Materials Science & Engineering A 690 (2017) 244–253

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

The microstructure, texture, and room temperature mechanical properties of friction stir processed Mg-Y-Nd alloy

A.M. Jamili[a], A. Zarei-Hanzaki[a,*], H.R. Abedi[a], P. Minárik[b], R. Soltani[c]

[a] The Complex Laboratory of Hot Deformation and Thermomechanical Processing of High Performance Engineering Materials, School of Metallurgy and Materials Engineering, College of Engineering, University of Tehran, Tehran, Iran

[b] Department of Physics of Materials, Charles University, Prague, Czech Republic

[c] School of Metallurgy and Materials Engineering, College of Engineering, University of Tehran, Tehran, Iran

ARTICLE INFO

Keywords:
Magnesium alloy
Friction stir processing
Texture
Microstructure
Mechanical properties
Electron backscatter diffraction (EBSD)

ABSTRACT

The effects of severe plastic straining, in the course of single and multi-pass friction stir processing (FSP), on the microstructure, texture and mechanical properties of an as-extruded WE43 Magnesium alloy are addressed in the present study. The latter was explored by applying a set of 1 and 3-passes FSP trials on the experimental material. The evolved microstructures were characterized through electron backscatter diffraction analyses. The results indicated an extraordinary reduction in grain size in addition to remarkable decrease in second phase volume fraction in the light of preferred strain rate and temperature conditions. The micro-textures of processed specimens were evaluated through plotting the Schmid factor maps and its distribution. The corresponding results showed that the basal planes poles intensity was increased after each step of FSP trials. The prismatic texture analyses also indicated the randomized and weakened distributed planes. The room temperature mechanical properties of the processed materials were also measured using tensile testing technique. The optimization of the strength and ductility values was attributed to the grain refinement, dynamic dissolution of the second phase and the texture strengthening at proper thermomechanical conditions.

1. Introduction

Over the past decades, an effective response to today's main designing goal entitled as "weight reduction accompanied by desired mechanical properties such as specific stiffness and strength at room temperature" has ended to a rapid development and usage of magnesium alloys within various industries in particular automotive and aerospace ones [1]. The accomplished efforts to further improving the magnesium alloys' performances have resulted in emerging a wide span of alloying systems to fulfill various industrial applications. In this respect, the addition of Rare Earth elements (REs) to magnesium alloys has essentially improved the formability of these alloys through their profound effects on the primary strong basal texture and the subsequent randomization of the overall texture [2,3]. The present literature clearly reveals that the noted texture weakening occurs as a direct consequence of different micro-mechanisms ranging from the change in stacking fault energy (SFE) of magnesium base matrix to solute drag effects on the grain boundaries and dislocations [4]. Hence, achieving an impressive outcome through addition of Yttrium and REs to magnesium alloys has been ended into the emergence of a novel magnesium alloy grade, known as WEs. These alloys have been classified into two main groups based on their chemical composition, which are recognized as WE54 [5] and WE43 [6]. The vital role of a randomized texture in a close combination with the enhanced mechanical properties have turned the RE-containing magnesium alloys to an attractive research topic [7].

The efforts to improve the mechanical properties through various severe plastic deformation (SPD) methods have been popped up mainly since 1990s [8]. On the basis of a valuable body of experimental evidences, it is clearly believed that the SPD would lead to a significant grain refinement as well as a profound influence on the precipitation processes [9,10]. The friction stir processing (FSP) is a solid-state SPD technique which was literally invented by the welding institute (TWI) in 1991 [11]. The effects of FSP on the microstructural evolution and mechanical properties modification of various materials and in particular magnesium alloys have been thoroughly investigated [12]. However, a major part of the latter efforts has been devoted to explore the effect of FSP on Mg-Al-Zn (AZs), the most engineering-commercial grade of magnesium alloys. In this respect, the related studies demonstrated a noticeable microstructural homogenization in a close concomitance with significant grain refinement. It is generally accepted that the applied SPD would end to the occurrence of dynamic

* Corresponding author.
E-mail address: zareih@ut.ac.ir (A. Zarei-Hanzaki).

http://dx.doi.org/10.1016/j.msea.2017.02.096
Received 22 November 2016; Received in revised form 23 February 2017; Accepted 25 February 2017
Available online 27 February 2017
0921-5093/

recrystallization (DRX) in terms of processing scheme [13–17]. In addition, various researchers reported that the applied SPD through FSP and equal channel angular pressing (ECAP) techniques could convert an inhomogeneous initial structure, containing secondary intermetallic phase particles, into a homogeneous counterpart. In addition, it has been proposed that the properties of the processed material were directly dictated by the processing parameters (which could be interpreted as the well-known Zenner-Holoman parameter) [18]. In the particular case of as-cast AZ80 magnesium alloy, Feng et al. [19] illustrated that the FSP could result in a well-homogenized structure analogous to the conventional solution treated material. It is worth mentioning that due to the low diffusion rate of Al in magnesium matrix, the complete dissolution of eutectic phase in AZs may transcend 40 h [20,21]. Therefore, this conventional time-consuming process would be remarkably shortened through a proper SPD route.

Within the last few years, a number of recently developed magnesium alloys holding REs have been subjected to FSP. According to the valuable work of Freeney et al. [22], it is ascertained that the enhanced creep-resistance of the processed WE43 material is directly connected to the effect of processing heat-input on dissolution and re-precipitation along with slight grain refinement. Moreover, further work by those authors on EV31A alloy (Mg-3.1Nd-1.7Gd-0.5Zn-0.3Zr) clearly indicates achieving a fine-grained microstructure holding dispersed fine second-phase particles holding a superior mechanical properties [23]. In line to these efforts, Kumar et al. [24] specified the undeniable role of FSP and subsequent heat treatment on the strength and ductility of Mg-Y-Nd-Zr alloy. This was attributed to the well-developed twin-free, fine-grained structure accompanying with intragranular precipitations.

A closer look at the present literature reveals that the number of processing pass, as a correlative indication of the applied cumulative strain, plays a crucial role in the microstructural evolution as well as the mechanical properties improvement of the processed material. Among the best is the recent study by El-Rayes et al. [25], which is devoted to the net effect of multi-pass FSP on the microstructural evolution of Aluminum 6082 alloy. It has been logically concluded that the increased number of passes would end to a more significant grain refinement and a simultaneous higher grain boundary misorientation angles and larger size of stir zone (SZ). On the contrary, based on the study by Tsujikawa et al. [26] on Mg-Y-Zn system holding Yttrium subjected to single and multi-pass FSP, the grain size was entirely independent of the processing passes. Based on the above literature survey, there is still much debate over the effects of multi-pass FSP and its cumulative effective strain on the various characteristics of WE magnesium alloys. Hence, as a primary goal, the present work aims at providing a thorough insight into the influence of number of processing passes on the microstructure, texture and mechanical properties of the WE magnesium alloys. In this respect, a recently developed WE43 magnesium alloy has been subjected to single and multi-pass FSP trials and a detailed microstructure and texture evolution in the course of processing has been investigated. Beyond this point, a number of dynamic dissolution micro-mechanisms in the course of FSP have been also proposed.

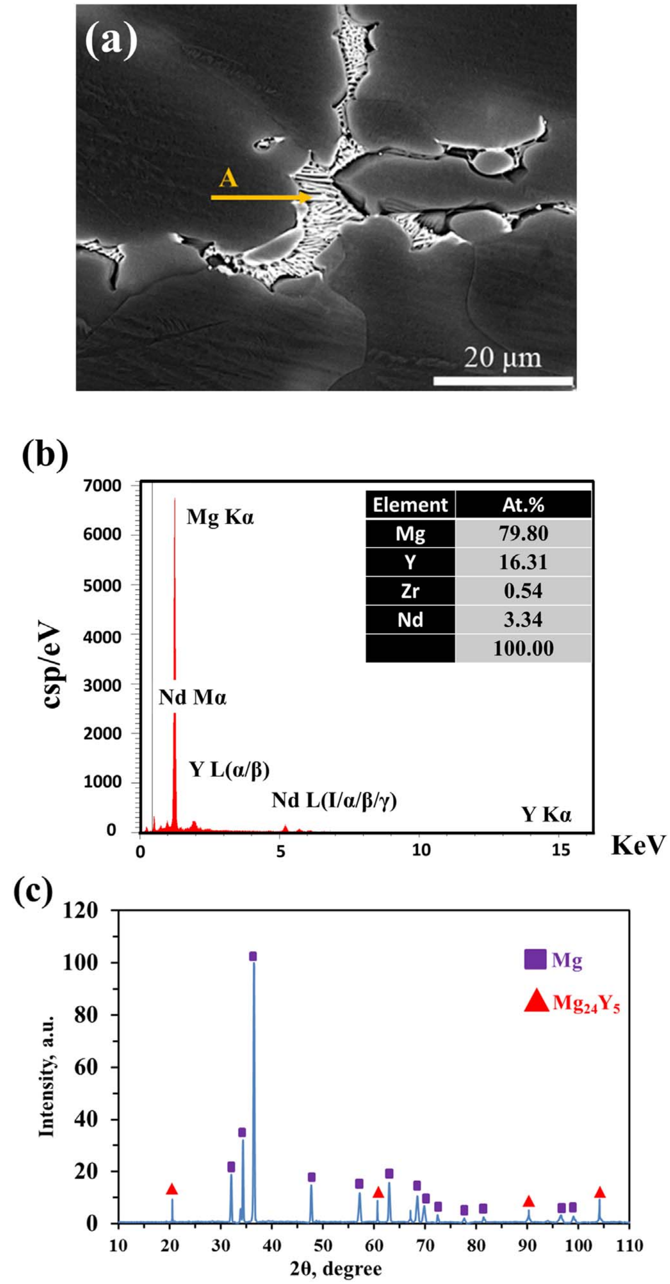

Fig. 1. The initial microstructure of as-extruded experimental WE43 magnesium alloy: (a) SEM image of extruded material, (b) point EDS results of the grain boundary second eutectic phase, and (c) XRD pattern of as-extruded experimental material.

2. Material and experimental procedure

In this study, the experimental material holding the chemical composition of Mg-4.37 wt%Y-2.9 wt%RE-0.3 wt%Zr was received in as-extruded condition (holding an extrusion ratio of 4). In order to avoid any undesired cutting-stress, the provided material was cut to 75*20*7 mm workpieces using an Electro Discharge Machine (EDM). All the prepared workpieces were then prepared by fine SiC sand-paper to generate flat working surfaces. The workpieces were then subjected to friction stir processing trials under a rotational speed of 630 rpm and a traverse speed of 63 mm/min. The processing trials were performed using a modified milling machine equipped with a processing tool made of commercial H13 hot-die steel, which had been adjusted to 2.5° as the tilt angle. The shape of processing tool was a conical one, holding a flat shoulder of 16 mm diameter, pin length of 2.5 mm, and pin diameter starting from 6 mm and ending to 3.8 mm conical tip. Based on the aims of present work, single-pass as well as completely overlapped three-passes FSP trials were applied on the workpieces. The temperature was recorded during processing using embedded K-type thermocouples within the workpieces. In order to avoid any undesired grain growth and to preserve the processed microstructure, the processed area was immediately quenched using a water-spray device right after the final tool passage. The sub-size plate type tensile specimens holding 8*2*1 mm dimensions at the gage area were then cut out from the center of the SZ using the stress-free EDM method. Additionally, to attain smooth surfaces and evading any ambiguity in tensile test results, the tension specimens were polished