Key Engineering Materials
ISSN: 1662-9795, Vol. 803, pp 22-26
doi:10.4028/www.scientific.net/KEM.803.22

Submitted: 2019-01-27
Accepted: 2019-02-13
Online: 2019-05-20

Severe Plastic Deformation of Al-15Zn-2Mg Alloy: Effect on Wear Properties

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Keywords: Al-Zn-Mg alloy, ECAP, Microstructure, Wear properties

Abstract. In the present work, Al-Zn-Mg alloy having highest zinc content was deformed by one of the severe plastic deformation (SPD) technique, equal channel angular pressing (ECAP) and effect of ECAP on the microstructure evolution and the wear properties were studied. ECAP was performed in a split die and the channels of the die are intersecting at an angle of 120º. ECAP was attempted at least possible temperature and the alloy was successfully ECAPed at 423 K. Below this temperature samples were failed in the first pass itself. After ECAP, significant drop in the grain size was reported. Also, ECAP leads to significant raise in the microhardness of the alloy. Predominantly, after ECAP, upsurge in the wear resistance of the alloy was noticed. To figure out the response of ECAP on the wear properties of the alloy; worn surfaces of the wear test samples were analyzed in SEM.

Introduction

Being lighter metallic material, aluminium has gained massive industrial attention in the near decades. However, compared to steel and other high strength materials, aluminium possess less strength in pure form. Aluminium can be strengthened by adding suitable alloying elements. Addition of zinc to the aluminium increases the strength and toughness properties [1]. Also, Adding magnesium to Al-Zn alloys increases the age hardening characteristics of the alloy. The strength of Al-Zn-Mg alloy could be further improved by decreasing the grain size and inclusion of high density dislocations in the material through various severe plastic deformation (SPD) methods [2]. Among several SPD methods, equal channel angular pressing (ECAP) receives more attention because of its simplicity. In ECAP process, deformation takes place by pure shear which leads to develop large magnitude of shear strain in the material and causes huge reduction in the grain size material [3]. In literature, numerous studies can be found on Al-Zn-Mg alloys subjected to various SPD processes; mainly related to the microstructure and mechanical properties [4-6]. In spite of that, wear study of the Al-Zn-Mg alloys processed by SPD have not gained much consideration. In this regard, in the current work, Al-Zn-Mg alloy having highest zinc content was processed by ECAP and response of ECAP on the wear properties was studied.

Material and Methods

The Al-15Zn-2Mg alloy studied in the current work was produced by die casting process. The casting procedure for alloy preparation is discussed somewhere else [7]. Before ECAP, the as-cast alloy samples were treated with homogenization process at 753 K for 20 hours. For ECAP, homogenized samples were machined to 16 mm diameter and 85 mm length rods. ECAP was performed in a split die and the channels of the die are intersecting at an angle of 120º. ECAP was tried at minimum possible temperature in route B_C. Microstructures of the ECAPed and unECAPed samples were examined in scanning electron microscopy (SEM). Hardness was measured in Vickers microhardness equipment by imposing a load of 0.4905 N for 15 sec. Dry sliding wear tests were conducted at ambient temperature in a pin on disc arrangement. For Wear test, ECAPed and unECAPed samples were machined to 10 mm diameter and 28 mm height rods. During wear tests, samples were slide adjacent to EN31 steel disc possessing a hardness of 62 HRC. To study the wear properties of the ECAPed and unECAPed samples, wear tests were conducted at different loads and sliding speeds (condition 1: 19.62 N & 1 m/s, condition 2: 19.62 N & 2 m/s, condition 3: 39.24 N & 1 m/s, condition 4: 39.24 N & 2 m/s). In all conditions, wear tests were performed for a span of 1 km in a circular track of Ø 120 mm. The surface morphology and the quantitative elemental analysis of the worn surfaces of the wear test samples were analyzed in SEM.

Results and Discussion

In literature, reports on the ECAP directs that optimal properties can be achieved by deforming the material at lowest possible temperature [3]. In this view, the alloy was tried to deform at least possible temperature. ECAP was unsuccessful in the first pass itself at ambient temperature, 373 K and 398 K. At 423 K, ECAP was successful in first pass and specimens were cracked in the second pass in route B_C. So, results related to the alloy deformed upto one pass at 423 K are presented.

Microstructure and Hardness

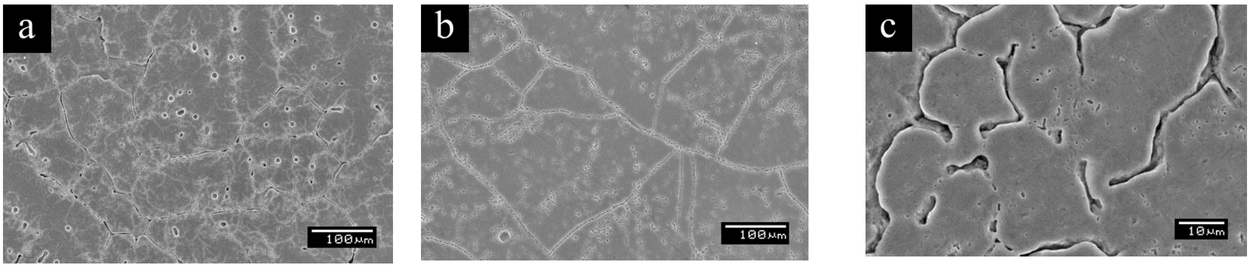

Figure 1. Microstructure of the alloy (a) as-cast, (b) homogenized and (c) ECAPed

In as-cast condition, the material exhibits a typical dendritic structure with precipitates in the dendrites as shown in Fig. 1(a). The precipitates in the inter-dendritic regions are identified as η' phase ($MgZn_2$) precipitates. The size of the dendrites measured in the as-cast condition is approximately equal to 200 µm. After homogenization process, dendritic structure was replaced with large size grains approximately equal to 180 µm as shown in Fig. 1(b). Also, precipitates in the dendrites were homogenously dispersed in the aluminium. After ECAP, grain size was approximately decreased to 40 µm as shown in Fig. 1(c). In as-cast state, the hardness of the material reported is 173 Hv. Hardness of the material changed to 189 Hv after homogenization. Hardness of the material is raised to 252 Hv after ECAP, (46% increase from the as-cast condition). Raise in the hardness of the alloy after ECAP is accredited to the drop in the grain size and strain-hardening of the alloy during ECAP [8].

Wear Properties and Wear Mechanisms

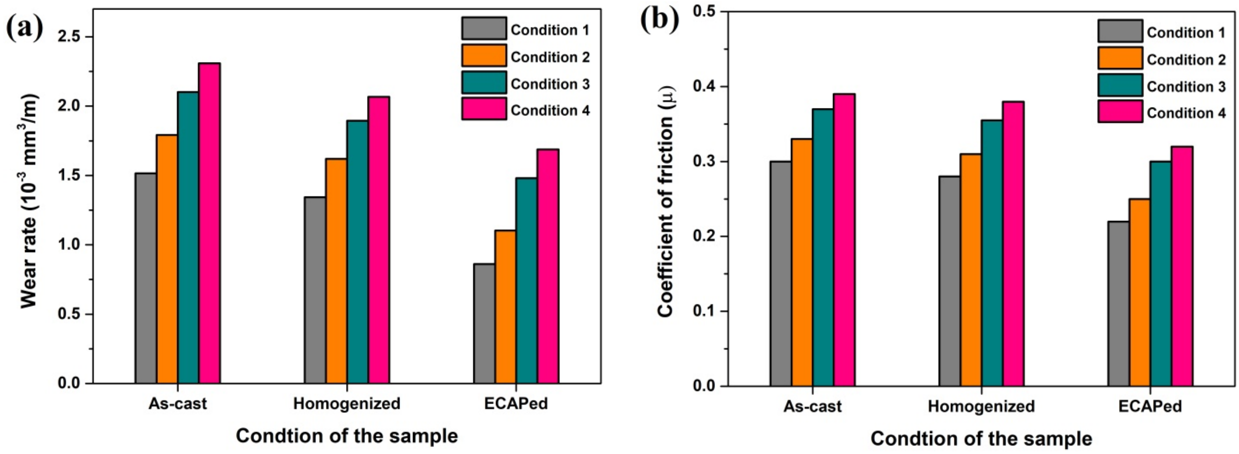

Figure 2. Wear properties of the alloy (a) wear rate and (b) coefficient of friction (µ)

Figure 2(a) presents the wear rate of the alloy in different conditions. The wear rate presented is in the magnitude of 10^{-3} mm^3/m. It is noticed that, wear rate is lower in ECAPed sample in contrast to the as-cast and the homogenized state. With raise in the load and sliding speed, wear resisting capability of the ECAPed sample was reduced. Although, in all wear testing conditions, ECAPed sample show better wear resistance in contrast to the as-cast and the homogenized specimens. The upsurge in the wear resistance of the alloy after ECAP is owing to the raise in the hardness of the alloy during ECAP [9]. Hence, it can be deduced that, even after one pass also noticeable upsurge in the wear resistance of the alloy could be achieved. Figure 2(b) presents the coefficient of friction (μ) of the material in different conditions. It is noticed that, μ value of the ECAPed sample is lesser in contrast to the as-cast and the homogenized state. With raise in the sliding speed and load, μ value of the ECAPed sample was increased. Although, in all wear testing conditions, ECAPed sample show lesser μ value in contrast to the as-cast and the homogenized specimens. The lessening in the μ value of the alloy after ECAP is due to the reduction in the grain size of the alloy during ECAP [10].

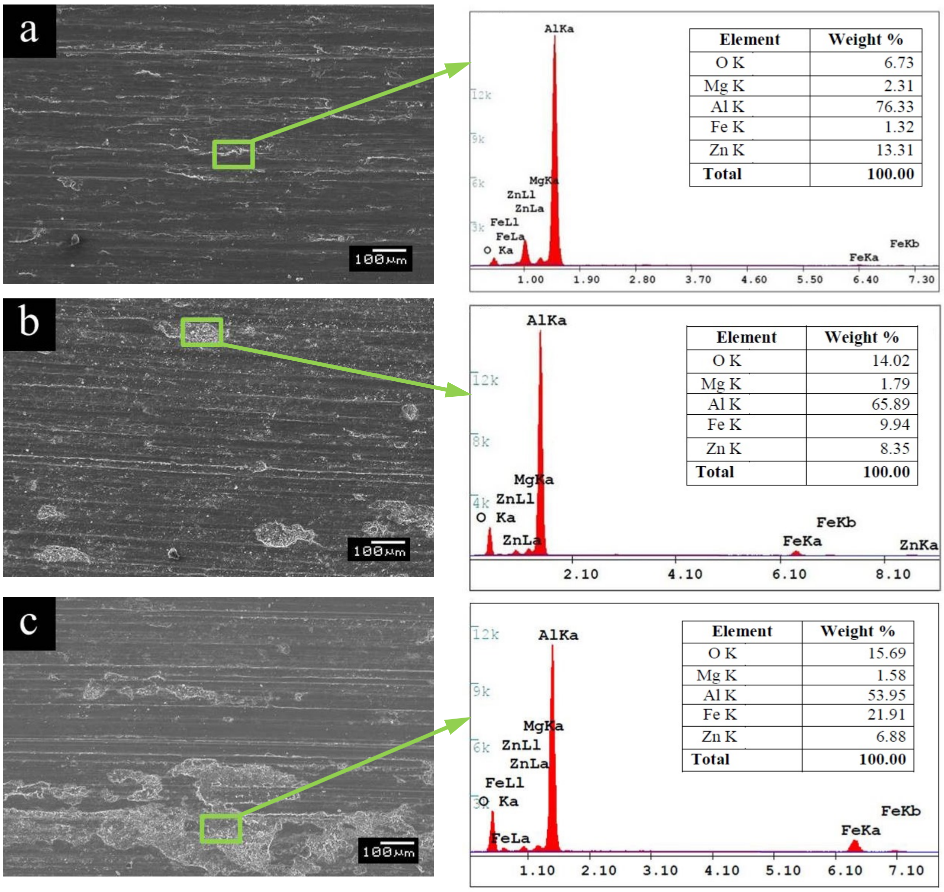

Figure 3. Worn surfaces of the alloy after wear test performed at condition 1 (a) as-cast, (b) homogenized and (c) ECAPed.

Figure 3 displays the worn surfaces of the alloy in different conditions, after wear test performed at condition 1. In as-cast specimen, micro-grooves and delamination of the material in the sliding direction were noticed as shown in Fig. 3(a). Hence, the wear mechanism presumed in as-cast sample is abrasive wear. In the EDS of the as-cast specimen, some traces of oxygen were noticed. But, the effect of oxygen on the development of oxide layers was not perceived in the worn surface. Identical to the as-cast specimen, delamination of the material and micro-grooves was observed in the homogenized sample, but in few regions gluing of wear debris are also observed as shown in Fig. 3(b). Both adhesive and abrasive wear mechanism was perceived in the homogenized specimen, but the effect of abrasive wear is more in contrast to the adhesive wear. Gluing of the wear debris to the worn surface of the homogenized specimen is owing to the raise in the hardness of the material after homogenization. In the EDS of the homogenized sample, considerable amount of oxygen was observed in the wear debris glued to the worn surface. The occurrence of the oxygen shows the development of oxide layers on the worn surface. Even though oxidation wear is observed in the homogenized sample, but the effect of the oxidation wear is very less in contrast to the abrasive wear. In the ECAPed sample, along with micro-grooves and delamination of the material, gluing of the wear debris also perceived on the worn surface as presented in Fig. 3(c). Gluing effect of wear debris to the worn surface is more in ECAPed sample, in contrast to the homogenized sample. In the EDS of the ECAPed sample, presence of oxygen and iron elements was reported in the adhered debris. Hence, it is presumed that, abrasive, adhesive and oxidation wear mechanism was noticed in ECAPed sample. Also, the occurrence of iron elements on the adhered debris indicates the transfer of the iron elements from the steel disc to the specimen surface [11]. Transfer of iron elements from the disc to the specimen surface is owing to the raise in the microhardness of the material after ECAP. The wear mechanism is changed from abrasive wear to oxidation wear after ECAP, which is owing to the raise in the microhardness of the alloy after ECAP.

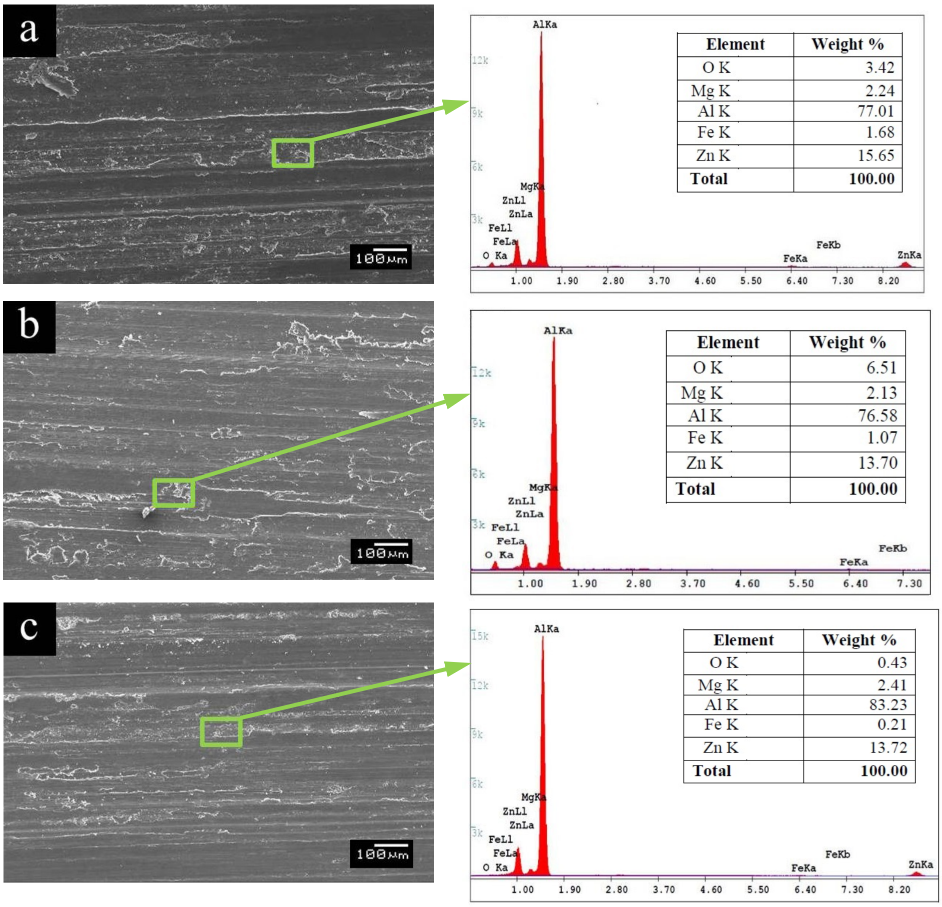

Figure 4. Worn surfaces of the alloy after wear test performed at condition 4 (a) as-cast, (b) homogenized and (c) ECAPed.

Figure 4 displays the worn surfaces of the alloy in different conditions, after wear test performed at condition 4. It is noticed that, due to raise in the load and the speed, the worn surfaces of the as-cast specimen was severely damaged as shown in Fig. 4(a). The worn surfaces were composed of deep grooves and scratches in the sliding direction. The wear mechanism reported in as-cast specimen is abrasive wear. Similar nature of wear morphology was noticed in the homogenized specimen. In the EDS of the as-cast and homogenized sample, although some traces of oxygen were noticed. But, the effect of oxygen on the development of oxide layers was not perceived in the worn surface. In the ECAPed sample the intensity of wear damage was reduced compared to unECAPed samples. This is owing to the raise in the hardness of the alloy after ECAP. Also, gluing of the wear debris was not perceived. As, in this condition of the wear test, the applied load and speed both are higher, due to which worn particles might have been separated from the worn surfaces instead of gluing. In the EDS of the ECAPed sample, very less trace of oxygen and iron were reported. This shows that, wear mechanism presumed in the ECAPed sample is abrasive wear. At this load and speed, only abrasive wear was reported in both unECAPed and ECAPed samples. It is noticed that, in the ECAPed sample, with raise in the load and speed, wear mechanism is changed from oxidation to abrasive wear.

Summary

In the present work, Al-15Zn-2Mg alloy was tried to ECAP at lowest possible temperature. After ECAP, significant drop in the grain size and noticeable raise in the microhardness was reported. Mainly, after ECAP, upsurge in the wear resistance of the alloy was reported. So, it could be deduced that, even one pass ECAP results in valuable consequences. The intensity of wear damage was less in the ECAPed sample compared to unECAPed samples. In ECAPed samples, at low load and low speed, adhesive and oxidation wear mechanism was reported. While at high load and high speed, only abrasive wear mechanism was reported.

Acknowledgments

One of the authors Mr. G. K. Manjunath would like to thank Dr. M. R. Ramesh, Associate Professor, Department of Mechanical Engineering, NITK Surathkal for providing the wear test facility and MHRD-Government of India for providing Institute Research Fellowship.

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