

# THE EFFECT OF SPECIMEN'S GEOMETRY ON THE UPSETTING TEST OF THE NANOSTRUCTURAL AL-6086 ALLOY MATERIAL PRODUCED BY EQUAL-CHANNEL ANGULAR PRESSING

**Muamar M. Ben Isa\*, Hitem A. Aswihli and Mostafa A. Shokshok**

*Mechanical and Industrial Engineering Department, Faculty of Engineering, Al-Asmarya Islamic University  
Zliten, Libya.*

*\* Corresponding author: muamarisa@yahoo.com*

## ABSTRACT

The increasing interest in bulk nanostructured materials (NSM), processed by severe plastic deformation technique (SPD), comes as a result of their physical and mechanical properties. The most common plastic deformation technology used in producing the bulk ultra-fine-grained (UFG) materials is known as the equal-channel angular pressing (ECAP), typically in the sub micrometer or nanometer range by applying a very high plastic strain to the material. The large plastic shear deformation could be achieved by forcing the material to change its direction by 90° (intersection angle between two channels). A commercial Al-Mg-Si alloy (6082) is deformed by ECAP in order to producing bulk nanostructured materials with a high length to diameter ratio as 15-16 using route C technique up to eight passes. During the upsetting of ECAP products (one, four and eight passes), the anisotropy phenomenon induced by the ECAP technology has led to an asymmetrical bulging/buckling of the specimen. In this work, three sets of the upsetting specimen's geometry (height / diameter ratio) of three ECAP passes specimens are used in the investigation of the anisotropy phenomenon and in the comparison with a conventional one. The results show that the number of ECAP passes and the height/diameter ratio of the upsetting specimens have significant effect on the anisotropy of the ECAP material. This anisotropy is reduced by controlling the height/diameter ratio of the upsetting specimens.

**Keywords:** *ECAP, Nanostructure, Upsetting and Tensile tests.*

## INTRODUCTION

Severe plastic deformation (SPD) should meet a number of requirements, which can not be realized, with the traditional techniques of plastic deformation, such as rolling, drawing or extrusion etc. The first

requirement, to achieve properties change, ought to be obtaining ultra-fine-grained structure with high angle boundaries. The second requirement is the production of the nanostructure in the whole sample, providing stable material properties. The last one is maintaining the workpiece clear of any mechanical cracks or damages before and after the process; caused by the large plastic deformation. While there are different techniques to obtain nanostructure material, the most commonly used is the equal channel angular pressing (ECAP). While forming the nanostructure, using equal channel angular pressing method produces extremely large plastic deformations (with true strain equal or more than 10) [1,2,3,7].

ECAP method is used for deforming bulk materials by the means of pure shear only. The main feature is to apply intense plastic strain to the material without changing the cross section area. Repeated deformation is possible by this method, also rounded and squared samples can be used, Figure 1.

In ECA pressing the billet or the sample is pressed multiply through the used die (one pressing operation is called one “pass”), the intersection angle value between the two intersected channels must be taken into account, where it is usually  $90^\circ$  (Figure1) [1,2,3,5,7]. In case it is hard to deform the material, ECA pressing could be applied at high temperature to avoid any failure in the channels and make the deformation easier [5-9].

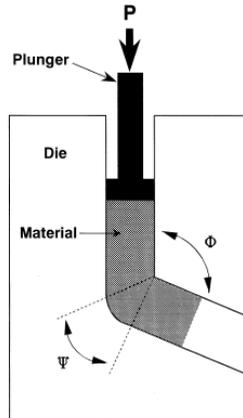
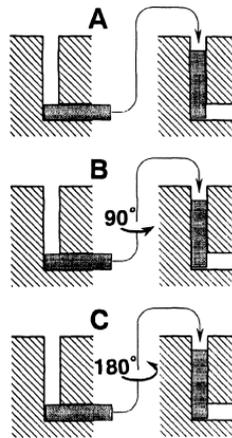


Figure1:  $\phi$  and  $\psi$  principles angles in ECAP channels.

Figure 1 illustrates the schematic principles of ECA pressing. The figure shows the die is constructed of two channels, equal in cross-section, intersecting at an angle of  $\phi$ . Another additional angle,  $\psi$ , defines the arc of the outer curvature of the intersecting channels. The specimen should be machined to fit tightly within the vertical channel and subjected to a pressure load (P), using a plunger. This load forces the sample to pass through the used die. As mentioned earlier, in order to increase the level of the imposed strain, the same specimen could be pressed several times through the die [1-7]. Generally, the ECA pressing experiments conducted up to the present day have used die angles with values  $\phi = 90^\circ$  and  $\psi = 0^\circ$ . However, it was shown by Gy. Krallics [4], through the finite element modeling of the ECA pressing configuration with  $\psi = 0^\circ$  that the use of angles close to  $\phi = 90^\circ$  makes it difficult to completely fill the die corner when pressing less ductile materials, unless a back pressure was applied at the die exit point. Alternatively, in [5,12,13] researchers avoided this tackle by performing

pressing experiments using a die angles with values  $\phi = 135^\circ$  and  $\psi = 0^\circ$ , by this way, in order to achieve the accumulate large strains, samples needed to be pressed through the die for more than 20 passes. On the other hand, Benisa [3] used the finite element modeling of the ECA pressing, and managed to fill the whole die corner with ductile material using configuration of  $\psi = 0^\circ$  and  $\phi = 90^\circ$  without applying the back pressure. According to Valiev[6,7], if the angles  $\phi = 90^\circ$  and  $\psi = 20^\circ$  were used as intersection angles, the strain value increases nearly by 1 in each pass. In the ECA pressing, the number of passes and the direction of the billet passes through the channel are very influent in the refinement of the microstructure [1,2,3,6,7]. According to Benisa and et al[1], there are three Patterns of the pressing process (routes); route A which in, the sample passes in the same direction without any rotation around its longitudinal axis. The other two routes are route B and route C, in route B the sample rotates around its longitudinal axis by  $90^\circ$  while in C the rotation is by  $180^\circ$ , Figure 2. The shear direction of these routes is affected by the number of the repeated passes of the workpiece through the intersection channel at ECAP process.



**Figure 2: Versions of ECAP method (a) shows route A, (b) shows route B and (c) shows route C.**

According to Valiev [7,10], when a sample passes a die having  $\phi = 90^\circ$  the original grains of the specimen material structure would be divided into a number of sub-grains, surrounded by boundaries with low angles of misorientation. These sub-grain boundaries evolve with further pressings into arrays of high angle boundaries. Grain refinement has been analyzed by the consideration of the shearing patterns, which was developed during pressing at  $\phi = 90^\circ$  [5]. Formation of homogeneous nanostructures in bulk material requires optimum conditions of a number of influent factors; which are: temperature, strain conditions of severe plastic deformation and friction conditions between the sample and the die [1,5,7].

## EXPERIMENTALS AND DISSCUSIONS

In this study, a commercial Al-Mg-Si alloy (Al 6082) was used as a raw material. The main components of this alloy are as shown in Table 1:

**TABLE 1: THE COMPOSITION OF THE USED AL 6082 ALLOY.**

Component	Al	Mg	Si	Mn
Wt. Percentage	97 %	0.6 - 1.2 %	0.7 - 1.3 %	0.4 - 1 %

Prior to the ECAP deformation, the material was annealed at 420°C for about 40 minutes. The annealed samples considered as the as-received material. Cylindrical billets of 15 mm in diameter and 230 mm length were pressed through an ECAP die set having 90° intersecting channels with identical cross section. One, four and eight passes were performed by route C (the rotation of the billets around their longitudinal axis after each pass is 180° clockwise). The well lubricated billets which having a slightly smaller cross-section than the die channel were placed into the vertical channel, then extruded by a punch to the second channel through the intersection. It is worthy to mention that, this technology was performed at the room temperature with ram velocity of 8 mm/min. The length - diameter ratio of the used specimens was relatively high (more the 15). Under these circumstances, the sample moves inside the intersected channels as a rigid body, the deformation would be achieved at the intersection area due to the simple shear effect. After the extrusion stroke, the punch returns to its initial position. Before inserting the second workpiece to the experiment set, a short Lead billet was placed inside the vertical channel upon the first workpiece, subsequently, the second workpiece is placed on the top of the Lead billet. Afterwards, the second stroke is initiated by the punch, extruding the first billet out of the horizontal channel. This procedure takes place repeatedly to the last pass. Figure 3 shows the four billets arranged

according to the passes they went through, from left to right, zero, one, four and eight passes [1].



**Figure 3: From left: zero pass, one pass, four passes and eight passes respectively using route C technique[1]**

For investigation purpose, the effect of the specimen geometry of Al6082 alloy on the normal (as received) microstructure and in the nanostructured condition after different number of passes (one, four and eight) by route C technique, the compression tests were carried out by the use of a pressing machine (an electro-mechanic testing machine). In order to avoid the recrystallization of the nanostructure, tests were conducted at room temperature. The speed of the clamping head was set to 2mm/min.

Used specimens were machined from the pressed workpieces parallel to their axis; three sets of three specimens were prepared with the same diameter (10mm) yet three different heights i.e. 15, 10 and 5 mm. After lubricating the contact surfaces of the specimen with an efficient lubricant, the specimen was located in the center point between two jaws with parallel smooth surfaces of the compression die. This procedure is applied on all other specimens, then this die was placed and fixed in a compression testing

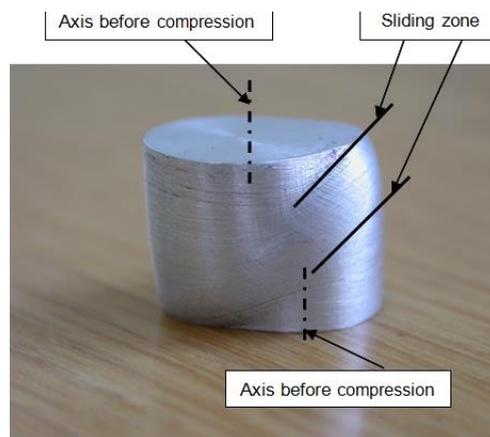
machine (TIRA test 2300 machine) shown in Figure 4. The tested specimen was objected to a pressure load, (up to 500 N) and then released. Afterwards, tested specimen was cleaned, and its height, minimum and maximum diameter were accurately measured using a measuring device (Mitutoyo Equipment with 0.01 mm resolution). Subsequently, the specimen placed again in the compression testing machine, reloaded by an incremental load equal to 0.5 KN added to the initial load and so on. This process was repeated many times until the equivalent strain value reached 0.7 then it was increased by 1 KN (an incremental load). These steps were repeated including the lubricating step after every measurement process.



**Figure 4: Upsetting machine with the die set [1]**

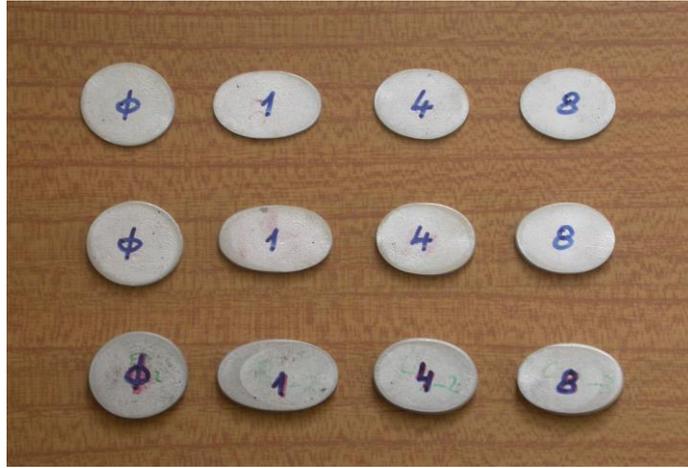
At first, all specimens had an axially symmetric shape, yet after the upsetting test, specimens lost their axial symmetry due to the strong anisotropy ending with a buckled shape as shown in figure 5.

Figure 5 shows the shape of the pressed specimen, where it clearly shows the deviation of the longitudinal axis of the cylindrical sample and the typical sliding layers. This phenomena could be illuminated by decreasing the initial height to diameter ratio ( $h_0/d_0$ ). However, it is known that smaller  $h_0/d_0$  ratios lead to increasing the influence of the friction on the strain state of the specimen. However, this phenomenon was not noticeable when the two other series (1 and 0.5 ratios) were tested.



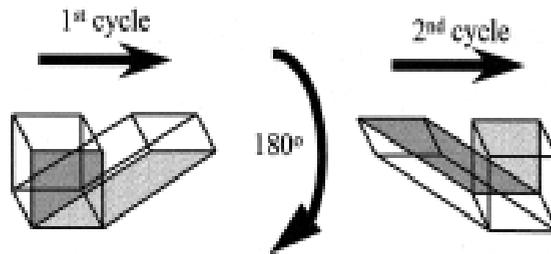
**Figure 5: Typical shape of compression specimen ( $h_0/d_0=1.5$ )**

The shape of one full set of the pressed specimens is shown in Figure 6. Specifically after the last load increment was applied at the same maximum force. The top row shows the pieces with 0.5 initial height/diameter ratio arranged from left to right according to the passes they went through; zero, one, four and eight ECAP. The second and the third rows represent the pressed specimens with initial geometric ratio as 1 and 1.5 respectively.



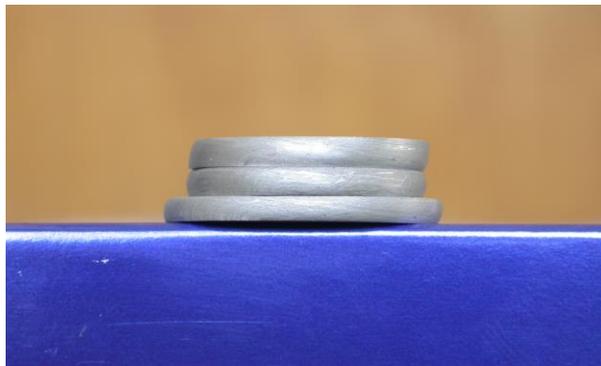
**Figure 6: Compression ECAP specimens with 10 mm initial diameter and with heights; from the top 5, 10, 15 mm and passes from the left zero, one, four and eight passes**

Figure 6 shows clearly the way how the cross section of the pressed specimens have changed from the circular shape to the oval one after the ECAP passes, indicating the presence of the induced anisotropy caused by this operation, it also shows that the maximum deviation from the circular to the oval shape occurs after the one pass. Benisa[1] explained this behavior to be a result of the cell return to its original shape after even passes i.e. route C is approached [1]. "After each even pass, the .egg-like shape is less significant, because during consequent passes (using route C) the shearing direction at the intersection plane is the opposite at each pass" as illustrated in Figure 7, where the rout C technique has been applied [1].



**Figure7: The cell transformation during ECAP passes using route C technique.**

A side view of the three upsetting specimens is shown in Figure 8. The specimens are arranged according to the number of passes they have went through, i.e. eight, four and one pass from the top of the figure to the bottom. One more time, it can be seen that the elliptical shape is in its maximum level after applying one pass, this phenomena is decreased when applying more passes (four and eight passes).



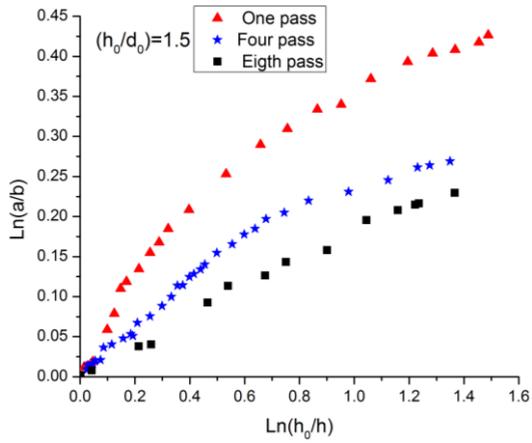
**Figure 8: The pieces with ( $h_0/d_0=1.5$ ) ratio of the three different passes, arranged from the top to bottom, eight, four and one pass**

For each ECAP pass and for every sample, the ratio between the maximum and minimum diameters was calculated. Figures 9, 10 and 11 indicate the

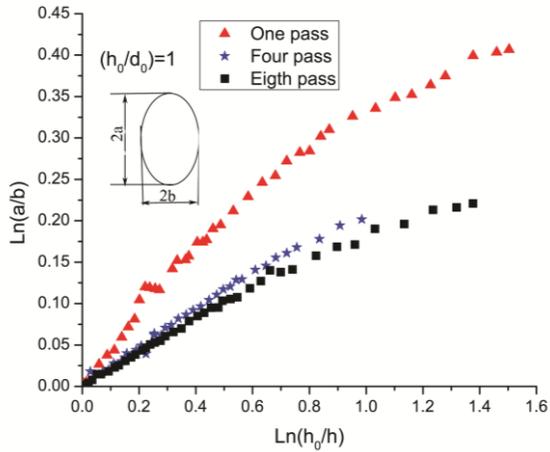
dependency of this ratio in the form of “ $\ln (a/b)$ ”, where: **a** and **b** are the half of the maximum and minimum diameters respectively.

The figures show the curves for the different passes in case of the height to diameter ratio was 1.5, 1.0 and 0.5 of the initial geometry respectively, where the specimen's diameter always constant (10mm). It should be noted that because of the barreling and sliding aside of the specimens, the measurement of the maximum and minimum diameter was not fully accurate, therefore the diameter ratio is informative only.

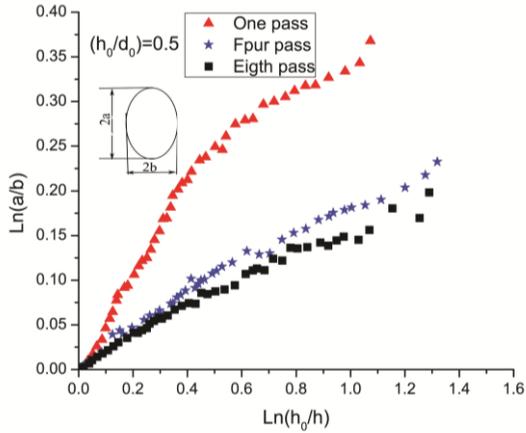
The three figures (9,10 and 11) show the curves of the relationship between the diameter ratio of the different passes (in the case of the height to diameter ratio was 1.5, 1.0 and 0.5 of the initial geometry respectively) and the upsetting strain for the different passes in the room temperature. Due to the barreling and sliding of the tested specimens, measuring the maximum and minimum diameters was not fully accurate. It can be noticed that the ECAP pass one had a higher level than the four and eight ECAP passes, which -their levels- have shown a close agreement to each other, Figures (9,10 and 11).



**Figure 9: Diameter ratio vs. upsetting strain at room temperature for Al6082 after different ECAP passes ( $h_o/d_o=1.5$ )**

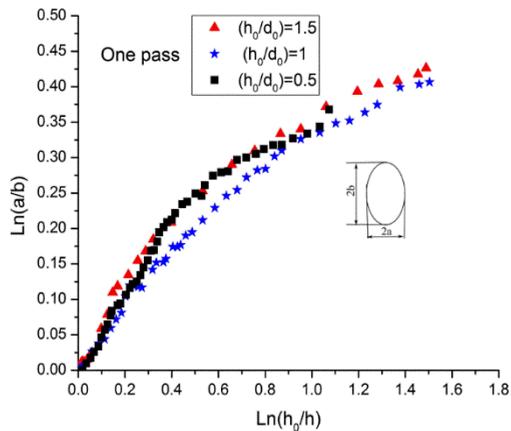


**Figure 10: Diameter ratio vs. upsetting strain at room temperature for Al6082 after different ECAP passes ( $h_o/d_o=1$ )**

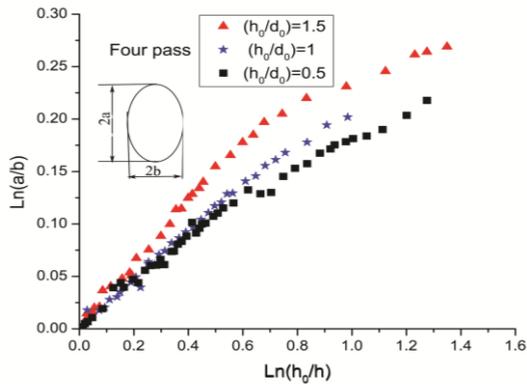


**Figure11: Diameter ratio vs. upsetting strain at room temperature for Al6082 after different ECAP passes ( $h_0/d_0=0.5$ )**

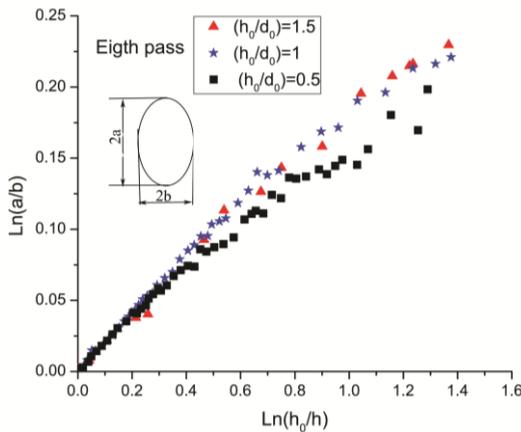
Moreover, for more clarification, three more figures (12, 13 and 14) were generated illustrating this relationship, for the three ECAP pass patterns (one, four and eight) respectively.



**Figure 12: Diameter ratio vs. upsetting strain at room temperature for Al6082 after one ECAP pass**



**Figure 13: Diameter ratio vs. upsetting strain at room temperature for Al6082 after four ECAP passes**

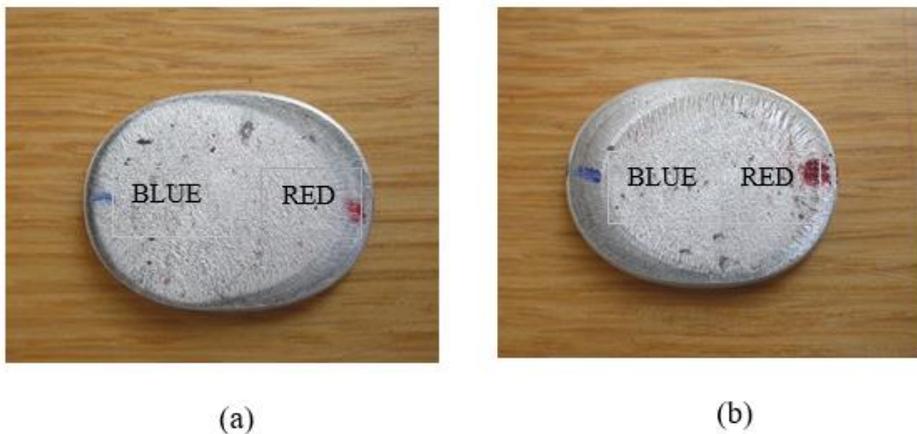


**Figure 14: Diameter ratio vs. upsetting strain at room temperature for Al6082 after eight ECAP passes**

In figures 12 and 13, it can be seen that in one and four passes, the 1.5 ratio has the higher levels than the other two ratios (1.0 and 0.5). Moreover, as the number of passes increases, (four and eight) the level of the three ratios (0.5, 1.0 and 1.5) are shown to be more closer. The reason of that might be due to the fact that the cell return

to its original shape after even passes i.e. route C technique is approached (Figure 7).

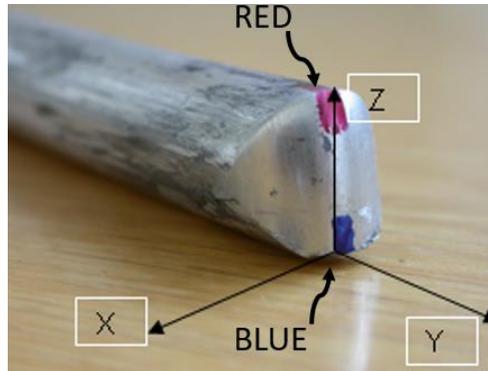
As mentioned earlier, the characteristic features of these nanostructured pieces is the anisotropic flow, which result in forming the elliptical shape. This shape should be described as an egg-like shape which is nonsymmetrical indeed. Figure 15 shows elliptical shape of one of the specimens.



**Figure: 15 Anisotropic flow where red shows the upper side and blue the lower side of ECAP billet, (a) upper surface of the upsetting specimen, (b) lower surface of the upsetting specimen**

Figure 16 shows the ECAP billet illustrated on it the maximum diameter of the elliptical shape (Z-axis). This characteristic was approved by machining the pressed ECAP billet along the longitudinal axis (Figure 16, Y-direction) and then marking the upper and the lower side directions of the specimen surface. The red mark refers to the upper side of the billet, whereas the blue one refers to the lower side exactly as they were observed and located after the last pass. It is worth to mention that, the direction of the maximum

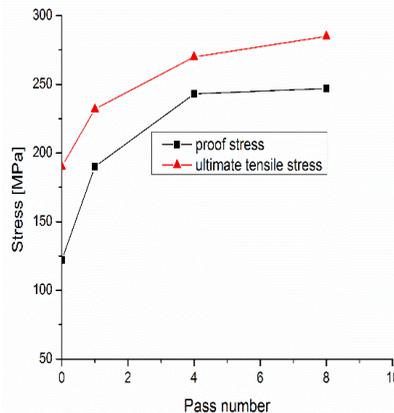
diameter of the oval shape during the upsetting test is perpendicular to the horizontal ECAP channel, also parallel to the vertical one i.e. perpendicular to longitudinal axis of ECAP billets.



**Figure: 16: The direction of ECAP and its axes, (a) the anterior view of billet after pass one (red sign is upper side and blue is lower side) and its axes of coordinates**

After ECAP process, investigations of mechanical properties were carried out on the specimens processed by ECAP. Tensile tests were conducted at room temperature (cross head velocity: 2mm/min) using the TIRA test 2300 machine (Figure 4), that was to investigate the change of mechanical properties (yield stress and ultimate tensile strength) of Al6082 alloy in the normal (as received) microstructure and in nanostructured condition after different number of passes (one, four and eight) using route C technique. The conventional (as received) and the nanostructured specimens were machined along their longitudinal axis. Figure (17) illustrates the dependences of yield stress and ultimate tensile stress for conventional and after ECAP process (one, four and eight). The nanostructure specimens have higher yield stress (proof stress) and ultimate tensile stress than the conventional ones due to the effect of strain hardening and the size and

shape of billet material grains. As the number of ECAP passes increase, the yield stress (proof stress) and ultimate tensile stress increase too, where there is no significant difference between pass four and pass eight. The reason of that according to Benisa [1,2] is that the cell returns its shape after even passes, Figure 7 (they have the similar material anisotropy).



**Figure:17: The ultimate tensile stress and the proof stress for the different ECAP passes**

## CONCLUSION

In this work, different results were achieved based on the different  $h_0/d_0$  ratios and for different ECAP passes. Unusual phenomenon has been observed on the shape of the specimen; which is an oval shape after the ECAP processing. This phenomenon is strongly effected by the anisotropy property. Where its maximum level (ovalizing) is observed after pass one, after even ECAP passes, this ovalizing shape seems to be less significant. Apparently, this comes as a result of the consequent passes (using route C technique). The isotropic phenomenon showed its higher level when the  $(h_0/d_0)$  ratio was 1.5, this level decreased at the ratios 1.0 and 0.5. It is worth to mention that, no significant variation was observed between the latter two ratios (1.0 and 0.5). During the tensile test, the ECAP specimens show higher yield stress (proof stress) and higher ultimate tensile stress when compared to the conventional alloy (as received), which increases as the number of passes increases, and there is no significant change between the four and eight passes.

These results are obtained when the specimens were prepared in a direction along to the longitudinal axis of the ECAP billet (Y-axis). A future study would consider the other two direction axes (X and Z) of the ECAP billet when preparing the test specimens. That might provide additional data relating to the nanostructured material behaviour.

## REFERENCES

- [1] M. M.Benisa, F.F.Eldabee, A. A.Edrwish. (2019). "The Effects Of Backward Extrusion On Bulk Nanostructured AL-6082 Materials Produced By Equalchannel Angular Pressing (ECAP)." *Journal of Sciences and Technologies (Engineering and Applied Science)*. Vol. 3, No.1,pp.52-65.
- [2] M. M.BENISA, G.A.Sanussi. (2014). "Investigation of Mechanical Properties For Bulk Nanostratural of AL-6082 Alloy Material Produced By Equal-Chanal Angular Pressing (ECAP)." *Structural Integrity And Life*. Vol. 14, No. 2, pp. 79-86.
- [3] M. M.Benias.,B.S.Yonis, H.A. Aswihli. (2019). "Experimental and Numerical Simulation for Bulk Nanostructure Material of AL-6082 Alloy Material Produced by Equal Channel Angular Pressing (ECAP)." *IJEIT*. Vol. 6, No. 1, pp. 17-21.
- [4] G. Krallics, D. Malgin, A. Foder. (2005). "Materials Scince Forum." Vol. 473, pp. 129-134.
- [5] G. Krallics, Z. Szeles, D. Malgyn. (2005). "Materials Scince Forum." Vol. 473-474, pp. 453-458.
- [6] R. Valiev, R. Islamgaliev, I. Alexandrov. (1999). "Nanostructured Materials From Several Plastic Deformation." *Nanostructured Materials*. Vol. 12, pp. 35-40.
- [7] R. Valiev, R. Islamgaliev, I. Alexandrov. (2000). "Bulk Nanostructured Materials From Severe Plastic Deformation." *Progress in Material Science*. Vol. 45, pp. 103-189.
- [8] R. Valiev, I. Alexandarov. (1999). "Nanostructured Mater." pp. 12-35.
- [9] R. Valiev, Y. Ivanisenko, E. Rauch, B. Baudelet. (1997). *Acta Mater*. 44:4705
- [10] M. Furukawa, Z. Horita, M. Nemoto, T. Langdon. (2001). *Journal of Material Science*. Vol. 36 , pp. 2835-2843.
- [11] V. Segal. (1995). *Mater Sci Eng*. A,197-157.
- [12] Y. Iwahashi, Z. Horita, M. Nemoto, T.Langdon. (1998). *Acta Mater*. 46:1589.
- [13] R.Valiev. (1995). *Nanostructured Mater*. 6:73.