

Corrosion Behavior of Ultra Fine Grain Pure Magnesium for Automotive Applications

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ABSTRACT

The contemporary challenge in automotive industry is weight reduction. Compared to conventional automotive materials, commercially pure magnesium is having enhanced strength-to-mass ratio and low density, which confers to optimal requirement for automotive applications. Amongst various other reasons such as low hardness, low corrosion resistance also prevents it from entering mass production. Severe plastic deformation by equal channel angular extrusion (ECAE) is regarded as one of the prominent method to increase the mechanical properties of magnesium. However, the investigation in corrosion resistance of extruded magnesium in automotive environment is not discussed in depth. This paper discusses the microstructure and corrosion characteristics of commercially pure magnesium which has been extruded by ECAE at 473K through the routes a and b_c up to eight passes and their three surfaces (extrusion direction, normal direction & transverse direction) in detail. The corrosion experiment has been performed using conventional electrochemical techniques such as open-circuit potential measurements and potentiodynamic polarization method in 3.5 wt% NaCl solution environment. The surface morphology of the magnesium billet was examined in detail using scanning electron microscopy (SEM) and the hardness was measured using micro Vickers hardness tester.

INTRODUCTION

Today Automobile manufacturers are being pressured into developing more fuel efficient vehicles. Reducing the overall weight of the vehicles is the key to achieving this goal. The use of Magnesium alloys to reduce weight in automobiles has grown approximately 20% annually since early 1990s [1] and the total 2008 production of primary magnesium in the world was approximately 722,000 tons[2]. Magnesium is having a number of practically excellent properties such as light weight and the highest strength-to-weight-ratio of all structural materials [3,4] and Mg alloys are being increasingly used

in the electronics, automobile and aerospace industries due to their low density and high specific strength [5]. With their hexagonal close packed (HCP) structure and low stacking fault energy, they generally exhibit limited ductility and strength at ambient temperature, thus the potential for magnesium applications are limitless.

Application of magnesium and its alloys at ambient temperature is still limited due to their Poor corrosion resistance, limited ductility which is essentially attributed to the limited number of slip systems owing to the hexagonal crystal structure and low strength. It is now well known that the decrease in grain size can increase the formability of magnesium [6]. Severe plastic deformation processes (SPD) are very effective in enhancing the workability and strength of Mg alloys can [7] and the various techniques currently used in laboratory studies are equal channel angular extrusion (ECAE) [8-12], high pressure torsion (HPT) [13-15] and accumulative roll bonding (ARB) [16-18]. Equal channel angular extrusion (ECAE) is one of the promising techniques for grain refinement to micron, submicron size in a wide range of metals, multi-phase alloys and metallic composites [19].

In this study pure Magnesium has been extruded by ECAE at 473K through the routes A and B_c up to eight passes and corrosion experiment has been performed on each specimen's three surfaces (Extrusion direction, Normal direction & Transverse direction) using electrochemical techniques such as open-circuit potential measurements and Potentiodynamic polarization method in 3.5 wt% NaCl solution environment with 6.83 pH. The hardness was measured using Micro Vickers hardness tester and surface morphology of the Magnesium billet was examined in detail using Scanning Electron Microscopy (SEM).

EXPERIMENTAL SETUP

The initial material was hot rolled commercially pure magnesium having strong basal texture. Keeping the ED (Extrusion direction), ND (normal direction) and TD (transverse direction) into account, rods of square cross section with the dimension 10 mm X 10 mm X 100 mm were extracted from this plate. The rods were deformed in an ECAE die with inter-channel angle 90° without rounding of corners, where an effective strain of 1.17 per pass could be imparted [14]. The rods were well lubricated and then inserted in the ECAE die with the ND in the front and the RD down (Figure 1). ECAE was carried out following the routes by A and B_c up to 8 passes. ECAE was carried out at 523K for the first 4 passes, while the remaining ECAE deformation was carried out at 473K, to a total of 8 passes. The billets were preheated to their respective ECAE temperatures for 10 minutes before entering the first channel of the die through the inlet.

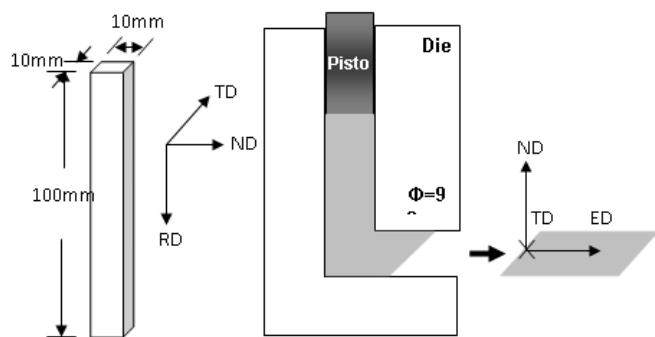


Figure 1. ECAE Die Set Up

To observe good reproducibility during the various tests the specimen were polished by Silicon Carbide paper up to 2500 grit size and the etchant used is a solution of 75% ethanoldiol, 24% distil water and 1 % HNO_3 . Finally the specimen is cleaned with ethanol and dried in warm air.

Corrosion measurement was carried out at $25 \pm 1^\circ\text{C}$ using conventional three electrodes GillAC ACM version 5 device. The system contains a saturated calomel reference electrode, platinum auxiliary electrode and working electrode. The three types of electrochemical testes carried out namely Open Circuit Potential, Potentiodynamic Polarisation, and Electrochemical Impedance Spectroscopy test. The solution used is 3.5 wt. % NaCl solutions [20] which are obtained by dissolving A.R. grade NaCl in distilled water. The specimens were kept in the test solution for 600 second for open circuit potential. The Potentiodynamic curve is obtained using a fast scan rate of 10 mVs^{-1} . To conduct the EIS test, the frequency range was set up to 10 kHz to 10 MHz and amplitude was 5 mV with respect to open circuit potential. The micro hardness of the magnesium was evaluated by using micro hardness tester with Vickers indenter, employing a constant load of 200 gram for 15 s [21] five different places on the samples surface were measured, and then the values were averaged.

RESULTS & DISCUSSION

EVOLUTION OF MICROSTRUCTURE - Figure 2 shows the evolution of microstructure through inverse pole figure (IPF) maps. The average grain size of the initial material, as determined by linear intercept method, was $\sim 21\mu\text{m}$. After 1 pass of ECAE, the grain size reduced to $6\mu\text{m}$. ECAE at this temperature up to 4 passes leads to similar grain size for both the routes A and BC. From the 5th pass the ECAE was done at 473K. At this temperature, after 8 passes the grain size reduced to $\sim 2.6\mu\text{m}$ for route A and $\sim 3.0\mu\text{m}$ for route BC. Table 1 shows the average grain size of the initial and the ECAE processed samples. The grain size distribution was found out to be unimodal.

A detailed analysis of microstructures as recorded through IPF reveals the presence of fine equiaxed grains with serrated grain boundaries, which is an indication of dynamic recrystallisation (DRX). This could be due to relatively high temperature of deformation. It is to be noted that the minimum recrystallisation temperature for pure magnesium should be $\sim 373\text{K}$. A comparison of relative fraction of low and high angle boundary for all the ECAE processed materials is shown in Figure 3. The fraction of low angle grain boundaries LAGBs increases from ~ 0.5 after 1 pass to ~ 0.66 and ~ 0.59 in the second pass for routes A and BC respectively, while it decreases to ~ 0.56 and ~ 0.4 after 4 passes for the corresponding routes. During the second stage of processing, that is ECAE from 5th to 8th pass which was carried out at 473 K, the fraction of LAGBs decreases with every pass. After 8 passes, the fraction of LAGBs decreases to ~ 0.28 and ~ 0.24 respectively.

In addition to a detailed boundary characterization described above, the extent of twinning was estimated from the analysis of EBSD data. The $\{10\bar{1}2\}$ tensile twin boundaries ($86^\circ \pm 5^\circ <11\bar{2}0>$), $\{10\bar{1}1\}$ compression twin boundaries ($56^\circ \pm 5^\circ <11\bar{2}0>$), $\{10\bar{1}1\}$ - $\{10\bar{1}2\}$ double twinning ($38^\circ \pm 5^\circ <11\bar{2}0>$) were calculated. A measurement of twin boundaries in all the ECAE processed samples indicated that their fraction of twin boundary was almost negligible (Fig. 3).