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THE EFFECTS OF BACKWARD EXTRUSION ON BULK NANOSTRUCTURED AL-6082 MATERIALS PRODUCED BY EQUAL-CHANNEL ANGULAR PRESSING (ECAP)

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ABSTRACT

Equal-channel angular pressing (ECAP) is one of the methods of severe plastic deformation for producing ultra fine-grained (UFG) material. The aim of this work is to study the impact of the backward extrusion on the bulk ultra fine-grained structure of commercial Al-Mg-Si alloy (6082), which is produced by equal-channel angular pressing (ECAP), using route C technique up to eight passes with a high length to diameter ratio between 15 and 16. The products are investigated after one, four and eight passes. Backward extrusion tests are performed in all the three ECAP conditions and raw materials to collect information about this real technology. The induced anisotropy is monitored on the backward extruded pieces, particularly after one pass. This phenomenon also shows a limitation in the formability, especially after eight passes.

المستخلص

تعتبر قناة الضغط بزاوية ومتساوية المقطع (ECAP) أحد طرق التشوه اللدن الشديد لإنتاج مواد فائقة صغر الحبيبات (UFG).

يهدف هذا العمل إلى دراسة تأثير البثق الخلفي لعينة كبيرة الحجم من سبيكة الألمونيوم التجارية (Al-Mg-Si6082) التي تم تشكيلها باستخدام قناة الضغط بزاوية ومتساوية المقطع (ECAP) لإنتاج بنية

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فائقة الدقة في صغر الحبيبات باستخدام تقنية المسار C وتصل إلى ثمانية تمريرات، بحيث تكون نسبة طول العينة إلى قطرها كبيرة تتراوح ما بين 15 إلى 16. يتم دراسة العينات المنتجة بعد تمريرة واحدة، وأربعة، وثمانية تمريرات. وتم بثق العينات الثلاثة المنتجة بثقاً خلفياً ومقارنتها بالعينة الأصلية التي تم بثقها أيضاً، وذلك لجمع المعلومات حول هذه الطريقة. حيث لوحظ إنسياب غير متماثل للقطع المنبثقة بثقاً خلفياً خصوصاً بعد تمريرة واحدة. كما وجد نقصان في قابلية التشكيل وخصوصاً بعد 8 تمريرات.

Keywords: ECAP technique, Nanostructure, Backward extrusion process

1. INTRODUCTION

Bulk nanostructured materials (NSM), which have been processed by methods of severe plastic deformation (SPD) have attracted the growing interest of specialists in materials science [1-7]. This interest is conditioned not only by unique physical and mechanical properties inherent to various nanostructured materials, such gas condensation or ball milling with subsequent consolidation [3-6]; but also by several advantages of SPD materials as compared to other NSM. Particularly, SPD methods resulted in overcoming of a number of difficulties connected with residual porosity in compacted samples, impurities from ball milling, processing of large scale billets and practical application of the given materials [4, 5].

The SPD methods are free from these disadvantages and more convenient for the investigation of the role of grain boundary on the physical properties in different materials. SPD can be used not only for ductile metals, but also for brittle alloys and intermetallic compounds. Moreover, SPD can be used to fabricate bulk material, which make it possible to measure the mechanical properties. Severe plastic deformation methods could meet a number of requirements, which cannot be realized with traditional methods of plastic deformation such as rolling, drawing or extrusion [1-5, 8, 9]. These requirements are as follows: Firstly, it is important to obtain ultra-fine-grained structures with prevailing high-angle grain boundaries since only in this case can a qualitative change in properties of materials occur. Secondly, the formation of nanostructures uniform within the whole volume of a sample is necessary for providing stable properties of the processed materials. Thirdly, Even though samples are exposed to large plastic deformations, they should not have any mechanical damage or cracks [1-5]. Formation of nanostructures in bulk samples is impossible without application of special mechanical schemes of deformation providing large deformations at relatively low temperatures (usually less than $0.4T_m$ where T_m is the melting temperature). At present, the majority of the obtained results are connected with application of two SPD methods: torsion straining under high pressure and equal channel angular pressing [1-5].

2. EQUAL CHANNEL ANGULAR PRESSING (ECAP)

The basic principles of ECAP have been delineated in several detailed reports [1-6]. Briefly, a die is constructed containing two channels, equal in cross-section, intersecting at an angle which is generally close to 90° as shown in Figure (1). The work-piece is machined to fit within the channel and it is pressed through the die (the material is subjected to deformation which approximates to simple shear).

Since the cross-sectional dimensions are unchanged in pressing, the sample may be pressed repetitively through the die, in order to attain a high total strain. In practice, the strain imposed on the sample in ECAP depends upon the two angles defined in Figure (2). There is an angle between the two channels and an additional angle (ψ) delineating the outer arc of curvature at the point of the channels' intersection. In case of hard to deform the material, ECAP is applied at a high temperature to avoid any failure in the channels and make the deformation easier.

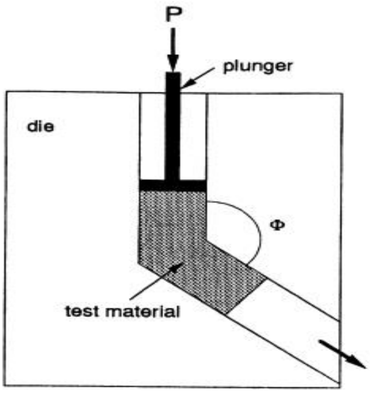

Figure (1): Schematic representation of a die for ECA pressing [2].

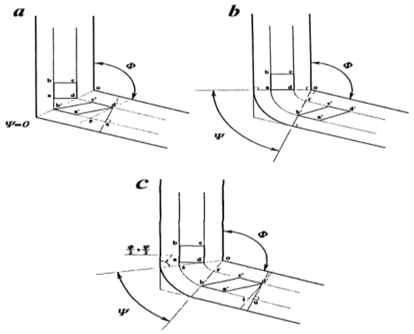

Figure (2): Principles of ECA pressing: (a) $\psi = 0^\circ$, (b) $\psi = \pi - \phi$ (c) ψ is between $\psi = 0^\circ$ and $\psi = \pi - \phi$ [2].

According to [1, 5, 7-9], if $\psi = 90^o$ and $\phi = 20^o$ are used as intersection angles, the strain value approximately increases by 1 in each pass. In the ECA pressing, the number of passes and the direction of billet passes through the channel are very important in the refinement of the microstructure. According to [1-3, 5], there are three kinds of passes (routes) as illustrated in Figure (3).

- Route A (the sample is not rotated around its longitudinal axis).
- Routes B and C (the sample is rotated around its longitudinal axis by 90° and 180°, respectively).

The methodology followed in this work is to investigate the backward extrusion effects on. The given routes are influenced in their shear direction at repeated passes of the workpiece through the intersection channel when ECA pressing is applied. As shown in Figure (4a), at the place of channels' intersection, the cell takes a shape of an ellipsoid during the first pass, if route A is used. As a result of repeated pass, the length of axis 1 is increased and the ellipsoid is elongated, where the shear direction is turned around the axis perpendicular to the longitudinal section of the channels with angle 2ϕ, Figure (4b). The repeated passes in route B lead to a change in the direction of the shear, and shear plane is turned with an angle of 120°. By using route C, the deformation during the repeated pass leads to shear in the same plane, but in opposite direction as shown in Figure (4c).

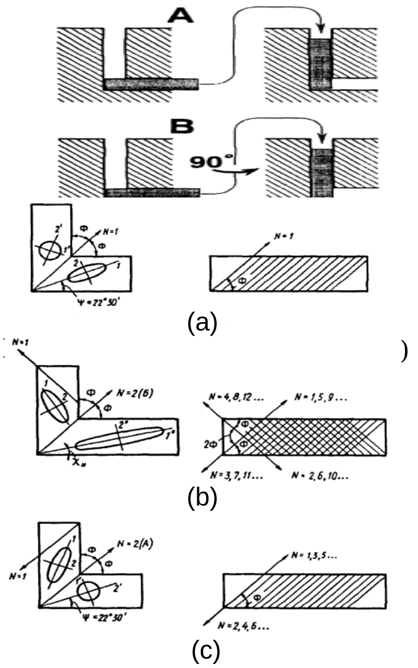

Figure (4): Regimes of simple shear during ECAP: (a) one cycle deforming; (b) route B; (c) route C [1].

3. EXPERIMENTAL WORK AND RESULTS

In this paper, ECAP parts were produced in three types of passes (one, four and eight), where the route C is applied. The material used in this study was a commercial Al-Mg-Si alloy (Al-6082). The main components of the alloy are shown in Table (1).

Table (1):
Composition of Al-6082 alloy

Al (%)	Mg (%)	Si (%)	Mn (%)
97	(0.6-1.2)	(0.7-1.3)	(0.4-1)

The well lubricated billets (having slightly smaller cross-section than the die channel) were placed into the vertical channel and then a punch extruded them through the intersection and then, passed to the second channel. This technology was performed at room temperature with a constant displacement rate of 8 mm/ min [1]. The length-diameter ratio of specimens was relatively high (more the 15). Under these conditions, the sample moves inside the channels as a rigid body and deformation is achieved only at the intersection by simple shear. After the extrusion stroke, the punch returns to its initial position [1].

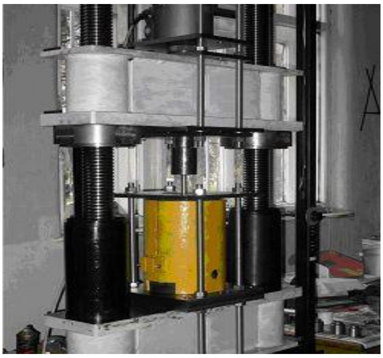

Figure (5): Pressing machine with the ECAP die set [1].

Figure (6): From the left: zero pass, one pass, four passes and eight passes respectively using route C technique [1].

Figure (5) illustrates the pressing machine with the ECAP die set.

In order to easily removing the sample from the second channel, a short billet (made in lead) is inserted into the channel before the next work piece inserted. The punch makes the second stroke by which the first billet is pressed out the horizontal second channel. Then the procedure is repeated until to achieve the required number of passes [1, 2]. Figure (6) shows the billets after different passes, form the left, zero, one, four and eight passes.

4. EFFECT OF ECAP ON BACKWARD EXTRUSION OF AL-6082 ALLOY

The main task is to investigate the effect of deformation, which is performed by ECAP for the properties of the backward extruded products. Figure (7) shows the equipment used for backward extrusion in the centre of the TIRA test 2300 machine. The applied ram speed was 2 mm/min.

The backward extrusion technology is used to test the further workability of the prepared nanostructure materials on pieces having 15 mm in diameter and 10 mm initial height. A stroke of 8 mm/ min was applied to produce cups with 15 mm outer diameter and 2 mm wall thickness. The basic comparison was between as-received (zero pass) material and nanostructural materials (one pass, four passes and eight passes). From each material conditions, three

Figure (7): The die set for backward extrusion.

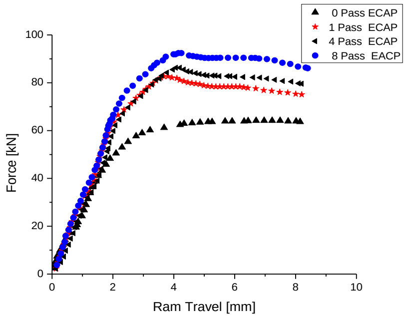

Figure (8): Backward extrusion force as a function of ram travel for conventional Al6082 and after ECAP (one, four and eight passes).

parallel test were performed. The remaining formability of nanostructure material after ECAP is affected by the anisotropy caused by ECAP, where this phenomena typically as mentioned in [1].

Figure (8) shows the typical extrusion forces as a function of ram travel. The ECAP specimens needed higher force than the conventional one, and the forming force increased as the number of ECAP passes increased and showed a significant peak point, while it was absent in the case of conventional material (zero pass).

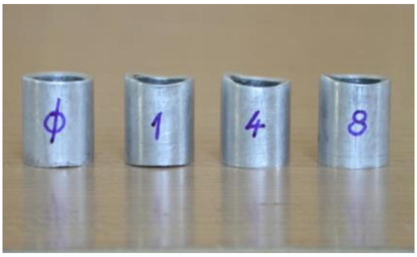

Figure (9): View of backward extruded cups, from left, after zero, one, four and eight passes.

Some characteristic features were observed on the pieces which were produced in ECAP materials. As it can be seen on Figure (9), the zero pass material did not show up anisotropic behaviour, at least not parallel to the symmetry axis. This means that the cup height along the circumference of the cup height is identical. On the pieces after ECAP passes, significant change was observed in the cup height (earing phenomenon) with two maximum and two minimum values as seen in Figure (9).

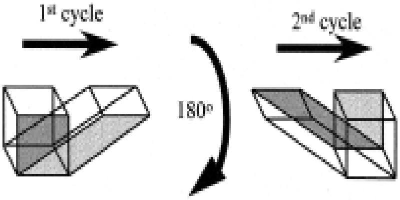

Figure (10): The cell transformation during the ECAP passes using route C technique [1].

This earing is the most significant in case one pass and a bit less in the case of four and eight passes. According to [1], the arrangement of the egg-shape is the most significant after the first ECAP pass during the upsetting test. However, during several double passes, the “egg-like” shape is less significant, as a result of using route C technique, the shearing direction at the intersection plane is the opposite of the passes' consequence.

The deformation cell has ellipsoid shape instead of the spherical, which return back to the original sample after event passes (four and eight passes) as illustrated in Figure (10), where the rout C technique is used [1].

Figure (11) presents the height of ECAP cups along their circumference. The anisotropic flow in the backward extrusion shows sine-like wave shape while the maximum amplitude obtained after one ECAP pass.

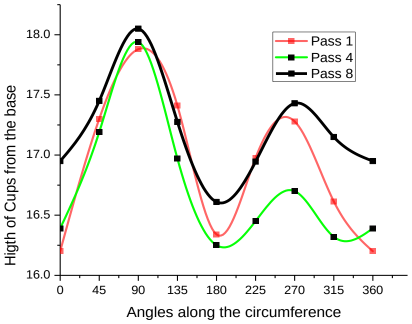

Figure (11): Anisotropic flow during the backward extrusion in ECAP cups..

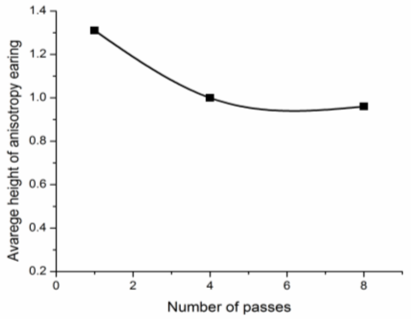

Figure (12): The average height of earing vs. number of ECAP passes for Al-6082 alloy.

To see this phenomenon more clear, Figure (12) illustrates the average height of the earing where each point in the curve was calculated by using the average of the parallel backward extrusion cups. The results prove the maximum induced anisotropy for pass one, and it decreases as the number of passes increases (the used samples), and looks to become about constant. It can be seen as shown in Figure (12), the four and eight passes are very close (earing phenomena). During backward extrusion experiments, the limitation in formability of Al 6082 alloy was monitored in cups produced after eight ECAP passes. The well-visible crack can be seen very clear at the top edge of all these cups, and their position was always the same (in between of the minimum and maximum point of earing), approximately in the middle angle. In all cases, just one crack was developed in one side. On the other hand, none of the other cups (specimens after one and four ECAP passes) showed this phenomenon (crack). Figure (13) shows the appearance of this typical crack and its typical position.

Figure (13): Typical crack on a cup produced by backward extrusion (after eight ECAP passes by route C, and Al-6282 alloy).

5. CONCLUSION

The ECAP (equal channel angular pressing) method was used to produce nanostructure cylindrical products by route C (the rod is rotated 180° around the longitudinal axis between each deformation steps). The test material was the Al6082 commercial Al-Mg-Si alloy. Backward extrusion tests were performed using the products made in the previous ECAP experiments. The backward extruded pieces suffered from the anisotropy induced by the ECAP deformation processes. It was appeared in the form of earing in two defined directions at the upper edge of the cup products. The maximum of earing was observed after the first pass. The formability was clearly reduced by the increasing number of passes. The cracks were appeared in a defined position on cups produced after eight passes. The forming force was increased with the increasing number of ECAP passes. These results are only the initial steps toward the applicability of the produced nanostructure materials in further forming technology steps. The full investigation of formability needs special investigation that was not the subject of this work.

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