maximal stress for Mg15Gd binary alloys with different grain size

430 µm		120 µm		35 µm	
$\sigma_{0.2}$ (MPa)	σ_{max} (MPa)	$\sigma_{0.2}$ (MPa)	σ_{max} (MPa)	$\sigma_{0.2}$ (MPa)	σ_{max} (MPa)
86	180	103	251	118	262

3.2. Gd concentration

The samples with the grain size of about 150 µm were selected for investigating of the influence of Gd concentration (Mg04Gd - 188 µm, Mg15Gd - 120 µm, Mg42Gd - 156 µm). The deformation curves with AE response are shown at the **Figure 4**. The increasing Gd content causes the increase of yield stress and decrease of ductility. The difference in the maximal amplitude of AE events is negligible but it is shifted towards higher stresses as a result of higher critical stress for twin nucleation. The Mg04Gd and Mg15Gd exhibits similar evolution of AE. They have a distinct peak around the yield point followed by the rapid drop of AE above it whilst the decrease of AE after the yield point is much lower for Mg42Gd. The growth of twins is hindered by solute atoms and nucleation of new twins is necessary for plastic deformation.

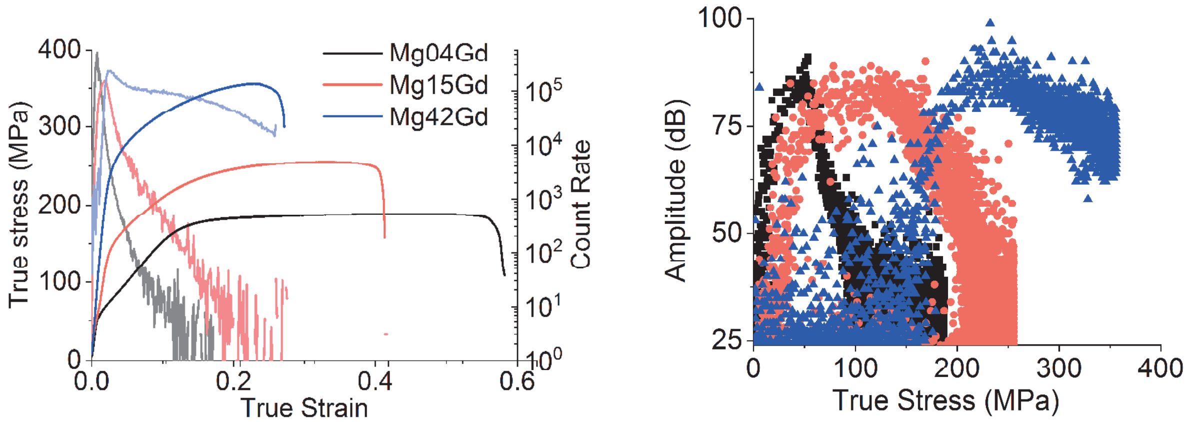

Figure 4 Deformation curves with the AE count rate and amplitude

The microstructure of deformed samples confirms that (**Figure 5**). Mg04Gd exhibits smaller number of large twins. The Mg15Gd samples show lower twinning activity, which is consistent with the lower AE activity. Many thin twins can be observed in the deformed microstructure of Mg42Gd samples which is consistent with the wide peak of AE.

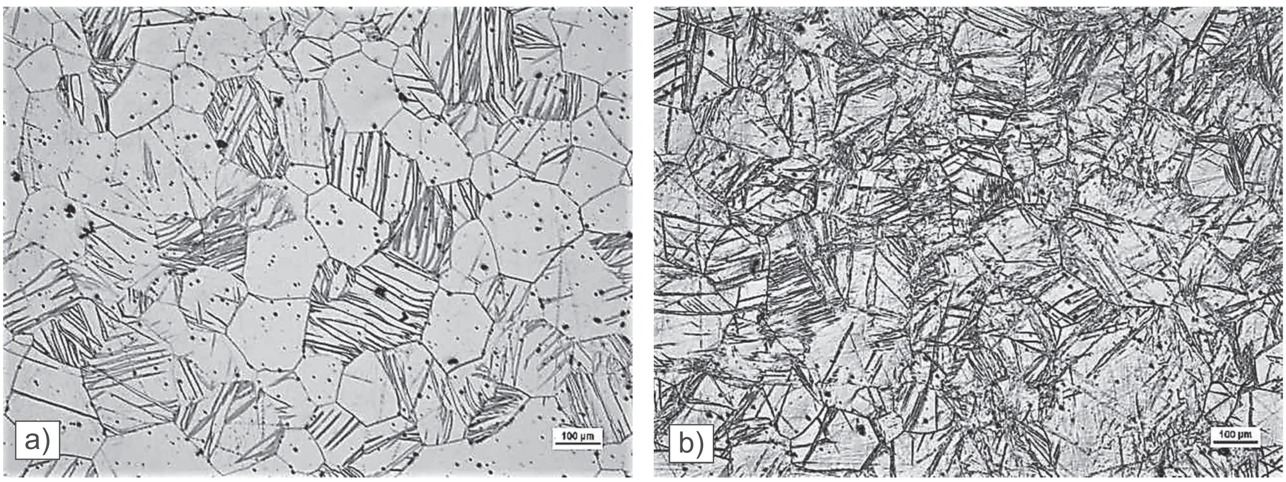

Figure 5/1 Microstructure of a, b) Mg04Gd, c, d) Mg15Gd, d) Mg42Gd samples deformed in compression to 2% plastic strain and up to the fracture.

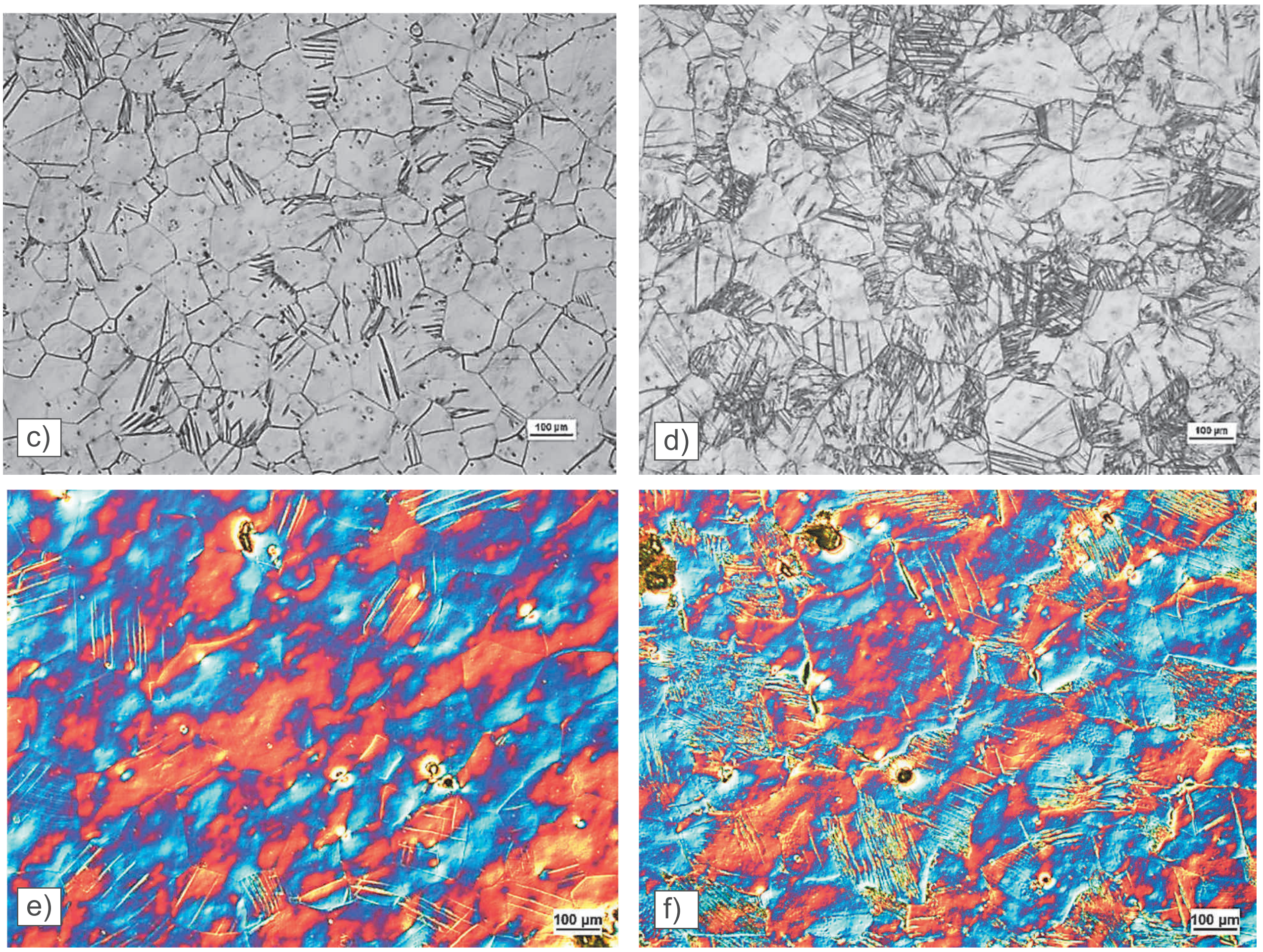

Figure 5/2 Microstructure of a, b) Mg04Gd, c, d) Mg15Gd, d) Mg42Gd samples deformed in compression to 2% plastic strain and up to the fracture.

4. CONCLUSION

We measured the Hall-Petch constants of Mg15Gd alloy by deforming samples with different grain sizes. The parameters are σ_o = 76±6 MPa and k = 0.26±0.05 MPa m$^{-½}$.

The increasing Gd content increases the stress necessary for twin growth and makes the dislocation slip more difficult, as a result the flow stress increases with increasing Gd content. Combination of AE and optical microscopy is suitable for characterization of deformation precesses in Mg-Gd alloys

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