Investigation the Effect of Die Angle and Punch Speed in ECAP Process on Improvement the Mechanical Properties of AA7075

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ABSTRACT

In this study, the possibility of improving the mechanical properties of aluminum alloy 7075 through the ECAP process was investigated. Three angles are 90º , 105º and 120º for ECAP die are adopted for samples of the alloy with a square cross-sectional area of 10x10mm and the two forming speeds are 5mm/min and 10mm/min. A die was made of tool steel and punches made of high speed steel were used. Through the implementation of the experiments, the sample failed with the angle 90º. The results of the process showed that the maximum load increases with the decrease in the angle and that the effect of speed in the first pass (rout A) was clear with the angle 120º and it did not appear to have a clear effect with the angle 105º. While in the second pass (rout B) for the same samples the maximum load increased for all samples and the effect of speed appeared with the two angles. For the purpose of evaluating the improvement in mechanical properties, a compression test was performed on the successful samples, as well as a micro-hardness test and microscopy test. The results showed that the hardness of the alloy was improved through the ECAP process for all angles and speeds used, and the yield stress of the alloy was also significantly improved compared to the base metal due to refining and rearranging of the metal grains. Rout B was carried out for four samples for angles 105º and 120º at two speeds for each angle. The results of the micro-hardness and yield stress test showed more improvement due to the increase of grain refining in the second pass

Keywords: ECAP process , AA7075 , Forming , Improvement of mechanical properties

1. Introduction

- Aluminum alloys are among the most significant industrial alloys, Heat treatments and all owing additives help aluminum to reach its ideal characteristics. ECAP has the benefit of keeping the billet's dimensions despite subjecting it to a lot of shear strain, One of the most significant advantages of the ECAP procedure is the ability to repeat it several times without changing the dimensions while raising the applied strain to the needed level [1]. Achieving the desired strength and ductility at room temperature is thought to be possible through grain refining. Recently many researchers studied this process in order to understand the effect of its parameters in improvement mechanical properties of material. **Evren Tan et al (2011)** [2] investigated the effects of various numbers of DCAP passes on the microstructure and mechanical properties of 6061 Al-alloy strips. Significant improvements in the strength and hardness of severely deformed strips have been observed. **Arkanti Krishnaiah et al (2014)** [3] investigated the microstructure and mechanical characteristics of pure aluminum specimens. The results revealed that after the first pass, the hardness increased considerably. **Seyed M. Ashrafizadeh et al (2017)** [4] studied the effect of ECAP for two and four passes, cold-worked AA6063 aluminum alloy. After the two-stage solution treatment, the alloy's hardness, yield strength, and tensile strength were significantly increased, while elongation to failure remained nearly unchanged. **Arezoo Esmaeili et al (2018)** [5]. Studied the ECAP procedure through repeated four times at room temperature. ECAP specimens were subjected to a rotating bending fatigue test. Due to the bimodal microstructure of fine and coarse grains, the fatigue fracture surface of a single pass sample was found to be granular and planer. **Arun, Chakkingal. (2019)** [6] studied three passes of ECAP with a die angle of 120° were performed on specimens utilizing processing route BC (90°) and C (180°). It was discovered that after ECAP, the activation energy for hot deformation fell from 161kJ/mol. to 132kJ/mol. **J. Kandasamy et al (2019)** [7] studied the flow of aluminum alloy A357 through multiple ECAP dies using Finite Element (FE) methods. They found that the rise in strain generated by the channel angle of the die and the decline in viscosity of the substance under inquiry causes sudden peaks in strain rate. **Manping Liu et al (2020)** [8] investigated the microstructure, mechanical properties and wear resistance of ultrafine-grained Al-Mg-Si alloy fabricated using a combination of ECAP and dynamic aging. The results showed that the ECAP alloy's grain size was significantly reduced. **Caruso, et al (2021)** [9] applied grain refining using extreme plastic deformation techniques as a method for controlling the mechanical properties and microstructure of pure aluminum conductor wires. A predictive numerical analysis showed the main importance of the die channel in controlling the hardening effect and microstructural changes of the material. **Kumar, Gudimetla et al. (2012)** [10] investigated a mechanical and microstructural properties of AA 7075 by equal channel angular pressing for four passes in four different routes. ultimate tensile strength, Tensile yield strength, and micro-hardness of the material increased by 73%, 168%, and 93%, respectively. **Mohan Reddy, et al (2013)** [11] employed the ECAE procedure to examine the impact of the process on tensile properties of AA 7075. Hardness and tensile strength both rise as the number of passes rises. **Go Horikiri et al (2017)** [12] concentrated on two approaches to improve the formability of high strength aluminum alloys AA7075; semi-sol casting and Equal-Channel Angular Pressing processing. In comparison to wrought AA7075-T6, four passes pressed modified AA7075 has lower tensile strength, higher total elongation, and higher toughness.

In the current study the effect of die angle, punch speed and second pass (rout B) in ECAP on improvement the mechanical properties of AA7075 were investigated.

2. Experimental work

2.1 Material used

The material AA7075 alloy, which has superior mechanical qualities and a wide variety of uses, was used in this study. The chemical composition of this alloy is displayed in Table 1. The University of Technology performed the chemical analysis.

Table 1; Chemical analyses of ASTM AA7075 alloy

Elements	Si %	Fe %	Cu %	Mn %	Mg %	Cr %	Ni %	Zn %	Ti %	V %	Pb %	Al %
Nominal	**0.40**	**0.50**	**1.3-2.0**	**0.30**	**2.1-2.9**	**0.2**	**-------**	**5.8-6.5**	**0.02**	**--------**	**--------**	**89**
Actual	**0.0694**	**0.1**	**1.90**	**0.0174**	**2.0**	**0.215**	**0.0098**	**4.95**	**0.0304**	**0.0103**	**0.0219**	**90.6758**

2.2 Equal channel angular extrusion die manufacturing:

design of the die used in ECAP is its most fundamental component. The assembly and support are highly difficult processes since it is components die. The active die blocks and punch are the active pieces for die design (Appendix A), and they have been put through modern analysis using the design package software SolidWorks to ensure that they will withstand the high pressure required for ECAP operation. The ECAP dies are depicted in Fig. 1 at several angles.

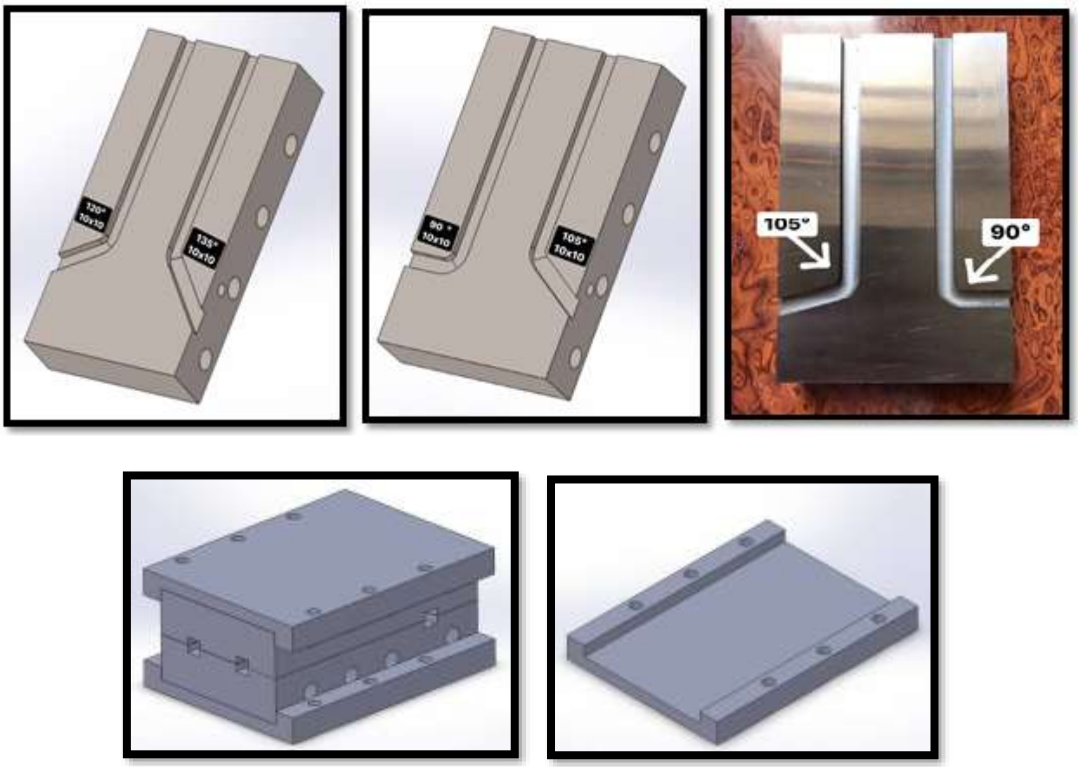


Fig.1; The halves of ECAP die at different angles.

The optimal design depends on a wide range of factors, such as the press's maximum load and capacity, process temperature, sample size, shape, and intended shape, run length, tool stacking restrictions, knowledge of the properties and characteristics of the metal to be extruded, and press operating procedure.

2.3 Die and Punch Materials.

The ECAE die was made of AISI D2 tool steel since it needed to have good compressive strength, fatigue strength, wear resistance, and dimensional stability after heat treatment. Long runs are best performed using AISI D2. The punch had a cross-sectional area measuring 10x10 mm. Because it has an excellent balance of wear resistance, compressive strength, and fatigue strength, AISI M2 high-speed tool steel was employed in this experiment to make punches.

Table 2: Chemical composition of tool steel

Elements	%C	%Si	%Mn	%P	%S	%Cr	%Mo	%Ni	%Al	%Co	%Cu	%V	%Fe
Nominal	1.41	0.30	0.45	0.028	0.03	11-13	0.9	- - -	- - -	- - -	- - -	1.0	Rem
Actual	1.61	0.295	0.418	0.028	0.008	13.05	0.79	0.18	0.01	0.02	0.06	0.79	Rem

2.4 Die Manufacturing Procedures

The die is made of two equal halves that are joined together to make one whole. Both of these sides have grooves with different angles. The active die block was created using a CNC grinding machine, and then it was milled using a CNC milling machine to achieve the final correct specifications of the internal radius of curves. The other two-active die parts, including the fixture and base, were finished machined using standard machining techniques.

2.5 Procedure of Equal Channel Angular Extrusion Process:

2.5.1 Billet Preparation

The billets are made of the alloy AA7075 (60x60x120mm) and machined using wire discharge machine to produce specimen of square cross-section 10 mm x 10 mm and 100 mm in length, as shown in Fig.2. Heat treatments were carried out on the samples in a special oven to a temperature of 450 (723 K) for two hours, then the oven was turned off and the sample was left to cool inside the furnce. The billet was polished using a grinding machine before being pressed inside of an ECAE die and lubricated with grease multi-purpose white-NLGI3 and graphite powder. If additional passes are required, the sample must be reshaped and republished; this is done by realigning the dimensions on a grinding machine.

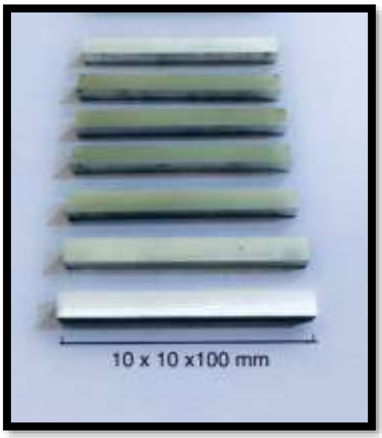


Fig.2: The billets produced

2.5.2 Die Polishing / Cleaning

The die was cleaned with ethyl alcohol and allowed to dry in the air after being polished, paying particular attention to the channels that had been cleaned, using a rotary tool and 3 mm diamond suspension polish.

2.5.3 Billet Heating and control of temperature

The temperature evolution of the extrusion dies was observed using calibrated Chromel-Alumel thermocouples (K-type) connected to a portable thermometer. It is prepositioned in the die at a distance of under 4 mm from the surface of the billet. To ensure a consistent temperature distribution along the channel path, the heating system used four 650-watt industrial pin heaters. The die assembly is depicted in Fig.3.

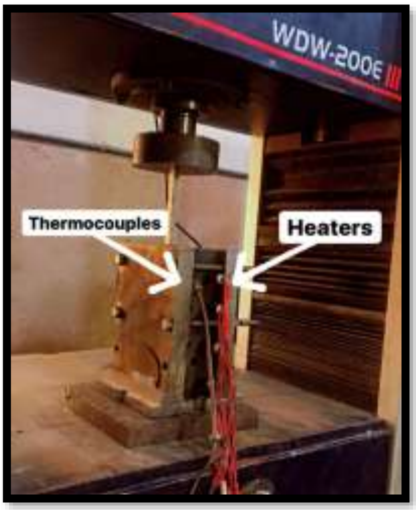


Fig.3: ECAP die with heating system

2.5.4 Test of Equal Channel Angular Extrusion (ECAE):

Steps of work firstly, insert the lubricated billet inside the die by (grease multi-purpose white-NLGI3 and graphite powder) lubricants and also inside the Channel of die to reduce as much as possible generated friction during pressing. Secondly, heating the dies and billet to the temperature of about 110°C on the external electrical heater for 15 minutes in order to enable the temperature in the sample to become fully homogeneous. After the system was heated to the required temperature, the load is applied. The plunger began to press the sample into the intersection of two channels of die with ram velocity equal to 5mm/min and 10mm/min.

The applied load was varied as necessary by the hydraulic press to maintain the constant feed rate. Samples at 10x10 cross-section area were applied at angles (90°,105°, and 120°) at different speeds (5mm/min and 10mm/min), , after that, the billet was rotated in the same direction at 90° by using route Bc for four samples, Finally, specimens were water-quenched immediately after each cycle of pressing to prevent any possibility of recovery at such elevated processing temperature. Fig.4. The angle of 90° failed in the test, did not pass through the curved channel.

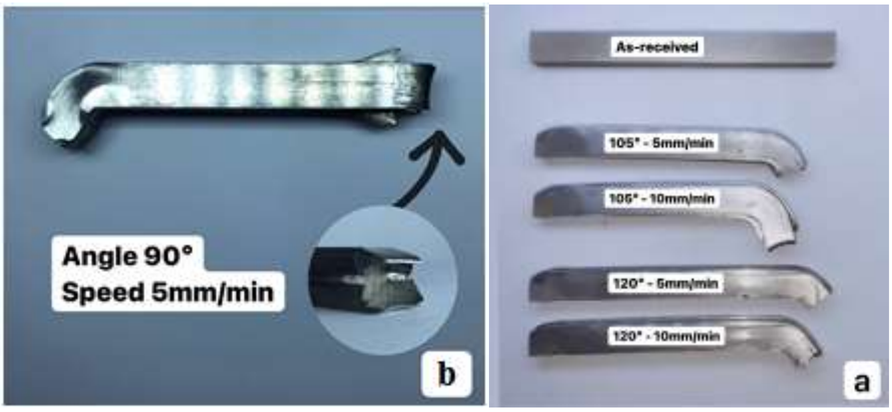


Fig 4: a) Angles with dim.(10x10mm), b)The failed angle 90°

2.5.5 Microstructure Examination

The examination of microstructure was carried out by (Optical microscope) connected to a camera with (20pexil). The preparation of specimens for this test has the following steps:

1- Wet grinding: The samples was accomplished by using emery paper in grits of ASTM 220,320, 400, 600, 800, 1000, 1200, and 2400.

2- Polishing: The samples were polished after drying, using a special type of cloth for light metals lubricated by a suspension of alumina of a granular size of 0.5 µm then the process was followed by washing and drying the samples, changing the cloth and using another type of granular size alumina 0.3 µm, then wash the samples well with water and alcohol and dry them with air dryer.

3- Etching: Keller's reagent was used for the etching step in the recipe of 1.0 mL HF, 1.5 mL HCl, 2.5 mL HNO_3, and 95.0 mL H_2O. The etching time was 15 seconds. (ASTM E23)

2.5.6 Compression Test

Compression tests have been done according to ASTM – E9 -89a where the specimens were cut from the AA7075 before and after extrusion. The specimens had L/D = 1.5 these specimens were cut and polished using emery paper of 2400 grade.10x10.

2.5.7 Hardness Test

A Micro-hardness test was used to assess the mechanical properties of the ECAE samples and to quantify any recrystallization, or any changes in microstructural or mechanical that happened. Hardness measurement was made from the surface to the center of the sample. In this work, the Vickers hardness test is used with a con of 32µm in diameter and the total load was an amount of 0.5 kgf to measure the hardness of alloy with the specification standard of alloy. Hardness test applied at The University of Technology.

3. Results and Discussio

3.1 The effect of angle of ECAP process and velocity of punch on forming load:

The results of load-displacement relationship for AA 7075 through ECAP process are illustrated in Fig. 5 below. It can be noticed that the max. load in this process increases when angle of ECAB decreased. Also the max. load increases in rout B of process compared to the rout A for two angles 105^o and 120^o at velocities of punch 5mm/min and 10mm/min as shown in Table 3. The reason for the greater load increase when the angle decreases is duo to the obstruction that the metal encounters during its flow when the angle is reduced and the metal shear occurs in a narrow space. After the completion of the tout A, the metal has become more hard duo to the formation and the occurrence of dislocations and deformation of the crystal structure. When the rout B is carried out, it requires a higher load. Therefore, an increase in the maximum load values can be observed at this process, for the angles 105^o, and120^o, and for the two punch speeds as well. From the above table, it can be seen that the effect of the punch speed in the rout A stage on the value of the maximum load was little with angle 105^o and the effect of the speed became clear with the angle 120^o, while at the rout B stage the effect of speed was clear for two the angles. The load at the 105^o angle increased with increasing speed, while the load at the 120^o angle decreased with the increase in speed. The reason is due to the correlation of the deformation state of the metal with the speed and its effect on the change of the angle at the same time.

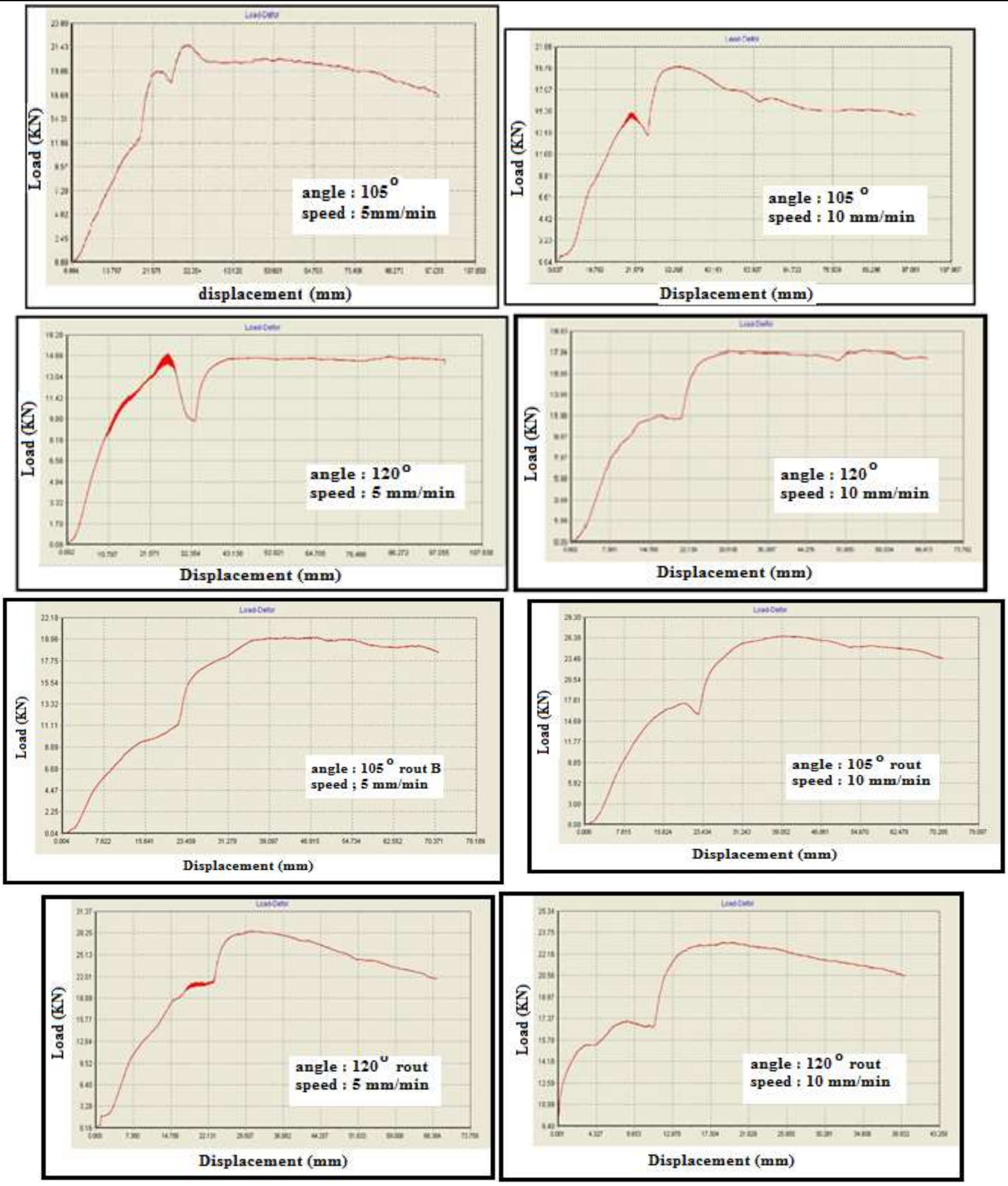


Fig.5 : Load – displacement of ECAP process for different cases

Table 3: Max. load in ECAP process

Angle of ECAP (degree)	Speed of punch (mm/min)	Max. load (KN)
105	5	21.4
105	10	20
120	5	14.7
120	10	18
105 (rout B)	5	20.2
105 (rout B)	10	26.6
120 (rout B)	5	28.5
120 (rout B)	10	23

3.2 The effect of ECAP on improving the hardness of the alloy.

In general, the angular pressing forming process improves the hardness property of AA7075 at different values of forming angles, as well as the forming speed in addition to the effect of the size of the cross-section area. as shown in Fig.6.

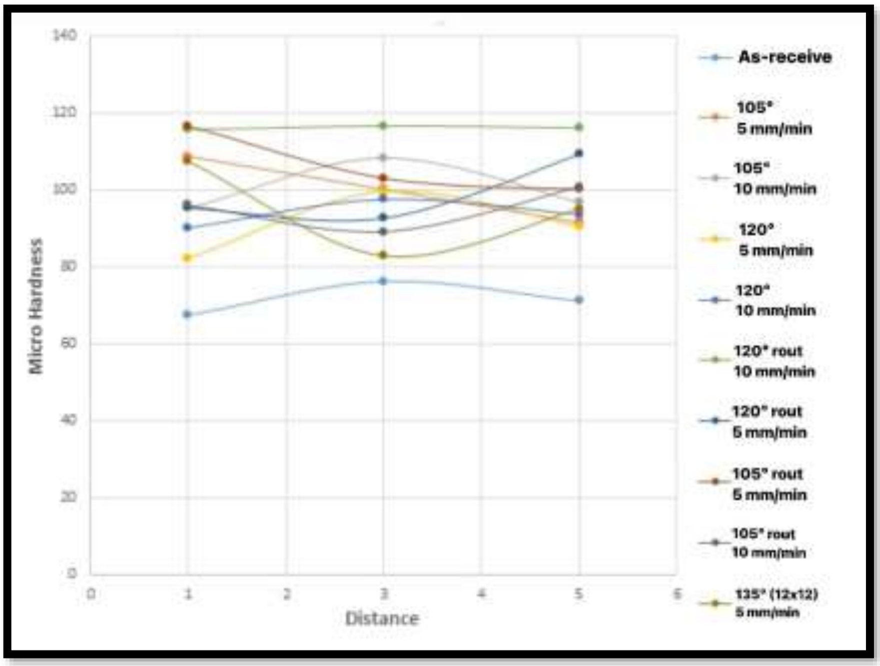


Fig.6: Micro-hardness results for different samples

3.2.1 The first pass of the alloy (rout A)

Fig.7 shows that the micro-hardness was improved through the first formation (rout A) of the sample and for the angles of 105° and 120°. The hardness improved by 26.75 % and 30.6 %when the angle was 120° and the forming speed was 5 mm / min and 10 mm / min respectively, and this percentage increased when the forming angle decreased to 105°, where the hardness improved by better a percentage than the angle 120 ° and at two speeds of 5 mm/min and 10 mm / min by 39.8 % and 39.77 % respectively. The reason for this is due to the increase in the shear that can happen to the metal, which leads to the refining of the grains through the atomic slip planes that rearrange the crystals. It appears from the results that the forming speed. has a clear effect in improving the hardness property. The effect of speed appeared with the angle 120 °, where the forming speed had no clear effect with the angle 105° at the rout A of the sample, where the same hardness values for the speeds appeared at this angle, while the improvement of the hardness at the velocity 10 mm / min increased by 3.04 % more than the velocity 5 mm / min. This is due to the occurrence of more dislocations with an increase in the speed at the angle of 120° leading to an increase in the hardness.

3.2.3 The effect of rotating the sample (rout B) on hardness:

The hardness results of the samples that were re-forming by rotating them 90° showed an increase in the hardness value than that in the first formation, except for the case of rotation at an angle of 105 ° and a speed of 5 mm/min, where the hardness value was close to its value in the first formation with a few decrease.

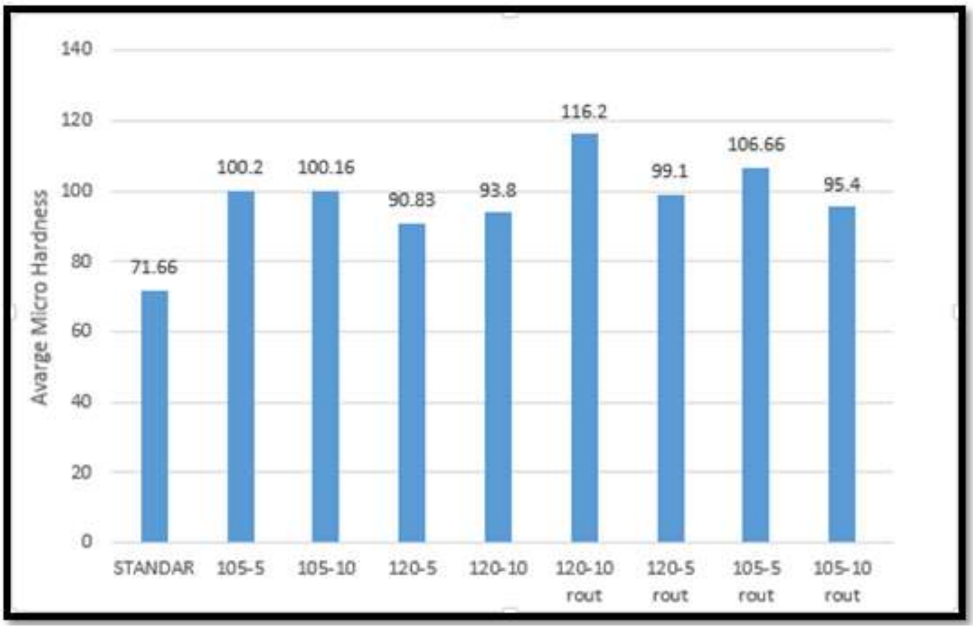


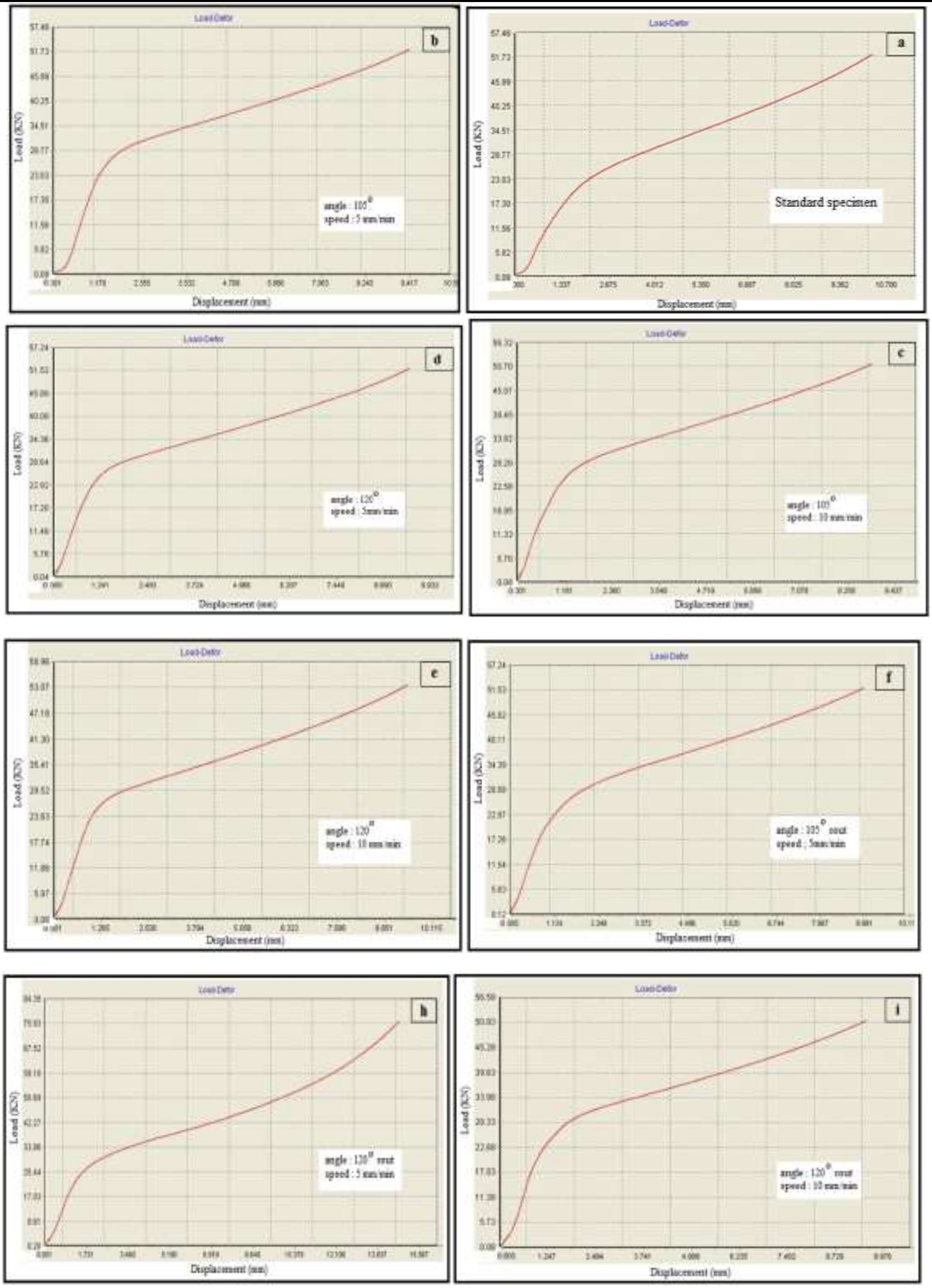
Fig. 7 : Average value of micro-hardness

The hardness improved significantly when rotating at the angle of 120° at a speed of 10 mm/min, where the percentage increase of 24.14 % was greater than the value of the increase in the first formation (rout A), while the increase for the same speed was 6.42 % with an angle of 105° which indicates the effect of the angle in improving the hardness when rotating. An increase in the angle allows the grains to be rearranged through dislocations that occur during forming, which in turn increases grain fineness and thus increases hardness. As for the effect of forming speed when rotating the specimen, it appeared angle of 120 °, where the percentage of increase in hardness improvement was 24-14 % at 10 mm/min and 5.03 % at 5 mm/min. This means that with an increase in the angle, an increase in the speed when rotating has an effect on the increase in the rate of strain, which leads to an increase in the dislocation density, and the hardness increases as a result.

3.3 The effect of the ECAP process on improving compression strength of AA7075

The results of the compression test of samples of aluminum alloy 7075 that were formed by the ECAP process at two different angles and speeds in addition to the rotation showed that the compression strength of the alloy was clearly improved under the influences of the ECAP forming process. Fig. 8 and Table 4 show that the yield stress of the alloy improved significantly for the samples formed by this process compared to the base sample except for one sample formed at an angle of 105° and a speed of 5 mm/min and was formed by route B.

The percentage of improvement in the yield stress of the alloy ranged between (2.5 % - 26.2 %), and the best percentage was when the sample formed at an angle of 105°, a speed of 10 mm/min, and route B. The improvement in the value of the yield stress is due to the refining that occurs in the alloy grains as a result of forming and the increase in the hardness of the alloy as a result. As for the best improvement rate at route B and forming speed of 10 mm/min, it is hardening due to the intensity of dislocations at this speed and rearranging the microstructure of the alloy to become more homogeneous as a result of its reformation.


b
angle : 105°
speed : 5 mm/min
Load (KN)
Displacement (mm)
a
Standard specimen
d
angle : 120°
speed : 5mm/min
c
angle : 105°
speed : 10 mm/min
e
angle : 120°
speed : 10 mm/min
f
angle : 105° rout
speed ; 5mm/min
h
angle : 120° rout
speed : 5 mm/min
i
angle : 120° rout
speed : 10 mm/min

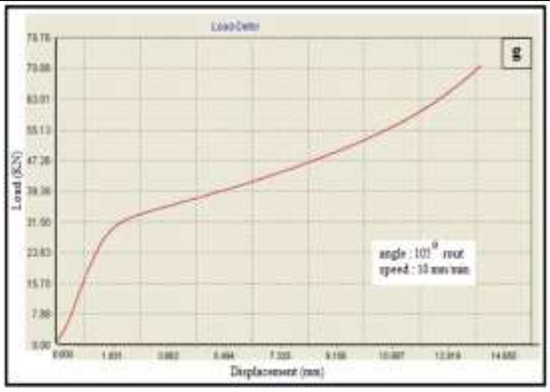


Fig.8 : Load – Displacement relationship of compression test for specimens according to the angle of die and speed of punch

Table (6.1): yield stress after forming

Angle of ECAP (degree)	Speed of punch (mm/min)	Yield stress (Mpa)
	As receive	244
105	5	268
105	10	265
120	5	269
120	10	274
105 rout	5	241
105 rout	10	308
120 rout	5	274
120 rout	10	250

3.4 Results of microstructure examination

The microstructure examination for nine samples showed that the grain size of base metal was coarse and became fine after ECAP process in general for different cases of angles and speeds as shown in Fig.9. Through the microscopy images, it did not show a clear effect of the speed difference on the microstructure of the metal at angle 105° at rout A as shown in Fig.(9,b,c), while with angle 120° the effect of speed 10mm/min is more than the speed 5mm/min in refining the grains as in Fig.(9,d,e). The microscopy images showed more fine refining of the grains when re-forming rout B, especially at the angle of 120° and a speed of 10mm/min. Thus a clear improvement appeared in the micro-hardness for this case, while there was no clear change in the microstructure of the sample with angle 105° at a speed of 5mm/min in the formation at rout B differed than the formation at rout A except that a small change led to a slight increase in the hardness, as shown in Fig.(9 f,g,h,i).

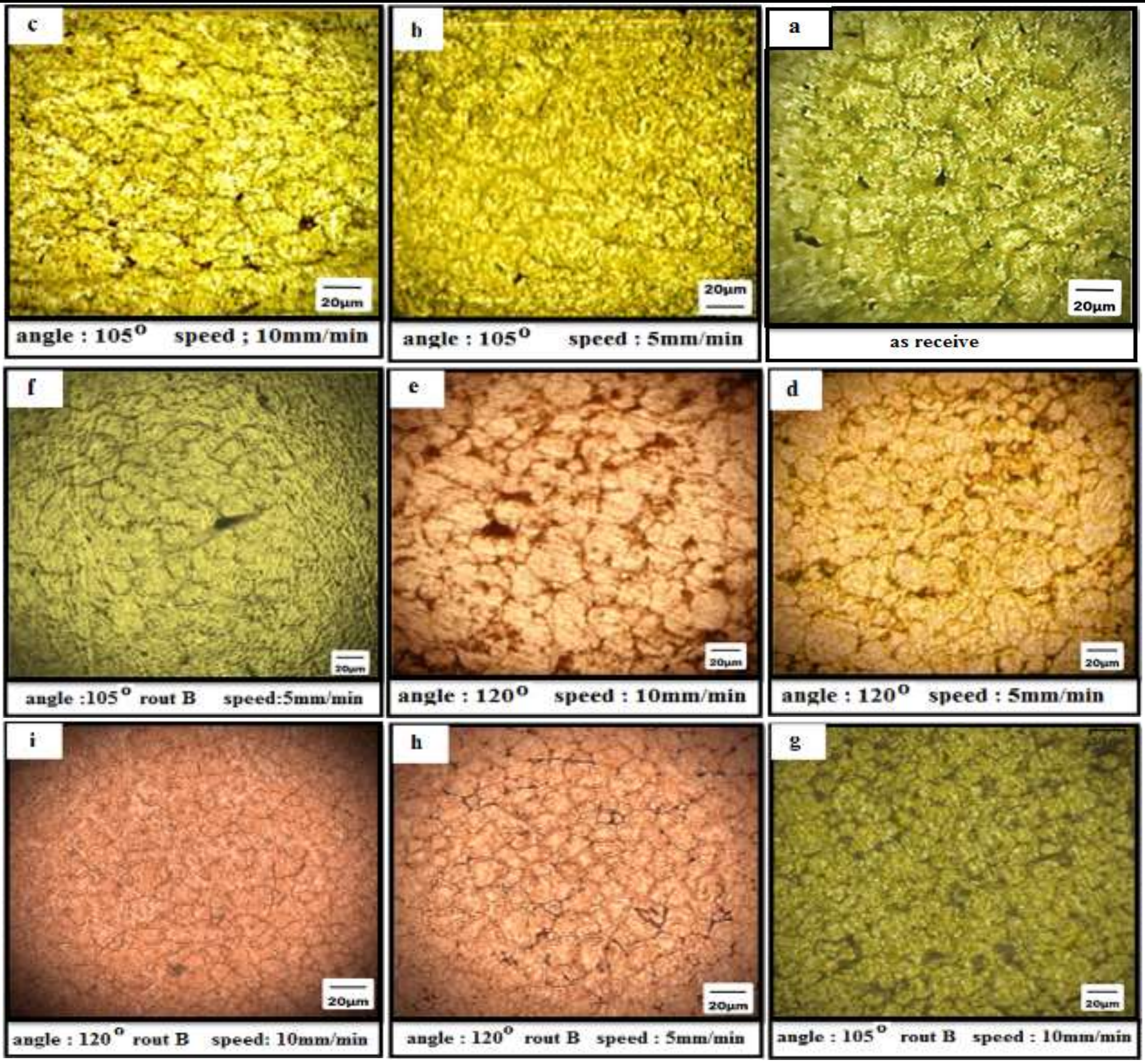


Fig. 9 : Microstructure of samples formed by ECAP process

4. Conclusions

1. ECAP process improved mechanical properties of AA7075 at different angles of die and two punch speeds.
2. When angle of ECAP process decreases, the maximum load of process increased
3. Minimum angle can be used in ECUP process to form AA 7075 is 105° for cross-section of sample 10x10mm.
4. The max. improvement in hardness for AA 7075was obtained at angle 120° and punch speed of 10mm/min by 62.15% when re-forming rout B.
5. The max. improvement in yield stress of AA 7075 was obtained at angle 105° and punch speed 10mm/min by 26.23% when re-forming rout B.
6. The effect of punch speed on improving the mechanical properties of the alloy is more at second pass rout B especially with the angle 105°.

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