Proceedings of the International Conference on Applied Mechanical Engineering Research (IC-AMER2019)
NIT Warangal, India – May 02-05, 2019
Paper No. XXX (The number assigned when the papaer is accepted)

AN EFFECTIVE AND ECONOMICAL METHOD TO IMPROVE STRUCTURAL HOMOGENEITY AND HARDNESS OF Al-Mg ALLOY PROCESSED BY ECAE

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The formation of the dead metal zone(DMZ) in Equal Channel Angular Extrusion (ECAE) process significantly affects the deformation uniformity and mechanical properties of work material. The aim of the present study is to investigate the effect of the dead metal zone on structural homogeneity and hardness of Al 5083 alloy processed by ECAE and suggest the way to minimize that adverse effect. In this work, the rectangular billets with 1mm thick copper casing on two longitudinal faces and square billets with no casing are processed by ECAE up to 4 passes in route A. It was observed that the soft and ductile nature of the copper casing allows smooth flow of the work material at low pressing loads as compared to the alloy ECAE'd without a casing. Field emission scanning electron microscope (FE-SEM) images of the processed material with casing shows the noteworthy improvement in structural homogeneity and grain refinement than another set of billets. The obtained structural homogeneity indicates the uniform strain distribution in the processed material is achieved by minimizing the formation of the dead metal zone at the intersection of ECAE die channels. The higher hardness measurements of the processed materials indicate the significance of grain refinement and uniform strain distribution. The variations in the test results confirm the non-homogeneous strain distribution caused by the dead metal zone is high for the billets processed with no copper casing.

***Keywords*:** ECAE, DMZ, casing, structural homogeneity, hardness

1. Introduction

ECAE is the widely used severe plastic deformation (SPD) method in which a high amount of strain is induced in the work material with no cross-sectional changes[1]. The work material experiences the severe strain while passing through the intersection of the channels of ECAE die and forms the ultrafine grain (UFG) structure which improves the strength and hardness as per the Hall-Petch equation[2]. The amount of effective strain and the deformation patterns of the processed material mostly depend on the selection of die geometry and operational parameters[3]. The ECAE die geometry consists of the channel angle (Φ), outer corner angle (Ψ), corner radii and the type of cross-section of the channels[4]. The processing route, temperature, coefficient of friction, number of passes are the important operational parameters of the ECAE process[4]. Out of all, the channel angle, outer corner angle, corner radius and a frictional coefficient between work material and the channel walls are the significant parameters which influence the formation of the dead metal zone at the intersection of channels[5]. A.R. Eivani and A. Karimi Taheri have studied the effect of DMZ on strain and required forming force in ECAE and they found that the chances of dead zone formation increase with increasing the friction between the die walls and the billets and by decreasing channel angles. They also found that the amount of required extrusion force increases with increasing the friction coefficient[5]. Balasundar et al. performed numerical and physical modeling of ECAE using die channel angle 90^0, outer corner angles 30^0 and outer corner radius ranging from 1mm to 5mm. They noticed that no corner angle and high coefficient of friction causes the sticking of metal to the lower surfaces of the channels and forms the dead metal zone.

They reported that by providing low corner angles and less friction coefficient there may be a chance of reducing the formation of the dead zone and increases the uniform strain distribution[6]. Stephane Ferrasse et al. reported that even with the smooth flow and pointed corners the DMZ exists. In their opinion, this effect can be reduced by using a movable bottom wall[7]. Arman Hasani et al. studied the deformation field variations in ECAE'd AA 6061 with back pressure and they expressed that the back pressure increases the swelling of the sample and required pressing force which leads to the formation of the dead metal zone[8]. F. Djavanroodi et al. conducted the finite element analysis to identify the effect of the ultrasonic-assisted ECAP on the required forming force at different vibration amplitudes, billet lengths, friction factors, and channel angles. They reported that the decrease of a load was observed by using ultrasonic vibrations, larger billet lengths, more friction factor, and die channel angles in the range of 65^0 to 135^{0}[9].

In the present study, the authors are attempted to introduce the concept of casing/shielding to minimize the DMZ in ECAE process in an inexpensive way. The copper sheets with 1mm thickness were considered as a casing to the work material in view of less frictional coefficient between sliding components of copper and die steel.

2. Experimental methods

Al-Mg alloy with 4.5%Mg is selected as a feedstock in the present study. The square billets of 16mmX16mm and rectangular billets of 16mmX14mm were prepared from the rolled slab. The longitudinal faces of the billets were well polished before ECAE to accelerate the smooth flow when they are pressed through die channels. Due to the more formability nature and having a low frictional coefficient between the sliding parts of the copper and steel[10], 1mm thick copper sheets were considered as a casing to the rectangular billets. The feedstock and copper casing were heat treated for 1hr at 530^0C and 400^0C respectively. The die geometry used in this work is shown in Fig.1 is used in this study. MoS_2 lubricant is applied to the sliding elements before every pass to reduce the rubbing forces. The rectangular billets with 1mm thick copper casing and square billets with no casing were extruded in route A(without any rotation about its axis) up to 4 times at a speed of 2mm/s. The cumulative strain of 3.452 induced in the extruded material for the considered angles. After the ECAE, the billets were sectioned across the longitudinal direction and polished as per the standard specimen preparation procedures. The structural analysis of the billets before and after ECAE is performed by the Field emission- Scanning electron microscope (FE-SEM). To observe the improvement in the properties of the processed material with ultrafine grain structure, the Vickers microhardness tester was used. The hardness tests were conducted at 200 grams load and for a dwell period of 15 seconds.

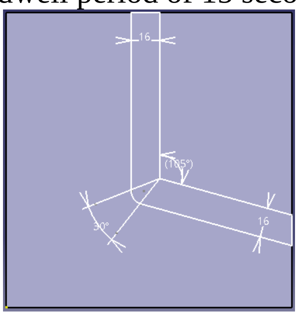

Fig. 1. Schematic of ECAE die

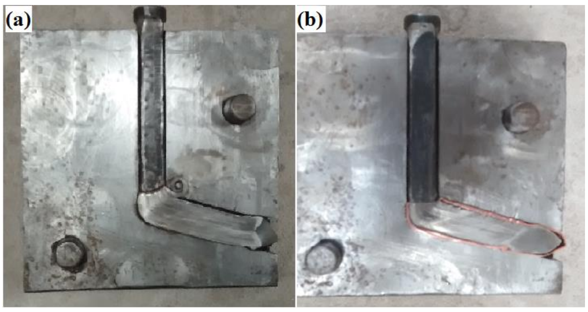

Fig. 2. ECAE of Al-Mg alloy a) with no casing b) with casing

3. Results and Discussions

3.1 Forming force

The requirement of forming forces in ECAE of Al-Mg alloy with and without casing is shown in Fig.3. It is noticed that the alloy ECAE’d without casing required more force than the alloy covered with copper casing in view of high rubbing forces between the sliding elements even with the sufficient lubrication provided.

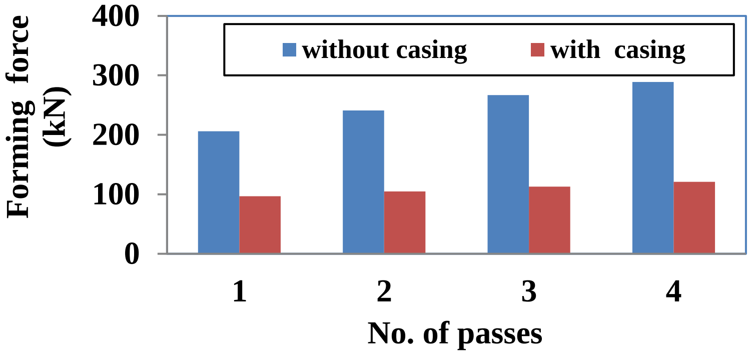

Fig. 3. Forming forces in ECAE of Al-Mg alloy

A noteworthy reduction in required forming force is observed for the billets extruded with copper casing due to less coefficient of friction between sliding parts i.e. copper sheet and steel die[5]. The copper sheet takes its advantage of high ductility and allows the smooth flow of the billets and this reduction in forming force continues up to four passes. The observation of forming forces required in this study are in good agreement with the other studies[11].

3.2. Structural Analysis

Fig. 4 shows the FE-SEM images of Al-Mg alloy after ECAE process. The average grain size of the material is measured using the line intercept method. The coarse grains of an alloy with a grain size of 60µm was refined to a few hundreds of nanometres after the very first pass of ECAE due to the severe strain induced in the work material. From Fig.4(a) and (b) it is clear that the grain sizes are significantly reduced to ~750nm and ~500nm after the first and fourth passes respectively, in the ECAE’d alloy. Even the submicron size grains produced after the first pass, some structural defects were observed in the processed material without copper casing and the severity of defects was reduced after the successive passes. Fig 4(c) and (d) shows the homogeneous ultrafine grain structure of the severely deformed alloy with copper shielding after the first and the fourth passes with an average grain size of ~710nm and ~420nm respectively. The ductile copper casing causes the uniform strain distribution and reduces the formation of DMZ by occupying the area at the intersection of channels during the pressing. The use of copper covering avoids the cracking on the top longitudinal surfaces of the billets and the formation of DMZ. The average grain sizes of an alloy after the first and fourth passes are presented in Fig.5.

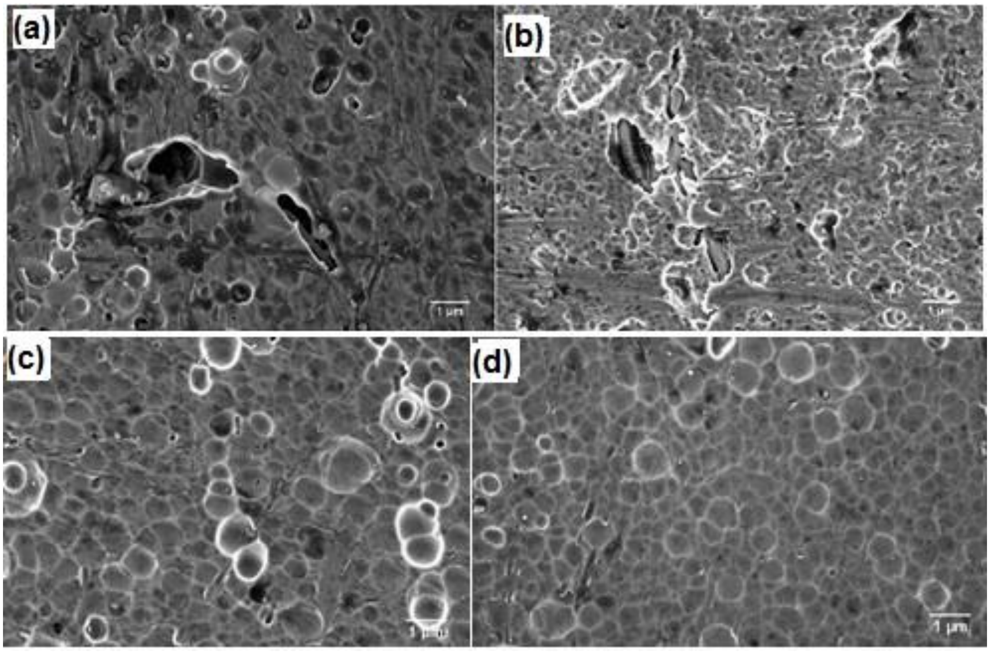

Fig. 4. SEM photographs of Al-Mg alloy
a) without Cu casing after 1st pass b) without Cu casing after 4th pass
c) with Cu casing after 1st pass d) with Cu casing after 4th pass

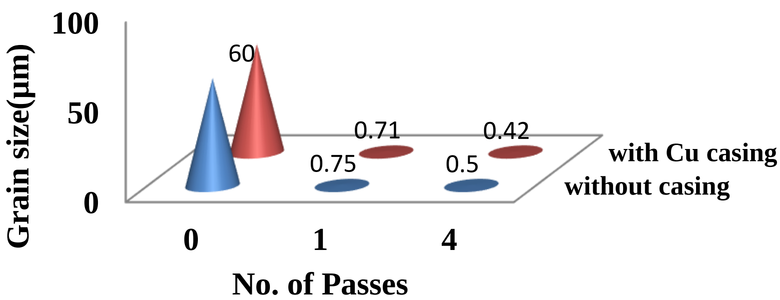

Fig. 5. Grain sizes of Al-Mg alloy before and after ECAE

3.2. Vickers micro-hardness

The hardness of the alloy ECAE'd without copper casing increases from 69 VHN to 97VHN and 134 VHN after the first and fourth passes respectively. Due to the development of non-homogeneous structure with few defects, the hardness values vary in different regions along the cross-section of the billets. Whereas the uniform strain distribution produces homogeneous ultrafine grain in the alloy ECAE'd with the copper casing. A fully dense ultrafine grain structure with no structural defects improves the average hardness value to 139 VHN and 176 VHN after the first and fourth passes respectively. The pattern of test results presented in this study is similar to the results reported by Reza Naseri et al[12].

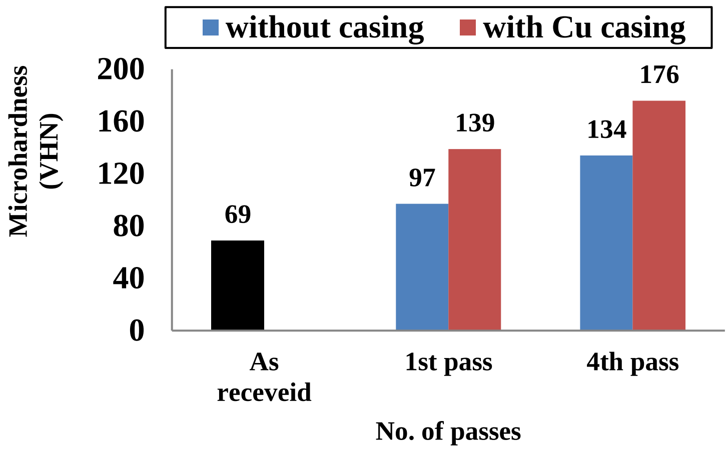

Fig. 6. Microhardness of Al-Mg alloy before and after ECAE

4. Conclusions

The summary of the observations of this work are:

- The effect of DMZ and the non-uniform strain distribution on the structural homogeneity and hardness is high for the alloy pressed with no copper shielding.
- The requirements of forming force significantly reduced by minimizing the rubbing forces when copper sheets are employed as a casing to the work material.
- The smooth flow of the billet avoids the formation of DMZ, improves the strain distribution and develops the homogeneous ultrafine grains.
- The hardness of severely deformed Al-Mg alloy with copper shielding increased more as compared to another case due to the formation of a fully dense ultrafine grain structure.

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