Budapest University of Technology and Economics
Faculty of Mechanical Engineering
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Summary of the Ph.D. Thesis

Forward Extrusion of Tube from Ultra-fine Grained Material

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Abstract

This work has been divided into three parts, each part studies one of the stages of the nanostructued Al-6082 tube production.

First part defined the SPD techniques and explained their Methods, in concentrated on Equal-channel angular pressing (ECAP). In this method, a commercial Al-Mg-Si alloy (6082) was deformed to produce bulk ultra fine-grained structure using route C technique up to eight passes with a high length to diameter ratio as 15-16. The products were investigated after one, four and eight passes.

In the second parts, the workability and the mechanical behavior of nanostructured Al-6082 alloy material have been investigated by using the upsetting test. The specimens were taken out from the three perpendicular axis of ECAP part and exposed to compressing test to determine the true stress true strain curves in all the three conditions. The tests were carried out using an electro-mechanical testing machine at room temperature to avoid recrystallization of the nanostructure, and the speed of the clamping head was 2 mm/min. During upsetting the anisotropy induced by the ECAP technology led to asymmetrical bulging/buckling. This phenomenon was reduced by lowering the height to diameter ratio of the upsetting specimens. The flow curves were plotted for all specimens in the three directions. A computer program was used to analyze the flow curve data to determine the stress and strain parameters, by plotting the fit curves on the flow curves. Ludwik equation was applied in this program to plot fitting curves lines. A simple yield criterion and material law are used to describe the plastic deformation of the nanostructured material. The parameters of anisotropy are determined. In this study many types of ductile fracture criteria were used to determine the limit of the bulk deformation. Metals produced by ECAP were reported to have high strength and high ductility.

In the third parts the extrusion process and tube extrusion of nanostructured Al-6082 alloy were investigated. The diameter of cross-sections area of a produced bar in the forward extrusion process were 10mm,8mm,and 6mm, while the initial diameter was 15mm. The processes were carried out at room temperature with the speed of the ram of 2mm/min for all types of specimens, and a special type of lubrication was use to reduce the friction between the billet and the die. The relation ship between the force and ram distance was obtained. The experimental results show that the pass 8 (route C) has the maximum value of extrusion loads and high value of hardness. This part of work was also examined various nanostructured Al-6082 alloy, as it undergoes the tube extrusion process of tube manufacturing. Forward extrusion processes were applied to produce a tube from nanostructured Al-6082 material. In this process, the die set consists of four parts: punch, container, piercing, and the base. The extruded materials were four types of nanostructured Al-6082 alloy: Pass 1, Pass 4 (route C) and Pass 8 (route C), which were produced by equal channel angular pressing (ECAP), in addition to the annealed material. The tests were simulated by using the finite element method and its results were compared with the experimental results. The finite element results were found to be nearly identical to the experimental results, with the Pass 8 alloy having the maximum extrusion load value.

1. Introduction

Severe plastic deformation (SPD) techniques are used to produce nanostructures in various bulk metallic materials by break down the microstructure into finer and finer grains.

In particular, SPD methods resulted in overcoming of number of difficulties connected with residual porosity in compacted samples, impurities, processing of large scale billets and practical application of given materials.

There are different techniques to obtain nanostructure material, some of them are the most commonly used methods, in this work the equal channel angular pressing (ECAP) is used to produce Ultra-fine grained Al-6082.

During the ECAP pressing a rod shaped sample is pushed through an angular die channel with a constant cross section (Fig. 1). The material is subjected to large plastic shear deformation when forced to change the direction by 90º (intersection angel between two channels).

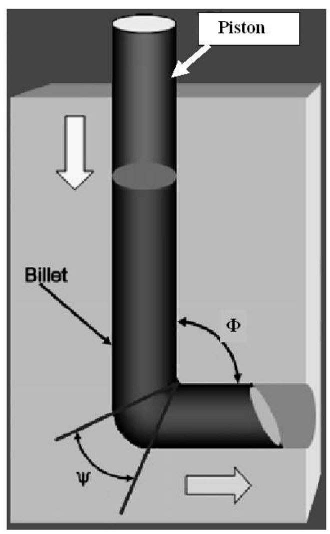


Fig. 1. ECAP die

The materials which produced by this technique have anisotropic behaviour, which means a different properties in different directions.

Most previously works are dealt with isotropic materials. This work describes the cold deformability of nanostructured Al - 6082 alloy material which was produced by (ECAP) technique, route ‘C‘(one, four and eight passes) and the upsetting tests were carried out on nanostructured Al-6082 alloy to investigate its workability, from these tests we noted that this material has different behaviour in different direction and the deformed specimens showed us that the elongation of the samples is different. Generally, for nanostructured materials produced by (ECAP) technique, the workability parameters are depending on the number of passes, type of route, and the direction of the specimen’s axis and it refers to the relative ease with which the material can be shaped through plastic deformation and it is a function of the material and the process.

On the other hand, workability is usually thought of as being limited by the onset of the fracture. Prediction of ductile fracture initiation allows prior modification of process, which can result in a defect-free final product with financial savings. It is well known that the greater ductility of the material allows greater deformation. Many ductile fracture criteria have been proposed and can be classified into two groups: (a) models based on microscopic observation about void nucleation, growth and coalescence; (b) empirical and semi-empirical models. In this study many types of ductile fracture criteria were used to determine the limit of the bulk deformation.

When this metal is extruded, it is compressed above its elastic limit in a chamber and is forced to flow through and take on the shape of an opening. Metal is extruded in a number of basic. The metal is normally compressed by a ram and may be pushed forward or backward and the products may be solid or hollow.

2. Objective of the work

There are three main objectives in this work:

Producing the nanostructured materials from commercial aluminium Al-6082 alloy, this objective can be accomplished by the following steps.

- Review some of the type of severe plastic deformation (SPD) processes and comparing between them to find the best method for producing these materials.
- Investigate the applying of equal channel angular pressing (ECAP) method to produce several type of nanostructured material.

-2 Creating some testing such as upsetting test to investigate the properties of nanostructured Al-6082 materials, from this objective we can determine the following points:

- True stress-true strain curves, effective stress-strain curves, and yield strength of some types of nanostructured materials.
- Describing the workability of nanostructured Al-6082 alloy material which was produced by equal channel angular pressing (ECAP).
- Using **Hu** and **Hill** anisotropic yield criteria to describe the anisotropic yielding behaviour of the bulk metal and ductile fracture limit by determining the anisotropic parameters.

-3 Applying some types of extrusion processes technology such as forward and backward extrusion to produce tubes from these material, this objective include the following points:

- Investigate the behaviour of the producing materials and the parameters of these processes.
- Using the finite element method to simulate these processes and comparing the result with the experimental results.

Experimental work

3.1. Mechanical properties of nanostructured Al-6082 alloy processing by ECAP technique

In this part of the presented work, the mechanical behavior of nanostructured Al-6082 alloy material has been investigated by using the upsetting test. The material of specimens was produced by the ECAP technique and the specimens were taken out from the three perpendicular axis of ECAP part. The tests were carried out using an electro-mechanic testing machine at room temperature to avoid recrystallization of the nanostructure, and the speed of the clamping head was 2 mm/min. The true stress-true strain curves were plotted for all specimens in the three directions. A computer program was used to analyze the data obtained from these curve to determine the stress and strain parameters, by plotting the fit curves on the true stress-true strain curves. Ludwik ductile criteria equation was selected for this program to plot fitting curves lines. The deformed specimens clearly show the anisotropic behaviour

3.1.1. Determination of true stress-true strain curves

To determine the flow curves for all types of materials, we need to calculate the true stress and true strain that can be calculated from the below formulas given below.

The true stress σ_i is

$$\sigma_i = \frac{P_i}{A_i} \tag{1}$$

where P_i is instantaneous force and A_i is the instantaneous cross-sectional area of the specimen, which can be calculated from volume constancy as:

$$A_0 h_0 = A_i h_i \,, \text{ So } , A_i = \frac{A_0}{h_i} h_0 \tag{2}$$

where A_0 = initial area of specimen, and h_0 is the initial height of the specimen.

Therefore,

$$\sigma_i = P_i \times \frac{h_i}{A_0 h_0} \tag{3}$$

The true stress-true strain curves of tests are shown in Fig. 2.
And the true strain can be determined as:

$$\varphi_i = \ln \frac{h_0}{h_i} \tag{4}$$

3.1.2. Fitting lines of true stress-true strain curves

After the true stress and true strain curves are plotted, the lines are fitted to these curves by using a computer program, and a special equation is selected to plot these fitting lines. This equation is assumed as:

$$y = b_1 + b_2 \varphi^{b_3} \tag{5}$$

where b_1, b_2, and b_3 are constants which are obtained from the fitting program. This equation is similar to the Ludwik equation.

The fit lines of true stress-true strain curves of Pass (8-Route C)- 90 º - direction, are shown in Fig. 3.

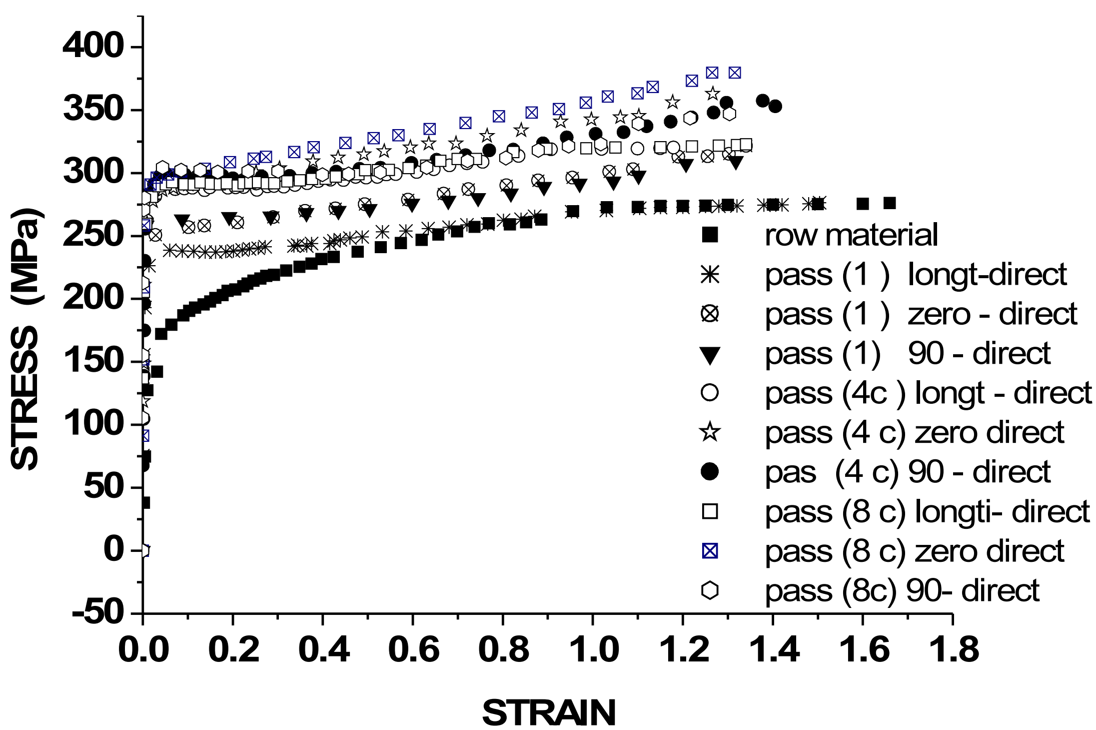


Fig. 2. All true stress-true strain curves

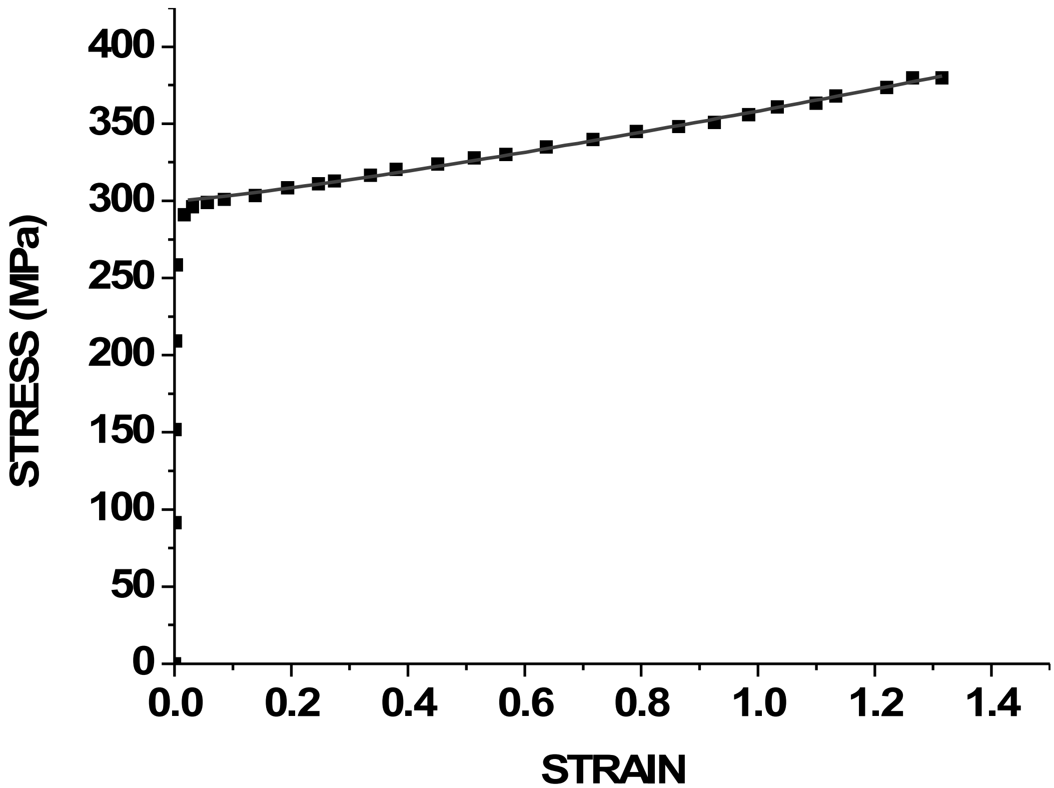


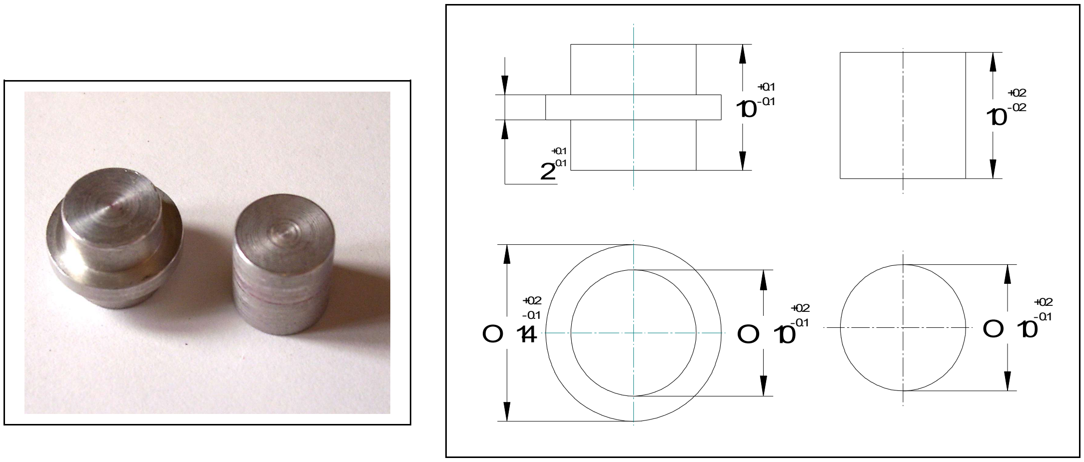
Fig. 3. Fit line- pass (8-route C)- 90 º - direction

From experimental upsetting tests we observed that:

- The flow stress of nanostructured Al-6082 alloy depends on the number of passes of the ECAP and the direction of the axis.
- The true stress in zero direction is greater than in the other directions, in spite of the low value of strain hardening, while the strain hardening in the direction of 90 º is the highest.

3.2. Workability of nanostructured Al-6082 alloy produced by ECAP technique

This article describes the workability of nanostructured Al - 6082 alloy material, produced by equal channel angular pressing (ECAP). Anisotropy has been recognized as a key factor of sheet forming for several decades, but this study has dealt with anisotropic behavior for bulk forming processes. A simple yield criterion and material law are used to describe the plastic deformation of the nanostructured material. The parameters of anisotropy are determined by upsetting tests on cylindrical and flanged pieces (Fig. 4), machined in three perpendicular axes of an ECAP part. Metals produced by ECAP were reported to have high strength and satisfied ductility produced in metals subject to ECAP.



All dimension in (mm)

Fig. 4. Cylindrical and flanged specimens before deformation

3.2.1 Anisotropy yield criterion

To calculate the ductile and fracture criteria, the stress state of the material, (i.e. value of stresses) is determined.

Many criteria have been developed to predict ductility of the anisotropic materials. In this work, **Hu** yield criterion is applied, this criterion was applied on the sheet metal and improved by **Fodor Árpád** [4] for applying on the bulk materials, the basic equation of this criterion is:

$$f = X_1(\sigma_{11} - \sigma_{33})^4 + X_2(\sigma_{11} - \sigma_{33})^3(\sigma_{22} - \sigma_{33}) + X_3(\sigma_{11} - \sigma_{33})^2(\sigma_{22} - \sigma_{33})^2 +$$
$$+ X_4(\sigma_{11} - \sigma_{33})(\sigma_{22} - \sigma_{33})^3 + X_5(\sigma_{22} - \sigma_{33})^4 + X_6(\sigma_{12}^2 + \sigma_{23}^2 + \sigma_{31}^2) \times$$
$$\left[(\sigma_{11} - \sigma_{33})^2 + (\sigma_{22} - \sigma_{33})^2 - (\sigma_{11} - \sigma_{33})(\sigma_{22} - \sigma_{33})\right] + X_7(\sigma_{12}^2 + \sigma_{23}^2 + \sigma_{31}^2)^2 - 1 = 0 \qquad (6)$$

where: X_1, X_2,……, X_7 are the anisotropy parameters.

In the case of the upsetting test of collar and cylindrical pieces at the free surface, the perpendicular component of stress (σ_{11}) is equal zero (Fig. 5); because there is no shearing in the compressing test, the shear stresses' components ($\sigma_{12}, \sigma_{23}, \sigma_{31}$) are equal zero too.

$$\sigma_{11} = \sigma_{12} = \sigma_{23} = \sigma_{31} = 0$$

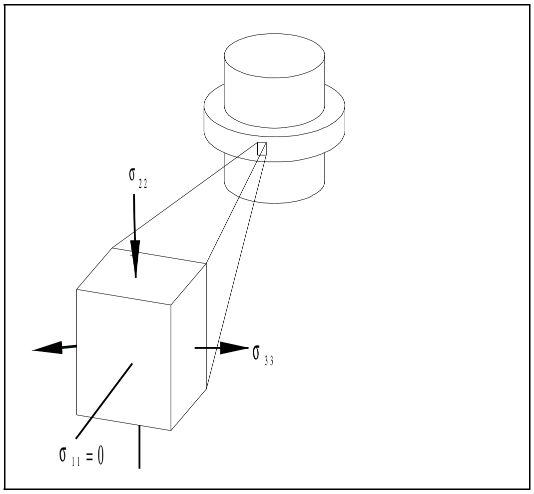


Fig. 5. Direction of stress components at free surface

By substituting the value of stresses in Eq. (6), the seven unknown anisotropy parameters are reduced to five, and the above equation becomes:

$$f = X_1(\sigma_{33})^4 - X_2(\sigma_{33})^3(\sigma_{22} - \sigma_{33}) + X_3(\sigma_{33})^2(\sigma_{22} - \sigma_{33})^2 - X_4(\sigma_{33})(\sigma_{22} - \sigma_{33})^3 + X_5(\sigma_{22} - \sigma_{33})^4 - 1 = 0 \qquad (7)$$

On the other hand, the three component of strain rate can be calculated from the flow rule equation as:

$$\dot{\varepsilon}_{ii} = \dot{\lambda}_i \frac{\partial f}{\partial \sigma_{ii}} \qquad (8)$$

where i is the symbol indicates the direction of stresses.

From Eqs. (7) and (8), the following is obtained:

$$\boxed{\begin{aligned}\dot{\varepsilon}_{22} = \dot{\lambda}_i(-X_2(\sigma_{33}^3) + 2X_3\sigma_{33}^2(\sigma_{22} - \sigma_{33}) - 3X_4\sigma_{33}(\sigma_{22} - \sigma_{33})^2 + \\ + 4X_5(\sigma_{22} - \sigma_{33})^3)\end{aligned}} \tag{9}$$

$$\boxed{\begin{aligned}\dot{\varepsilon}_{33} = \dot{\lambda}_i(4\sigma_{33}^3 - 3X_2\sigma_{33}^2(\sigma_{22} - \sigma_{33}) + X_2\sigma_{33}^3 + 2X_3\sigma_{33}(\sigma_{22} - \sigma_{33})^2 - \\ - 2X_3\sigma_{33}^2(\sigma_{22} - \sigma_{33}) - X_4(\sigma_{22} - \sigma_{33})^3 + X_4\sigma_{33}(\sigma_{22} - _{33})^2 - \\ - 4X_5(\sigma_{22} - \sigma_{33})^3)\end{aligned}} \tag{10}$$

The equivalent stress and equivalent strain curves of some types of the materials are shown in Fig. 6. These curves were fitted to the curves line by using special computer software to obtain the mathematical formula for all curves.

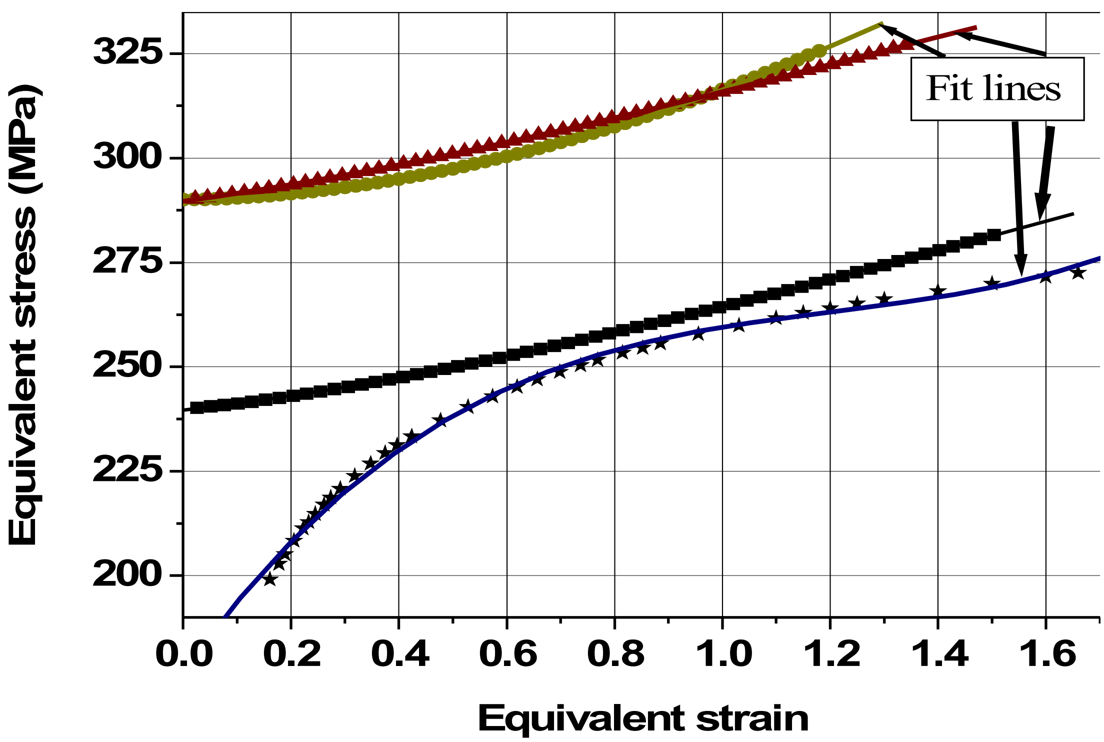


Fig. 6. Fitting lines of equivalent stress – equivalent strain

From the results of the experimental tests, the authors noted that the equivalent stress of the 4C pass material are closed to the equivalent stress of the 8C pass material, this is because the values of shear stresses resulting from the ECAP process are equal in both of them, and the equivalent stress of the row material has the lowest value. From the value of fracture criterion constant, the authors noted that the pass 8C has the maximum value of $\boxed{C_f}$, while the value of effective strain is small.

3.3. Ductile fracture of nanostructured Al-6082 material

In this paper we investigated the ductile fracture in cold forming of nanostructured Al - 6082 alloy material during axi-symmetric collar (flanged) tests and cylindrical upsetting tests by using eight types of fracture criteria. . The material of specimens was produced by one, four, and eight passes (route C) of ECAP process and taken out of three perpendicular axes .The material has ultrafine grain size and an anisotropic behaviour. Hill yield criterion and material law are used to describe the plastic deformation of the nanostructured material. The collar tests and cylindrical upsetting tests produced typical ductile fractures in all types of specimens.

3.3.1. Calculation of constants of Hill ductile yield criterion

In order to calculate ductile yield criteria we need at least a certain kind of destructive test and a special an isotropic yield criterion, and results were simulated using computer programme to determine anisotropic parameters, in this part we use Hill equation to determine anisotropic parameters. Each ductile fracture criterion needs to calculate stress state and effective stress. Hill yield criterion can be expressed as:

$$\boxed{\begin{aligned} &F(\sigma_{22}-\sigma_{33})^2+G(\sigma_{33}-\sigma_{11})^2+H(\sigma_{11}-\sigma_{22})^2 \\ &+2L\sigma_{23}^2+2M\sigma_{31}^2+2N\sigma_{12}^2=1 \end{aligned}} \tag{11}$$

Where $F,G,.....,N$ are anisotropy parameters.

The above equation becomes:

$$\boxed{F(\sigma_{22}-\sigma_{33})^2+G(\sigma_{33}-\sigma_{11})^2+H(\sigma_{11}-\sigma_{22})^2=1} \tag{12}$$

But in all directions there is only one of stress components then:

$\boxed{\sigma_{11}=\sigma_{22}=0}$

And the equivalent stress becomes:

$$\boxed{\bar{\sigma}_{eq}=\left(\frac{\sqrt{3}\left[\sigma_{33}^{2}(F+G)\right]}{2\sqrt{(FH+FG+GH)}}\right)^{\frac{1}{2}}} \tag{13}$$

The equivalent strain can be expressed as:

$$\boxed{\bar{\varepsilon} = \frac{\sqrt{6(F+G+H)} \times \sqrt{\frac{(G^2+HF+GH)^2}{F+G}} \times \ln\frac{h_0}{h}}{3(HF+FG+GH)}} \tag{14}$$

The values of anisotropy parameters can be calculated by solving these equations:

$$\boxed{(F+G)\sigma_y = m_1} \tag{15}$$

$$\boxed{\frac{G-H}{G+H} = m_2} \tag{16}$$

$$\boxed{\frac{H-F}{F+H} = m_3} \tag{17}$$

Where is the yield stress and , and are the slope of the curve lines in Fig.7 where a and b are principal axes of the ellipse of deformed specimen (Fig. 8).

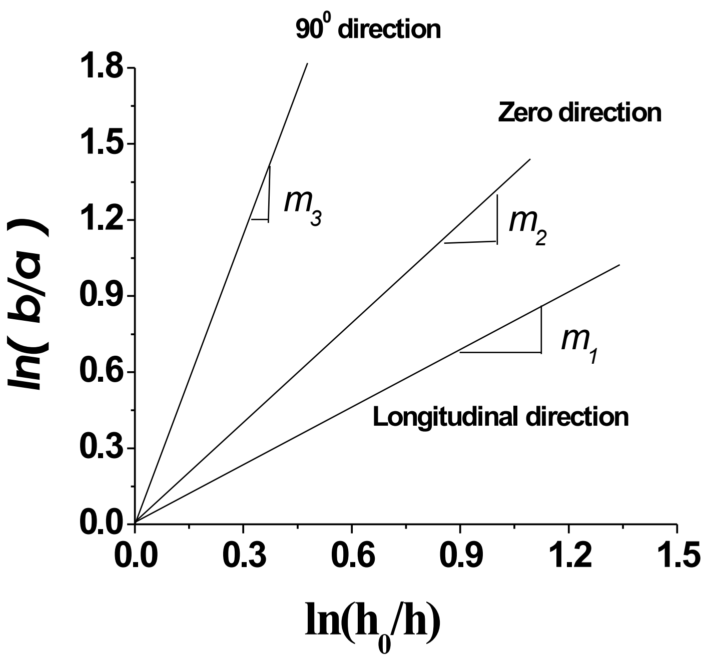


Fig. 7. Values of m_1, m_2, and m_3

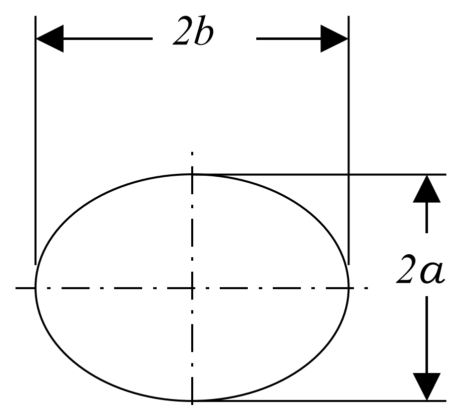


Fig. 8. Ellipse axes of deformed specimen.

3.3.2. Ductile fracture criteria

The empirical formulas of these criteria are described below.

1. Cockcroft and Latham fracture criterion

This criterion is based on true ductility and it is suggested that the fracture occurs when the tensile strain energy reaches a critical value:

$$\boxed{\frac{1}{\sigma_y}\int_0^{\bar{\varepsilon}_f} \sigma_1 d\bar{\varepsilon} = C_1} \tag{18}$$

Where is the maximum tensile stress and is the yield stress

2. Brozzo et al fracture criterion

Brozzo et al have made a modification to the *Cockcroft and Latham* criterion (Eq. (18)). This criterion depends on the maximum tensile stress and hydrostatic (mean) stress :

$$\boxed{\int_0^{\bar{\varepsilon}_f} \frac{2\sigma_1}{3(\sigma_1 - \sigma_m)} d\bar{\varepsilon} = C_2} \tag{19}$$

3. Freudenthal fracture criterion

It is assuming that the total plastic work to fracture is constant:

$$\boxed{\frac{1}{\sigma_y}\int_0^{\bar{\varepsilon}_f} \bar{\sigma} d\bar{\varepsilon} = C_3} \tag{20}$$

Where is the effective stress, is the effective strain at fracture and is the yield stress.

4. Im and Argan fracture criterion

This criterion assumes that the integration of the amount of hydrostatic stress and effective stress is constant:

$$\boxed{\frac{1}{\sigma_y}\int_0^{\overline{\varepsilon_f}} (\sigma_m + \bar{\sigma}) d\bar{\varepsilon} = C_4} \tag{21}$$

5. Oyane el al. fracture criterion

This criterion assumes that the fracture occurs at a critical volumetric strain:

$$\boxed{\int_0^{\bar{\varepsilon}_f}\left(1+\frac{\sigma_m}{A\bar{\sigma}}\right)d\bar{\varepsilon} = C_5} \qquad (22)$$

Where $A = 2/3$ (i.e. between unixial and triaxil stress states).

6. Oh and Kobayashi fracture criterion

It assumes that the ratio of the maximum tensile stress and effective strain is equal to constant

$$\boxed{\int_0^{\bar{\varepsilon}_f}\frac{\sigma_1}{\bar{\sigma}}d\bar{\varepsilon} = C_6} \qquad (23)$$

7. Shabaic and Vujovic fracture criterion.

This criterion considers the ratio of mean stress and effective stress and it gives the following fracture model:

$$\boxed{\left(\frac{3\sigma_m}{\bar{\sigma}}\right) = C_7} \qquad (24)$$

8. Tresca energy fracture criterion

This is a simple criterion. Considering the difference between tensile and compression stresses, and it is as follows:

$$\boxed{\frac{1}{\sigma_y}\int_0^{\bar{\varepsilon}_f}\left(\frac{\sigma_1-\sigma_2}{2}\right)d\bar{\varepsilon} = C_8} \qquad (25)$$

Where is the maximum tensile stress, is the maximum compression stress and is the yield stress. , , , , , , and are constants.

Fig. 9 illustrate the constant values of fracture criteria for all types of nanostructured Al-6082 alloy.

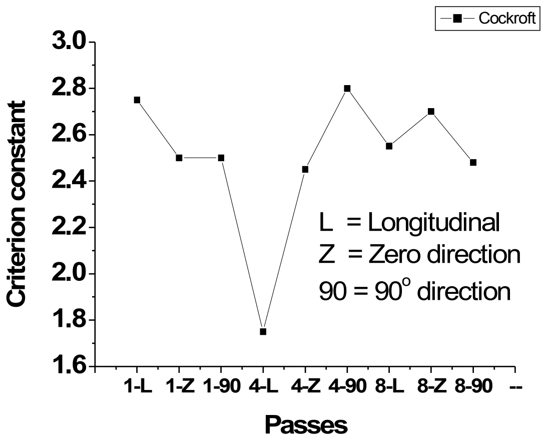


Fig. 9-a. Constant value of Cockcroft and Latham fracture criterion

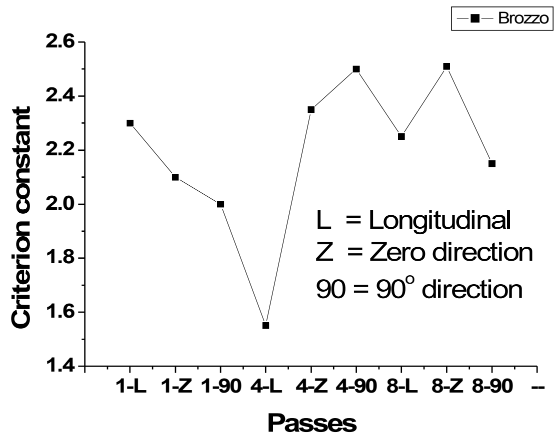


Fig. 9-b. Constant value of Brozzo fracture criterion

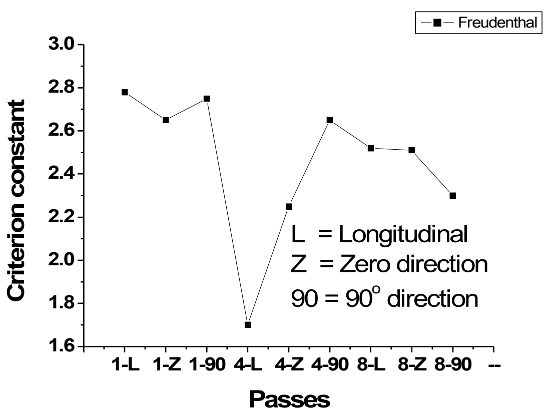


Fig. 9-c. Constant value of Freudenthal fracture criterion

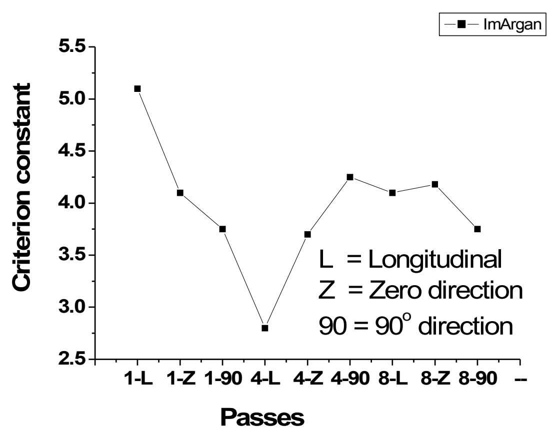


Fig. 9-d. Constant value of Im &Argane fracture criterion

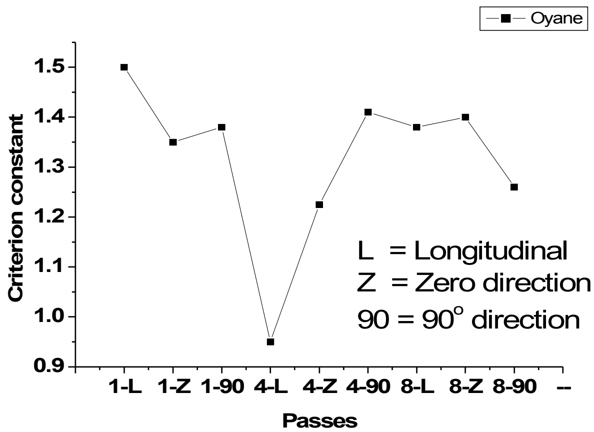


Fig. 9-e. Constant value of Oyane el al fracture criterion

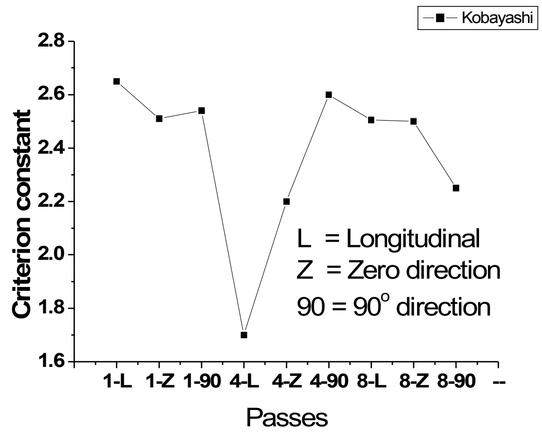


Fig. 9-f. Constant value of Oh and Kobayashi fracture criterion

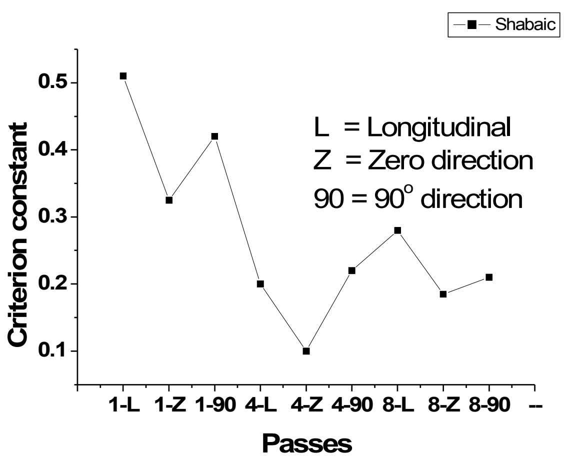


Fig. 9-g. Constant value of Shabaic and Vujovic fracture criterion

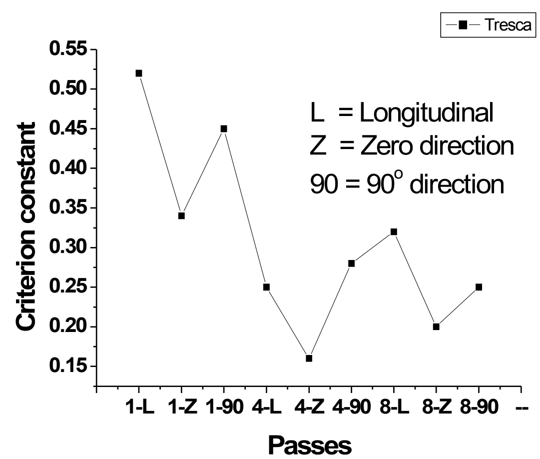


Fig. 9-h. Constant value of Tresca energy fracture criterion

From the results of experimental tests we concluded that the minimum value of ductile fracture criteria occurred at pass four in longitudinal direction of specimen's axes and the maximum value of ductile fracture appeared at pass one in longitudinal direction. The reason for that is may be the fact that the value of effective strain at fracture in pass four is the lowest.

3.4. Tube extrusion of nanostructured Al-6082 materials

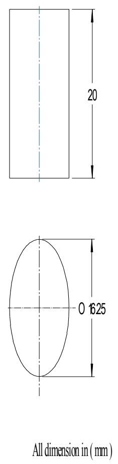
Extrusion is the process in which the cross-sectional area of a billet is reduced by forcing it through a die with a certain shape. In tube extrusion, the die set consists of four parts: (a) punch, (b) container, (c) piercing, and (d) the base. In this work, forward extrusion processes were applied to produce a tube from nanostructured Al-6082 material. The extruded materials were four types of nanostructured Al-6082 alloy: Pass 1, Pass 4 (route C) and Pass 8 (route C), which were produced by equal channel angular pressing (ECAP), in addition to the annealed material. The tests were simulated by using the finite element method and its results were compared with the experimental results. The finite element results were found to be nearly identical to the experimental results, with the Pass 8 alloy having the maximum extrusion load value.

3.4.1. Forward extrusion of tube.

In the forward extrusion of tube process, the authors use a die set which consists of four parts: (1) container,(2) mandrel (piercing), (3) base, and (4) punch. These parts are manufactured from tool steel (K9) in previous Hungarian classification, the chemical composition of which is given in table 1. The die set was then subjected to the heat treatment to increase their hardness. The outer diameter of the final tube was [D = 16.26 mm], and the inner diameter of the tube was [d = 12 mm]. The geometry workpiece and the dies are illustrated in Fig. 10. The processes were carried out at room temperature with the speed of the ram of 8 mm/min for all types of materials. A special type of lubrication was used to reduce the friction between the billet and the die the final extruded of workpiece is shown on Fig. 11.

3.4.2. Finite-element simulation

In this work, the finite element method was used to simulate the forward extrusion of tube processes for all types of nanostructured Al-6082 materials by using Q-*form* software. In this software, a hydraulic press was applied, with coefficient of friction of $\mu = 0.2$ between the die and the billet at room temperature. The software was provided with materials data that were obtained from the upsetting test. The force–displacement curves are plotted Fig. 12; and the comparison between experimental and finite element data are illustrated in Fig. 13.



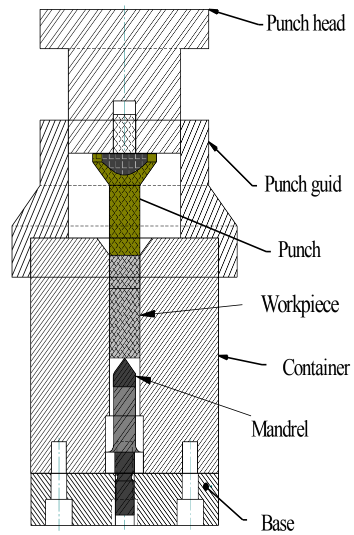


Figure 10-a. Dimension of specimen

Figure 10-b. Geometry of die set

Table 1. Chemical compositions of forward tube extrusion die material

Elem	C	Si	Mn	Cr	W	Mo	V	Ni	P	S
Min %	1.9	0.10	0.15	11.0	0.5	0.6	0.15	Max	Max	Max
Max %	2.2	0.40	0.40	13.0	0.80	0.90	0.30	0.35	0.03	0.03

Fig. 11. Final products of tube extrusion

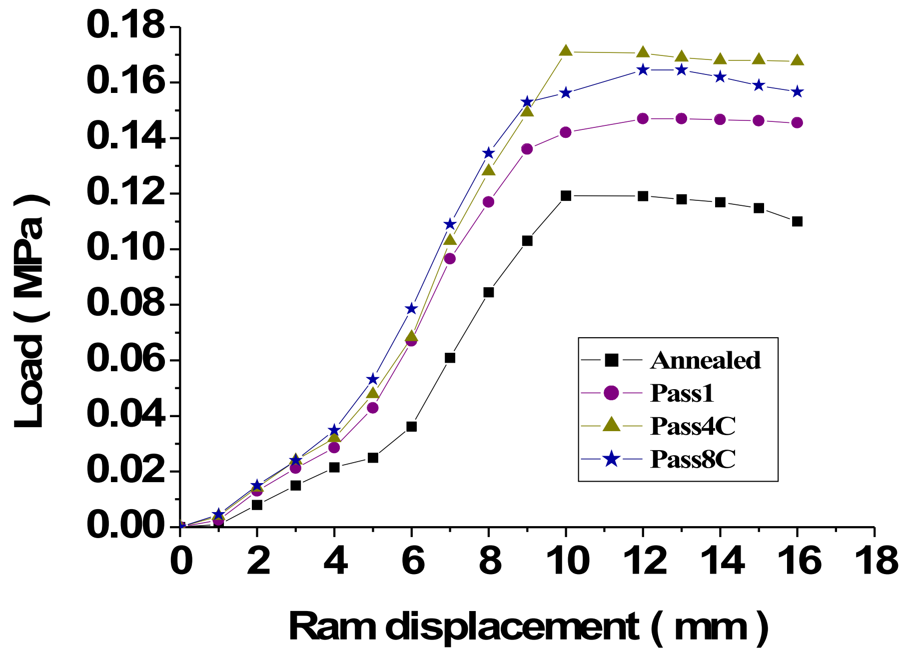


Fig. 12. Extrusion load - ram distance curves from experimental data

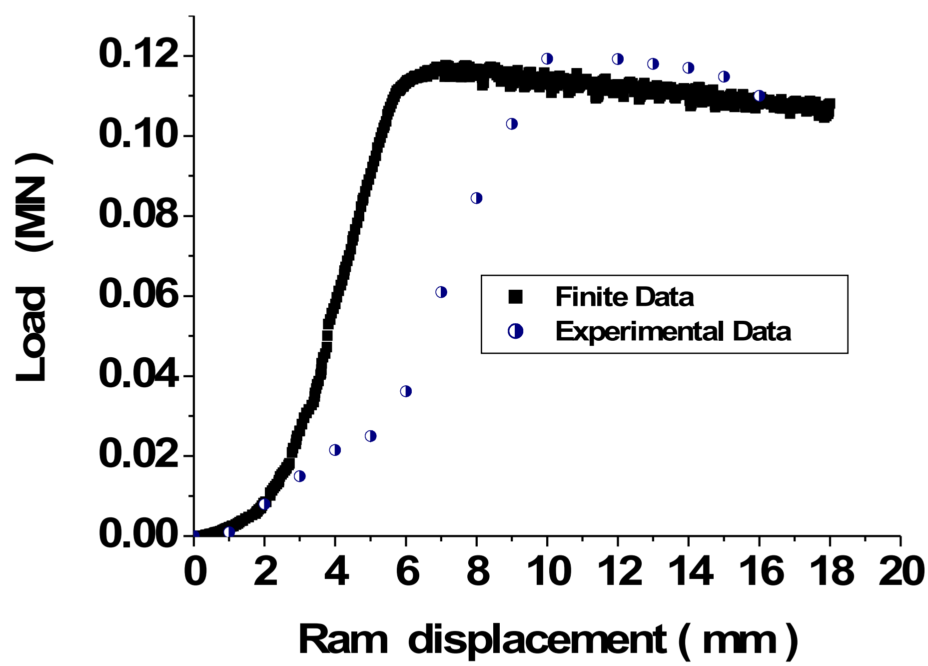


Fig. 13-a. Finite element and experimental data for annealed material

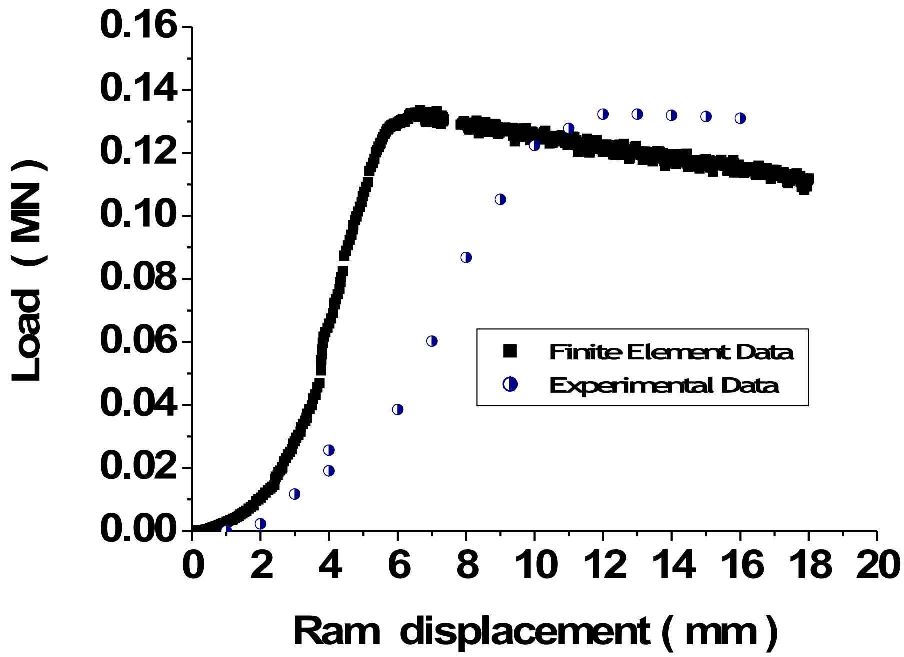


Fig. 13-b. Finite element and experimental data for pass 1 material

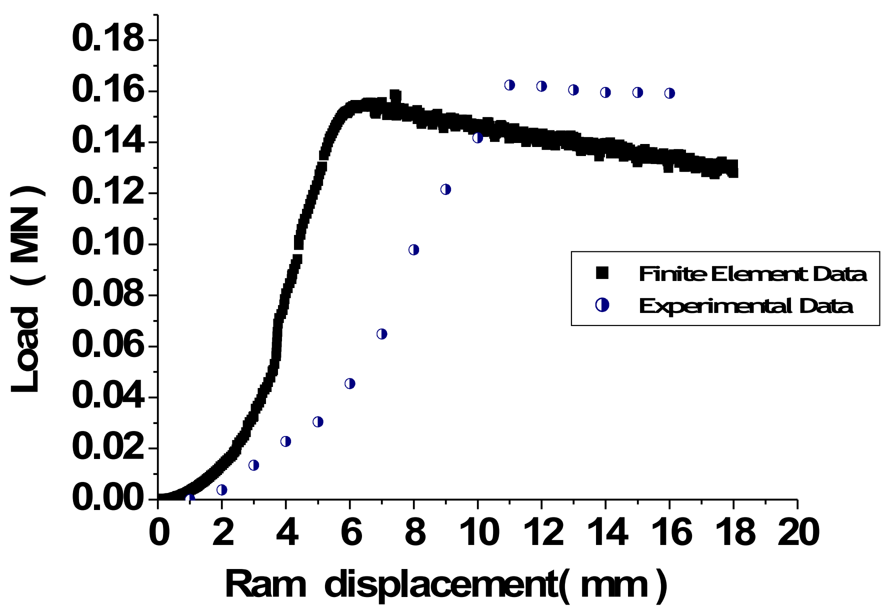


Fig. 13-c. Finite element and experimental data for pass 4C material

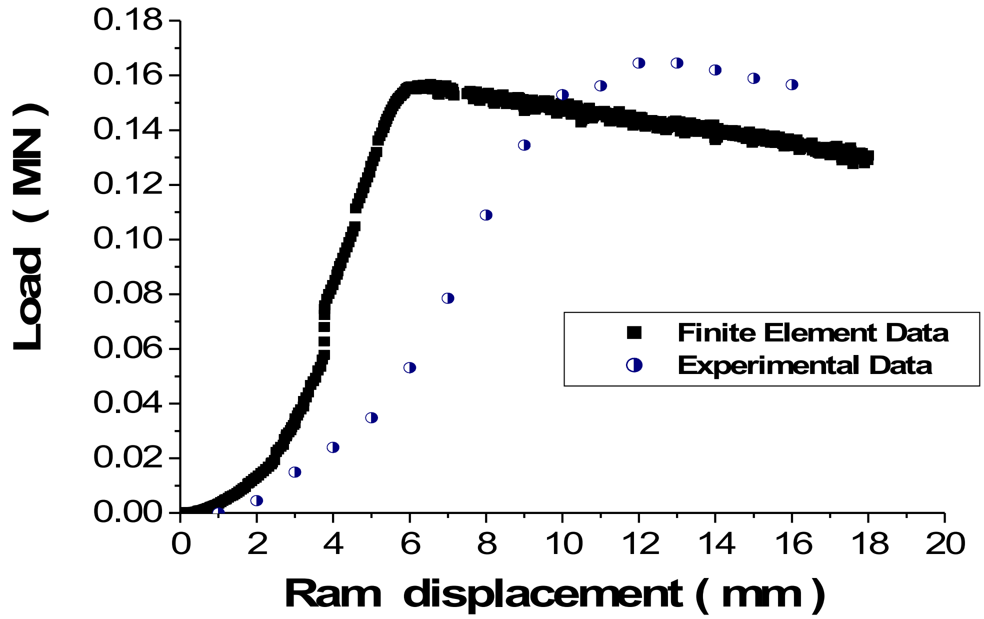


Fig. 13-d. Finite element and experimental data for pass 8C material

At the end of the experiment tests, the authors measured the surface roughness of the inner and outer surface of each specimen. The annealed material exhibited the highest amount of surface roughness, while the least amount of surface roughness was in pass 8C material, as shown in Table 2.

Table 2. Surface roughness of inner and outer surfaces of final products

Type of material	Ra (**μ m) of inner surface**	Ra (**μ m) of outer surface**
Annealed material	0.68	1.15
Pass 1 material	0.57	1.09
Pass 4C material	0.48	0.95
Pass 8C material	0.34	0.68

From the results the authors concluded that, the formability of Al 6082 alloy changed when the material was subjected to the ECAP process. The maximum value of the extrusion loads were obtained using Pass 4 (route C). The results also showed that the experimental results and the finite element results exhibited the same behavior and were nearly identical, although initially, the experimental results shifted to the right side.

Thus, the extrusion process produces tubes of high quality, where, the quality of surface roughness improves with the increasing the number of passes.

3.5. Future Work

Because, most of the nanostructured materials have anisotropic behavior, and they are a new field of investigation, and from the results of this work, we suggest continuing the investigation on the following topics:

1. Producing a nanostructured material from other metals and alloys such as: cupper, other type of aluminum alloys, steel and others by using ECAP and other technique.
2. Investigate the properties of these nanostructured materials and create comparison between them.
3. Creating other processes on the nanostructured Al-6082 alloy such as: forging, rolling, welding, and others and investigate the properties of the final products.
4. Investigate the effect of heat treatment on the properties of nanostructured Al-6082 alloy.

4. Theses

1. The true stress and equivalent stress curves of nanostructured Al-6082 alloy produced by ECAP were determined in this work. From these curves it was concluded that:
   - The true stress of nanostructured Al-6082 alloy depends on the number of passes of the ECAP and the direction of the axis.
   - The true stresses of zero direction of the three ivestigated passes (pass1, pass 4, and pass 8) are higher than those of the other directions, on the other hand, the value of the yield stress of pass 8 is shown to be higher than those of the other passes.
2. It was noted that the properties of Al-6082 alloy changed from isotropy to anisotropy when the material was subjected to ECAP process, and the strain path (the relationship between compressive strain and tensile strain) in all cases of passes is approximately a straight line. The anisotropic constants of **Hill** yield criterion were determined using the slop of strain path.
3. The ductile fracture in cold forming using eight types of fracture criteria were investigated in this work. From the results the followings are noted:

- The curves of the fracture criteria constant obtained from the eight criteria (except Shabaic and Vujovic fracture criterion and Tresca criterion) have the same behaviour.
- The minimum value of ductile fracture criteria constant occurred at pass 4 in longitudinal direction and the maximum value of ductile fracture constant appeared at pass 1 in longitudinal direction.

4. From the experimental result of forward tube extrusion, it was concluded that:
   - The best nanostructured material for producing tube is the pass one material if the extrusion load is the important factor to be taken into account, because this material needs the minimum value of extrusion load.
   - The best surface roughness was on pass 8 material.

4. Publications

1- Gyorgy. K, Arpad. F, and Ahmed.A, Anisotropic mechanical properties of an ultra-fine grained aluminum alloy, Ultrafine Grained Materials 4, TMS, USA, 2006.

2- Gyorgy Krallics, Ahmed. Agena, "Investigation of Workability of Al-6082 Nanostructured Materials", The 12^{th} International Arab Conference, P. 282-287, 2006.

3- Gyorgy. Krallics, Ahmed. Agena, "Investigation of Ductile Fracture of Nanostructured Al-6082 Material". Periodica Polytechnica Ser, Mech. Eng, Vol. 50 -2, P. 89-97, 2006.

4- Gyorgy Krallics, Ahmed. Agena, "Investigation of Workability of Al-6082 Nanostructured Materials", Emirates Journal for Engineering Research, V. 12 (3), P. 9-13, 2007.

5- A. Agena, G. Krallics, "Mechanical Behavior of Nanostructured AL-6082 Alloy Produced by Equal Channel Angular Process (ECAP)", under published on industrial research journal, industrial research center, Tripoli Libya.

6- Gyorgy Krallics, Ahmed. Agena, "Tube Extrusion of Nanostructured Al-6082 Materials", 6th Hungarian Materials Science Conference-OAK, 14-16 October 2007.

7- Ahmed S.M. Agena, "A study of flow characteristics of nanostructured Al-6082 alloy produced by ECAP under upsetting test", under publishing in journal of materials processing technology, 2008.

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