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The effect of compression rate on hardness for pure Al, Al-5083, and Al-1050 with equal channel angular pressing

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Abstract— Compared to common metals, with a grain size of tens or hundreds of μm, Ultrafine Grained (UFG) metals, also known as nanocrystalline metals or nonmetals, have their grain size reduced mechanically to about 0.1–1 μm. This structural change affects many mechanical and physical properties of metals. The effect of severe plastic deformation (SPD) during equal-channel angular pressing (ECAP) on grain refinement and strain hardening are studied and was attempted at room temperature to refine grain size of pure Al, Al-5083, and Al-1050. Mechanical properties and the deformation behavior of the ECAP processed material were investigated by the hardness . We can summarize that the increase in velocity (ram speed) on pure Al, Al-5083, and Al-1050 leads to decrease in hardness and an increase in temperature during the ECAP and thus given the opportunity to re-crystallization (geometric dynamic re-crystallization (GDR)) occurs.

Keywords— Equal channel angular pressing; severe plastic deformation; Grain size; Aluminum, Hardness

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1 INTRODUCTION

The nanocrystalline and ultra-fine grain (UFG) materials can be used as super high strength materials, intelligent metal materials and super plastic materials. In applications, the nonmaterial's are promising for developing the systems of microelectronics, informatics, and micro electro-mechanics [1, 2].

Therefore, this material, processed by severe plastic deformation (SPD) methods has been the subject of intense study in the last decade [1]. Among all SPD techniques equal channel angular pressing (ECAP) Fig.1 has the advantages of producing of large samples [3] and the potential for commercialization [4]. This process first invented by Segal et al. [5] to achieve large strains and later Valiev et al. [6,7] were first to develop this method to produce UFG materials with superior mechanical properties. Briefly in this method a billet is pressed through a die having two intersecting channel with channel angle of Φ and an outer arc of curvature ψ. During this process an equivalent plastic strain ε_N of about 1.15 can be calculated according to equation 1[5].

$$\varepsilon_N = \frac{N}{\sqrt{3}}\left[2\cot\left(\frac{\varphi}{2}+\frac{\psi}{2}\right)+\psi\,\mathrm{cosec}\left(\frac{\varphi}{2}+\frac{\psi}{2}\right)\right] \quad (1)$$

Where, N is the number of passes.

Since the strain required for changing to the desired microstructure is usually 4–8, the billet has to be pressed repeatedly through the die. This also gives the opportunity for billet rotation about its axis between each pass of ECAP (Fig. 2). The three fundamental options for this rotation are called A (no rotation), C (180° rotation) and BC (90° rotation in the same direction).

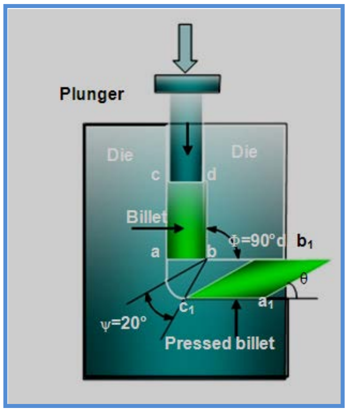

Fig.1 Equal channel angular pressing (ECAP)

Some researchers have concluded that route BC (in which the billet is rotated 90° clockwise or anti-clockwise) is the most effective route for producing UFG material [8], whilst others have suggested that route A (without any rotation) is more effective [9,10].

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Two superior features of UFG materials produced by ECAP are the very high strength and the potential of super plasticity at lower temperatures and higher strain rates [2]. The absence of the strain hardening is another important characteristic of the deformation behavior of these materials [11]. Also there is some evidence of decreasing hardness/yield stress during ECAP as the number of passes increases [12–14]. Till now there have been little attempts to analyze this event. Torre et al. [14] used two single parameter models to describe this effect.

Newly, the small overall internal combustion engine and the high strength threaded articles have been successfully used in practical application. Another application close to implementation is medical implants made of UFG titanium [15]. Other applications will certainly follow, taking advantage of high strength and weight savings so valued in the aerospace and automotive industries [16, 17].

In this study will be to study the effect of speed on the hardness of the pure Al , Al 1050 and Al 5083 after one pass during ECAP processing.

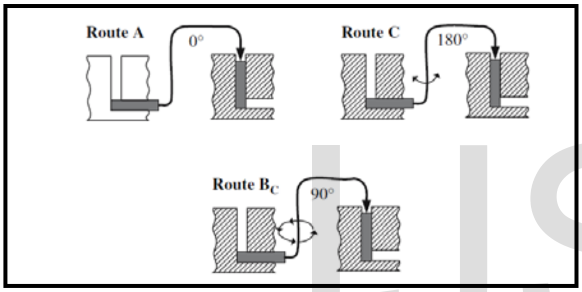

Fig. 2 Three basic options for billet rotation between consecutive passes through ECAP die.

2. EXPERIMENTAL PROCEDURES

The experiments were conducted using three different materials: high-purity aluminum, Al-5083 alloy and Al-1050 alloy. Aluminum was chosen because its highly-symmetric crystal structure (FCC) leads to geometrically similar dislocation densities, and because aluminum and its alloys are widely used in engineering applications.

The materials are provided in the form of rods and plates by Egypt Aluminum Company, situated at Naga Hammady in Egypt.

The specimens are prepared in the form of bars with cross-section of area 12mm^2 and 37 mm length.

TABLE 1 CHEMICAL COMPOSITION OF THE MATERIALS USED IN THIS WORK.

component	Fe	Si	Mn	Mg	Cu	Cr	Ti	Zn	Al wt.%
Pure Al %	0.062	0.041	0.001	0.001	-	-	-	-	99.895
Alloy 1050 %	0.25	0.12	0.03	0.03	0.03	-	0.02	0.02	99.5
Alloy 5083 %	0.4	0.4	0.85	4.5	0.1	0.12	0.15	0.25	93.38

The ECAP process are carried out at room temperature with different speeds of 1, 3and 10 mm s^{-1}. A split die is used having an internal channel with an angle of Φ= 90° and with an outer angle of curvature of ψ = 20° where the two parts of the channel intersect.

All extrusions (ECAP) are conducted using an Instron 8505 machine (shown in Fig.3) of 1200 KN and 1000 KN static and dynamic loading capacities, respectively. The die and sub press equipment (punch and clamps) material is made of tool steel and molybdenum disulfide (MoS_2) and Teflon are used as a lubricant (Fig.4).

Fig.3. The used die mounted on Instron machine

The exit billets (shown in Fig.5) were cut perpendicular to their longitudinal axes. The Vickers hardness in (kg/mm^2) is measured using an Instron universal hardness testing machine at load of 10 kg. A series of individual measurements are recorded on each polished section whereby the Vickers indenter is moved over the surface and measurements of the Vickers hardness are recorded in a regular grid pattern with spacing of 3 mm.

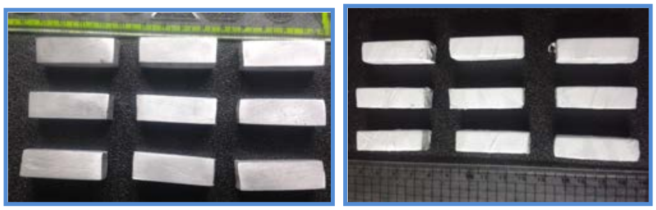

Fig.4 The samples before ECAP where they are warped by Teflon

Fig.5 The sample after ECAP

3. RESULT AND DISCUSSION

3.1 Effect of ram speed on hardness for pure Aluminum

All of the hardness measurements were plotted in Fig.6 the locations of individual hardness values on the cross-sectional planes perpendicular to their extruded axes. The distributions of the hardness values are unchanged as sensible along the cross-section of the sample after ECAP (one pass) and non effect by change velocity rate.

The hardness distributions on the cross-sectional plane for pure A1 prior to ECAP and after a single pass of ECAP are shown in Fig. 6. It can be seen that the sample exhibits a homogeneous hardness distribution throughout the whole cross-sectional plane and the measurements give an average value of hardness of ~19. After a single pass of ECAP at velocity rate 1 mm s-1, a much greater value of hardness, ~39 was achieved.

Fig.7 shows the variation of Vickers hardness on pure Al at different rates of (1, 3, and 10 mm s^{-1}). Compared with the as received material hardness, in 1, 3, and 10 mm s^{-1} rates the hardness increase for every rate by 51, 48.9, and 39.7% respectively. From obvious the Vickers hardness decreased at increase in velocity rate on pure Al materials. Also, it can be seen that the sample exhibits a homogeneous hardness distribution throughout the whole cross-section with rate 10 and 3 mms^{-1} is less than a homogeneous hardness at rate 1 mms^{-1}.

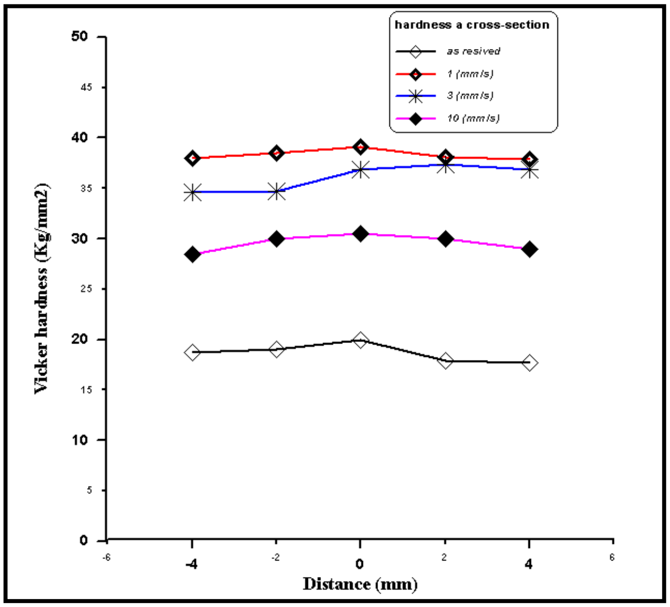

Fig.6 Average Vickers hardness across the cross-section for the as received and ecaped pure Al at three different rates.

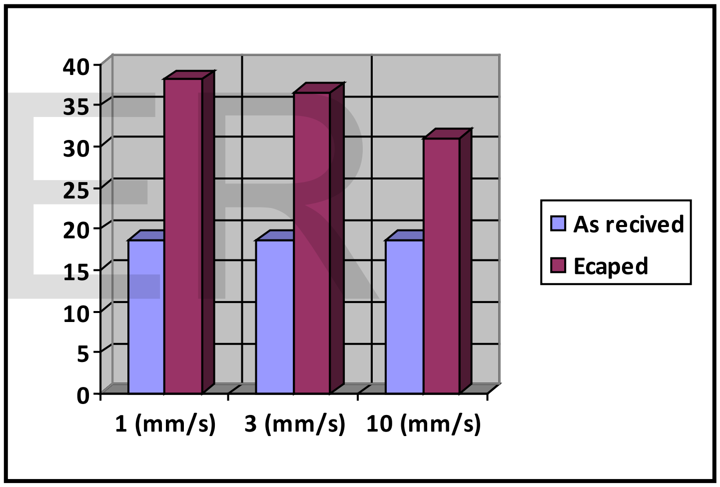

Fig.7 Average Vickers hardness for three different rates with the hardness values of the as received and ecaped pure Al material.

3.2 Effect of ram speed on hardness for Aluminum 5083

The hardness distribution on the cross-sectional plane for Aluminum 5083 prior to ECAP and after a single pass of ECAP is shown in Fig. 8. The figure shows that the sample exhibits homogeneous hardness distribution throughout the whole cross-sectional plane and the measurements give an average value of hardness of ~88. After a single pass of ECAP at velocity rate 1 mm s^{-1}, a much greater value of hardness, ~130 is achieved.

Figure 9 shows the change of Vickers hardness for Al-5083 at different ram speed of (1, 3, and 10 mm s^{-1}). Compared with the as received material hardness the hardness increase by 33, 27.9, and 26.7% respectively. From this result the Vickers hardness decreases as increase velocity for Al-5083 materials, but this percentage increase in Vickers hardness less than that for pure Al.

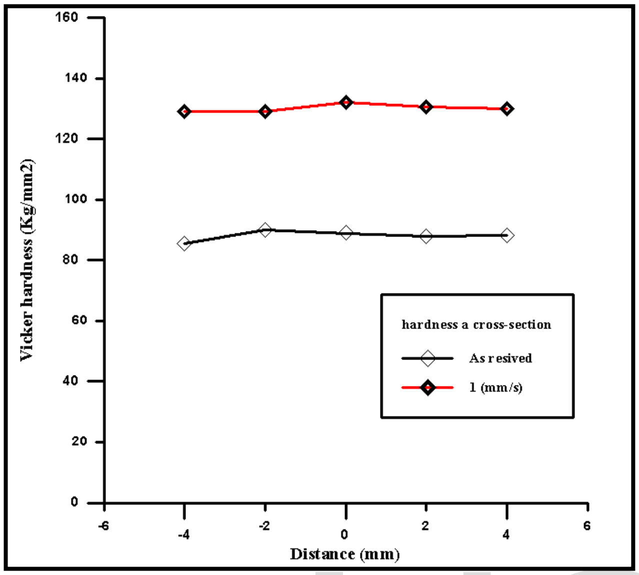

Fig.8 Average Vickers hardness across the cross-section for Al-5083as received and ecaped at 1mms-1 velocity rate.

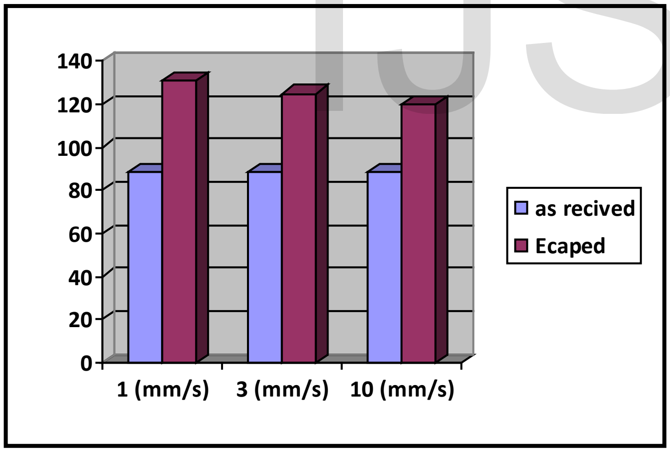

Fig.9 Average Vickers hardness for three different rates with the hardness values of the as received and ecaped Al 5083 material.

3.3 Effect of ram speed on hardness for Aluminum 1050

The hardness measurements shown in figure 10 shows the hardness values are the cross-sectional planes. The effect of different rate of (1, 3, and 10 mm s^{-1}) on Vickers hardness for Al-1050 is shown in Fig.11. Compared with the hardness of as received material the hardness increase by 63.3, 61.2, and 59.2% respectively. The measurements revealed that the hardness decreases as the velocity for Al-1050.

The increase in Vickers hardness for Al-1050 is greater than the increase in Vickers hardness for both pure Al and Al-5083.

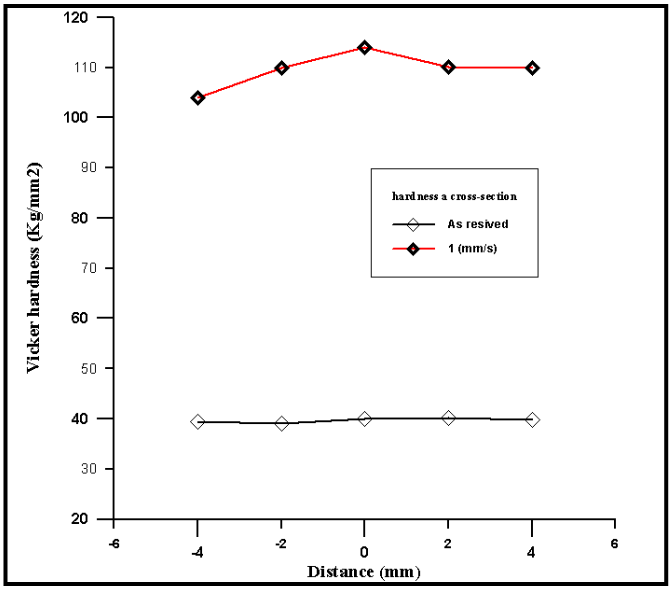

Fig.10 Average Vickers hardness across the cross-section for Al-1050 as received and ecaped at 1mms-1 velocity rate.

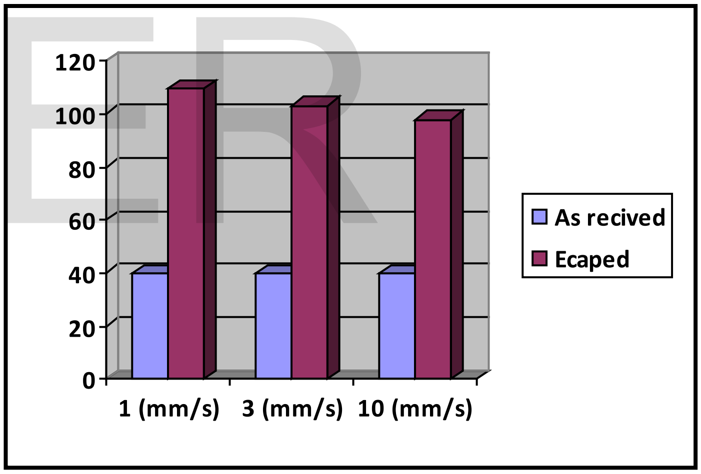

Fig.11 Average Vickers hardness for three different rates with the hardness values of the as received and ecaped Al 1050 material.

Finally, the pressing speed usually refers to the ram speed of the press and is assumed to influence the effect of ECAP because it is directly related to the deformation rate of the material. The temperature rise during ECAP. Apparently, the temperature rise increases with the increase of ram speed and it is possible to introduce a non-uniform temperature distribution on the sample. This temperature rise might cause dynamic recrystallization resulting in the decrease in hardness. However, this needs further investigation.

4 CONCLUSION

Equal Channel Angular Pressing is capable of producing bulk materials with ultrafine-grains and thus achieving advanced properties. The method is very attractive because of its potential for scaling-up in industrial applications. An investigation carried out in this work is to evaluate the characterizations processed by ECAP of some aluminum alloys that of importance in industry. The conclusion can be illustrated as:

1- A lower pressing speed (ram speed) produces a homogeneous microstructure more quickly than a higher pressing speed.

2- The increase in ram speed leads to an increase temperature cause dynamic re-crystallization are resulting in the decrease in hardness.

3- The Vickers hardness decreases by increasing the velocity of the ram, but this increase in Vickers hardness for Al-5083 and Al-1050 is less than the increase for pure Al.

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