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Original Article

Grain size and microhardness evolution during annealing of a magnesium alloy processed by high-pressure torsion☆

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ABSTRACT

High-pressure torsion (HPT) was used to impose severe plastic deformation on a magnesium alloy AZ31. The material was processed for 0.5, 1, 2, 3, 5 and 7 turns at room temperature under a pressure of 6.0 GPa. Samples were annealed for 1800 s at temperatures of 373 K, 423 K, 473 K, 573 K and 673 K. Microhardness tests and metallography were used to determine the evolution of strength and grain size as a function of the annealing temperature. The results show that recrystallization takes place at temperatures higher than 423 K. The annealing behavior is independent of the number of turns in HPT.

1. Introduction

The techniques of severe plastic deformation (SPD) [1] have attracted significant attention because they are capable of producing significant changes in the material structure and properties. Ultrafine grained structures, defined as structures with average grain size of less than 1 μm, are readily attained in bulk samples. Among these processes, high-pressure torsion (HPT) [2] is one of the most used. It is characterized by the application of high compressive stresses and simultaneous torsion.

HPT has been used to process different metallic materials, including magnesium and its alloys. Earlier papers reported significant grain refinement in these alloys after processing including an average grain size of 100 nm in a Mg–10% Gd alloy [3], 0.4 μm in a Mg–9% Al alloy [4] and ~1.0 μm in a Mg–3% Al–1% Zn (AZ31) alloy [5]. Provided these fine grain structures are stable at high temperatures, these materials may exhibit superplasticity [6]. It has been shown that the refined structure

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is stable in a Mg–9% Al alloy processed by HPT and it exhibits superplasticity at 473 K [4]. However, the Mg–9% Al alloy is expected to contain second phase precipitates that prevent grain growth. The grain structure stability at high temperatures in a single phase magnesium alloy has not been studied yet. The present paper aims to process a single phase AZ31 alloy by HPT and determine its annealing behavior.

2. Material and methods

The material used in the experiments was an AZ31 (Mg–3% Al–1% Zn) commercial alloy provided by Timminco Corporation (now Applied Magnesium International), Aurora, CO. The material was received as 10 mm diameter extruded rods with an initial average grain size of ~10 μm [7]. Discs of the AZ31 alloy were cut from the rods with thicknesses of ~1.5 mm and ground to a thickness of 0.8 mm. The discs were then processed by HPT for 0.5, 1, 2, 3, 5 and 7 turns at room temperature and under a pressure of 6 GPa using a quasi-constrained equipment operating at 1 rpm (~0.1 rad/s) [8]. It is expected that the temperature rise during processing saturates at ~20 K [9] considering the average flow stress of the AZ31 alloy as 1/3 of its hardness after HPT [5].

The processed discs were cut into 8 parts, wedge shaped, using a diamond coated saw blade operating at low speed. Each sample was annealed for 1800 s at temperatures varying between 373 K, 423 K, 473 K, 573 K and 673 K. After annealing, the samples were polished, tested for microhardness and etched to reveal the microstructure. The microhardness tests were carried out along the radius of the disk from the center to the edge with a minimum of 12 indentations in each sample separated from each other by at least three times the indentation size and the average hardness was determined from all indentations. Representative images of the microstructure were recorded near the center, at the mid-radius and near the edge of the samples. The average grain size after annealing was determined as the average linear intercept length obtained at these different locations.

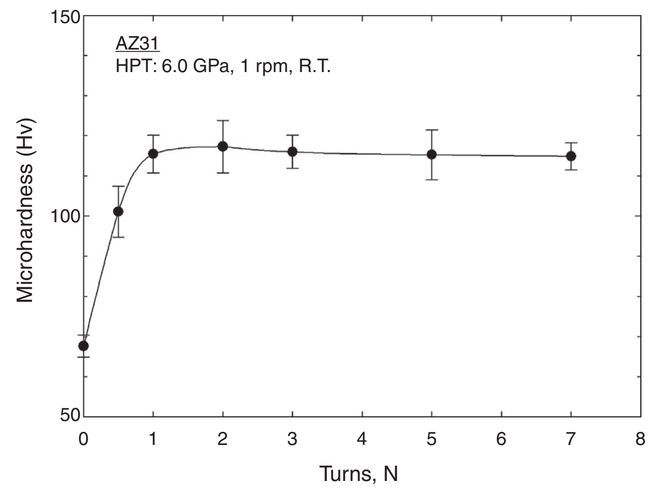

Fig. 1 – Microhardness of the AZ31 alloy processed by HPT for 0.5, 1, 2, 3, 5 and 7 turns at room temperature.

3. Results

The average hardness of the AZ31 alloy processed by HPT is plotted as a function of number of turns in Fig. 1. It is observed that the initial hardness of AZ31 alloy, ~67 Hv, increases to ~117 Hv after two turns and saturates at ~115 Hv.

Representative images of the microstructures of the AZ31 alloy processed by different number of rotations of HPT and subjected to annealing at different temperatures are shown

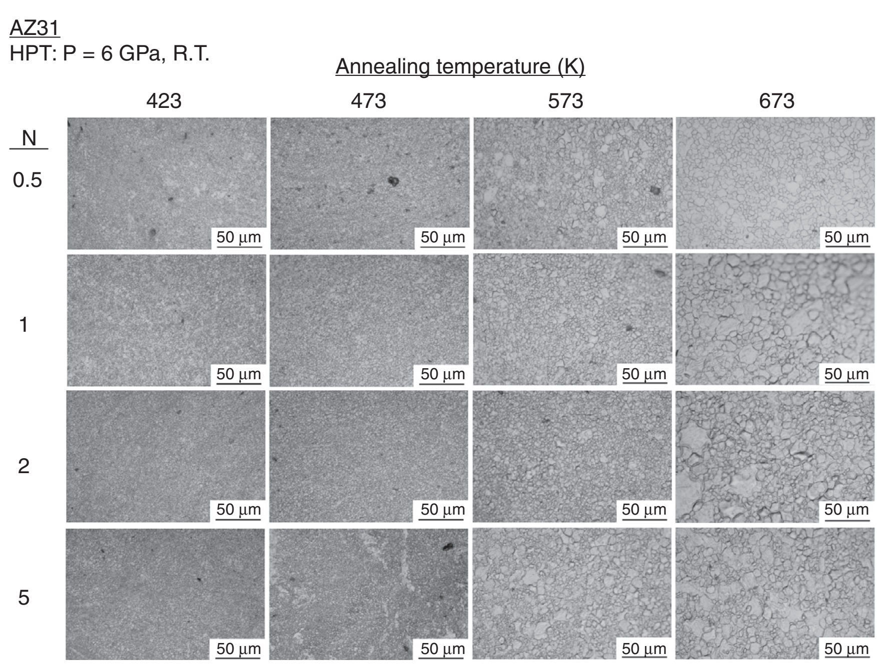

Fig. 2 – Microstructure of the AZ31 alloy processed by HPT for 0.5, 1, 2 and 5 turns and annealed at 423 K, 473 K, 573 K and 673 K.