

PAPER • OPEN ACCESS

## Study the Effect of Casting Method on the Mechanical Properties of ZA-27 Alloy Formed by Equal Channel Angular Extrusion

To cite this article: Reham Raad Ahmed *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **518** 032058

View the [article online](#) for updates and enhancements.

# Study the Effect of Casting Method on the Mechanical Properties of ZA-27 Alloy Formed by Equal Channel Angular Extrusion

Reham Raad Ahmed<sup>1</sup>, Ali Hassan Saleh<sup>2</sup> and Khudhaye J. Jadee<sup>1</sup>

<sup>1</sup>Technical Eng. College-Baghdad, Middle Tech. University-Iraq.

<sup>2</sup>Institute of Technology-Baghdad, Middle Tech. University-Iraq.

Email: rehamraad25@yahoo.com, alihassan56@yahoo.com

**Abstract.** In this study the effect of casting technique or method of ZA-27 alloy and die angle of equal channel angular extrusion (ECAE) process on the mechanical properties of alloy after forming was studied. Two casting methods, New Rheocast (NRC) and Gravity Die Cast (GDC) were employed to produce the alloy. Four dies of ECAE with different angles (90°, 105°, 120° and 135°) were used in this process at (100° C). Test specimen was manufactured with circular cross section (12mm in diameter and 85mm in length). The results show that the (NRC) method and 90° angle of die in (ECAE) gave the best of compression strength and hardness due to refinement of microstructure more than other angles. The load in (ECAE) process strongly depends on angle of die and specimen product by (NRC) required higher load.

## 1. Introduction

Equal Channel Angular Extrusion is one of the forming techniques used for producing ultra-fine grain structure through simple shear strain without changing the billet size or dimensions [1]. This process achieved by pressing the workpiece through a die containing two channels symmetrical in cross-section and meet at a predetermined angle. The grain refinement depending on several parameters like temperature, number of passes and the die's angle. Whenever angle of die is small the improvement of mechanical properties is higher. Zinc alloy die castings have physical and mechanical properties, resistance to atmospheric corrosion and the impact strength higher than that of other die casting alloys. The family of zinc-based alloys containing aluminum are known generically as ZA- 8, ZA -12 and ZA -27 have special combination of properties midway between those of aluminum and ductile iron. Zinc- aluminum alloys extend the capabilities of traditional zinc alloys which have been used successfully for decades in applications involving low to moderate stresses, and where the advantages of die casting could be applied. ZA alloys have low melting temperatures. Casting of ZA-27 alloy can be achieved by two casting; Gravity Die Casting (GDC) and Rheocasting (RC). The main difference between the two methods is the cooling rate of alloy through solidification. Many researchers interested in this field. [2] investigated the directional solidification of Pb-Sn alloys as a function of the cooling rate, growth rate, and temperature gradient and they observed secondary dendrite arm spacing and primary dendrite arm spacing decreased with a temperature gradient in the liquid while increasing the cooling rate and the growth rate. Dey et al. [3] used rheocast and conventional gravity die casting to cast A356 alloy. Fully dendritic microstructure achieved for conventional gravity die casting whereas



nearly spheroidal morphology for the rheocasting process. [4] produced ZA-alloy using GDC and RNC and found that the yield strength, tensile strength and elongation of the tested alloy improved by 11%, 18%, and 32% respectively with RNC compared with GDC. [5] used GDC and NRC to produce Mg- Sn based alloy and noticed that the primary  $\alpha$ -Mg phase was non-dendritic in rheocast microstructures while appeared in dendritic shape with GDC in addition the tensile strength considerably higher with NRC. [6] experimentally tested pure Al and Al-1%Mg during equal channel angular pressing (ECAP) deformation. They revealed that at lower pressing speed (available additional time) established more equilibrated microstructures and absorbed a higher dislocation in the grain boundaries. [7] processed Al-40Zn-2Cu alloy by Multipass equal channel angular extrusion. They found that ductility and strength of this alloy were improved after the ECAE process. Saray et al. [8] used eight passes of equal channel angular sheet extrusion (ECASE) to process interstitial free steel sheets and concluded that the yield and ultimate strength values doubled to about 2.6 and 1.9 times, respectively. [9] observed that the equal channel angular extrusion of Al 5083 alloy increases the wear and strength properties with homogeneous and refined microstructure. [10] carried out equal channel angular pressing on pure aluminum to investigate its effect on the hardness and strength and observed that these properties were improved significantly. Patricia et al. [11] optimized the ECAP process to get nanostructure of AA 6060 alloy using finite element method (FEM). They used six different configurations to design die's channel together with three coefficients of friction and suggested performing multiple ECAP passes to produce nanostructures and homogeneous deformation of the work piece. Mohammed A. J. [12] studied the effect of casting method and die profile in forward extrusion on mechanical properties of ZA-27 alloy using GDC and NRC as casting methods and found the best results with NRC. Nazari et al., [13] modeled the equal channel forward extrusion pressing force using finite element method and validated the model using experimental results. The work included different parameters such as coefficient of friction, length to width ratio and the height of the main deformation zone. In this study the effect of casting technique or method of ZA-27 alloy and die angle of ECAE process on compressive strength and hardness of alloy were investigated.

## 2. Experimental procedure

### 2.1 Chemical Composition of ZA-27 Alloy

In this work, ZA-27 alloy was used as material which has higher mechanical properties with wide range of application. The chemical composition of this alloy is shown in Table (1). The chemical analysis was carried out at the Ministry of Science and Technology.

**Table 1.** Chemical analyses of ASTM ZA-27.

Element	%	Al	Cu	Mg	Fe	Cd	Pb	Zn
<b>Material</b>								
<b>Nominal</b>		25-28	2-2.5	0.01-0.02	0.1	0.003	0.004	Rem.
<b>Actual</b>		27.74	2.12	0.017	0.045	0.0017	0.0023	Rem.

### 2.2 Production of ZA-27 alloy

Production of ZA-27 alloy includes melting of pure elements of zinc, aluminum, copper and magnesium together. Tables 2, 3 illustrate the chemical composition of pure zinc and pure aluminum respectively.

**Table 2.** Chemical composition of commercial pure zinc

Element%	Si	Fe	Cu	Mn	Al	Ni	Sn	Ti	Zn
<b>Material</b>									
<b>Nominal</b>	0.1	0.4	0.05	0.01	0.05	0.02	0.01	0.02	Rem.
<b>Actual</b>	0.007	0.36	0.04	0.006	0.02	0.004	0.009	0.003	Rem.

**Table 3.** Chemical composition of commercial pure aluminum

Element%	Si	Fe	Cu	Mn	Zn	Sn	Ti	Cr	Al
<b>Material</b>									
<b>Nominal</b>	0.1	0.4	0.05	0.0023	0.05	0.034	0.02	0.01	Rem.
<b>Actual</b>	0.02	0.03	0.007	0.001	0.03	0.032	0.005	0.003	Rem.

### 2.3 Production of Master Alloy Al-Cu

The process to product master alloy was done by using electrical tube furnace with use graphite crucible, first, melting the copper at Temperature of 1084°C, then added Al to the molten in order to obtain alloy of Cu and Al with melting point of 650oC that near to melting point of zinc. The mixture was poured into a cylindrical steel mold with 14×150 mm dimensions and then the casting cut to pepper size. Table (4) illustrates the chemical composition of 50 % (Copper-Aluminum).

**Table 4.** Chemical composition of 50% (Copper-Aluminum)

Element	Cu	Si	Fe	Al	Others
<b>Actual</b>	47.78	0.02	0.33	51.13	Rem.

ZA-27 alloy has Mg in composition of (0.01-0.02) and to ensure that Mg was available in this alloy added AA 2024 alloy to the molten mixture. The chemical composition of commercial AA2024 is shown in Table (5), the chemical analyses were done at the Central Organization for Standardization and Quality Control.

**Table 5.** Chemical composition of AA 2024

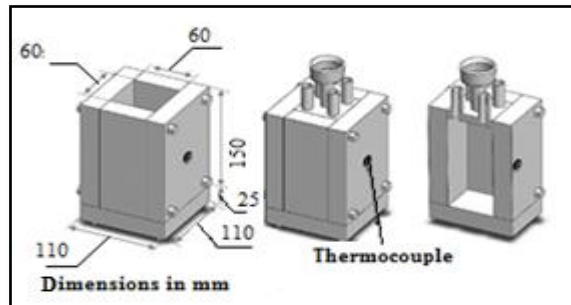
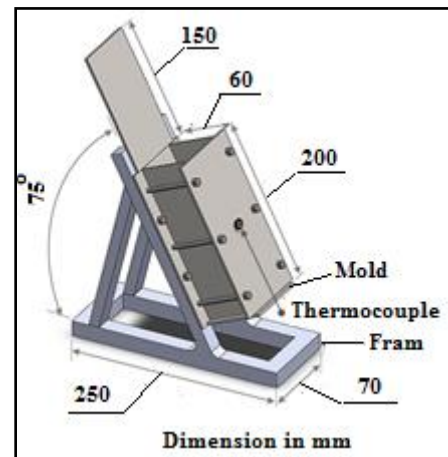
Elements %	Cu	Mn	Cr	Si	Fe	Zn	Ti	Mg	Al
<b>Material</b>									
<b>Nominal</b>	3.8-4.9	0.3-0.9	0.1	0.5	0.5	0.25	0.15	1.2-1.8	Rem.
<b>Actual</b>	4.1	0.5	0.002	0.007	0.178	0.081	0.0014	1.57	Rem.

### 2.4 Gravity Die Casting (GDC)

Mold with dimensions of 6×6×15 cm, thickness of 20 mm was manufactured from tool steel AISI H13 as shown in Figure 1. The mold must be preheated at (~250°C) before pouring of molten in order to allow smooth flow, gradual cooling, burn off moisture and reduce the possibility of blowholes forming in the large mass. Two thermocouples (K-type) was used to measure the temperature of pouring and temperature variation during solidification.

### 2.5 New Rheocasting (NRC)

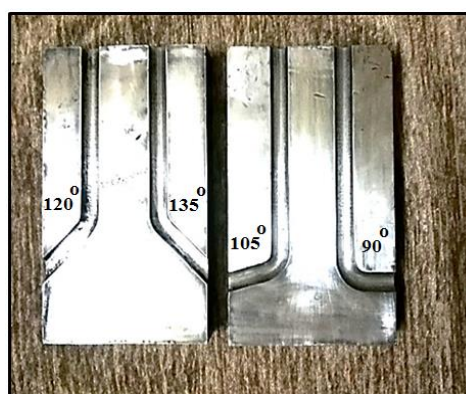
The concept of new rheocasting depends on forced homogenous nucleation of which keep on growing in globular shape, because of controlled cooling. Stainless steel mold AISI 304 with 3 mm of wall thickness and 6×6×20 cm was used (Figure 2). To increase the contact zone between molten metal and mold-wall the mold was inclined at an angle of 75° [12]. The mold was water cooled when temperature reached 420 °C. The thermocouple was inserted into the cast to determine the temperature at which a quenching was carried out.

**Figure 1.** GDC mold [12]**Figure 2.** NRC mold [12]

### 2.6 Equal channel angular extrusion die manufacturing:

**2.6.1 Die and Punch Materials** AISI D2 Tool steel was used for manufacture of ECAE die because of its high compressive strength, fatigue strength and wear resistance and has dimensional stability in heat treatment. AISI M2 high-speed tool steel was used for manufacturing of punch in because of its good combination of wear resistance, compressive strength and fatigue strength. Heat treatment was done after manufacturing of die and punch to increase the hardness.

**2.6.2 Die Manufacturing Procedures** The die is formed from two halves in the same of equal channel both of these halves have groove with variable angles as shown in Figure 3. The active die block was manufactured by CNC milling machine and after that for final accurate dimensions of interior radius of curves it was machined by CNC grinding machine. Other two-active die parts such as fixtuer and base machined to their final dimensions by ordinary machining such as milling, grinding, and drilling.

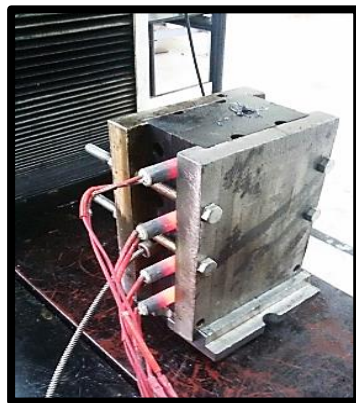
**Figure 3.** Halves of ECAP die at different angles

### 2.7 Production Operation

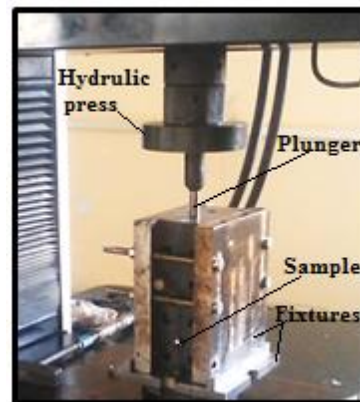
**2.7.1 Billet Preparation** The billets are cylinder cross section specimens of diameter 12 mm and 85 mm length, cut and machined from the casting (60x60x120mm) for NRC and GDC

techniques. These dimensions were chosen according to billet size calculations. The billet was polished with 1000 grid emery paper and then lubricated by MoS<sub>2</sub> before being pressing inside of the ECAE die.

**2.7.2 Heating system and test of ECAE** Four pin heaters with thermocouples (K-type) and digital control unit were built in the flat side of the die. The assembly of die is shown in Figure 4. After the system was heated to a required temperature, the load is applied. The plunger began to press the sample heated to 100oC into the intersection of two channels of die with ram velocity equals to 10mm/minute. Figure 5 shows the testing operation.



**Figure 4.** ECAE die with heating system



**Figure5.** ECAE testing operation

### 2.8 Grain size calculated

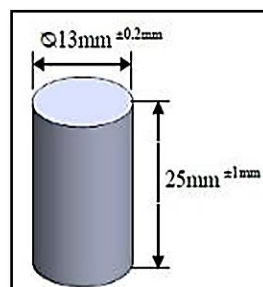
The particles size can be calculated by using computer program (Image-J) depending on microstructure pictures. Dendritic Arm Spacing (DAS) is measured by Mean Linear Intercept after mounting, polishing and examination by a microscopeto determine the total distance from the first to the last arm using equation [16]:

$$DAS = L / MN \quad (1)$$

Where: L:line length (μm), M: Themicrograph magnification, N: The number of exists dendritic arm sat this area.

### 2.9 Compressive Test

Compression test have been done according to ASTM – E9 were the specimens cut from the ZA-27 alloy for GDC and NRC before and after extrusion. The specimens had L/D = 2.0.



**Figure 6.** Compression test specimen

### 2.10 Hardness Test

Hardness of castings was measured using vickers hardness test to compare its value with specification standard. Test was carried out on all extruded samples and specimen without extrusion to investigate the effect of ECAE process on hardness.

## 3. Results and discussion

### 3.1. Mechanical Properties

The mechanical properties of alloy ZA-27 that produced by two different casting techniques are shown in table (6). It is clear that the mechanical properties of alloy are higher with NRC method than GDC method except yield stress. The yield stress is strongly affected by microstructure that the dendritic shape of alloy produced by GDC play a main role in raising the value of this property. The hardness of ZA-27 alloy of NRC is higher than GDC due to the increase in volume fraction of eutectic and grain refinement of  $\alpha$ -Al phase.

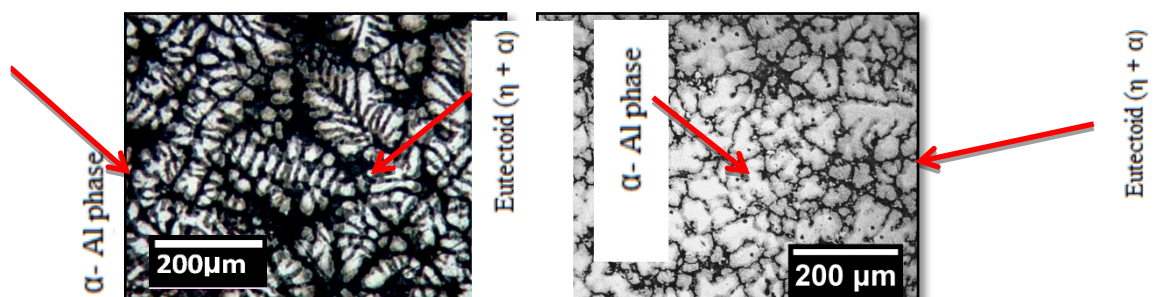
**Table 6.** Mechanical properties of ZA- 27 alloy

	Compression Strength (MPa)	Yield stress (MPa)	Elongation %	Hardness Kgf/mm <sup>2</sup> (HB)
<b>Nominal ZA- 27</b>	310-325	280	2.4	100-115.83
<b>GDC ZA - 27</b>	321	282	2.3	102.08
<b>NRC ZA - 27</b>	370	231	5.7	123.75

### 3.2 Microstructure of cast alloy

Alloys of ZA-27 produced by GDC techniques have a dendritic structure. The dendritic arms spacing from wall toward the center depending on casting parameters. Structure of GDC of ZA-27 alloy consists phases  $\alpha$ , and  $\eta$  as shown Figure 7.

Microstructure of NRC method revealed fine and equalized grain instead of dendritic structure Figure 8 due to rapid cooling to get average grain size equal to (36  $\mu$ m) near the wall, increases to (41 $\mu$ m) at the center with average equal to (38 $\mu$ m). The volume fraction of  $\alpha$ - Al phase was 0.59 as compared with GDC ZA-27 alloy that equals 0.65. The variation from dendrite shape to equiaxed grain leads to improvement in mechanical properties.



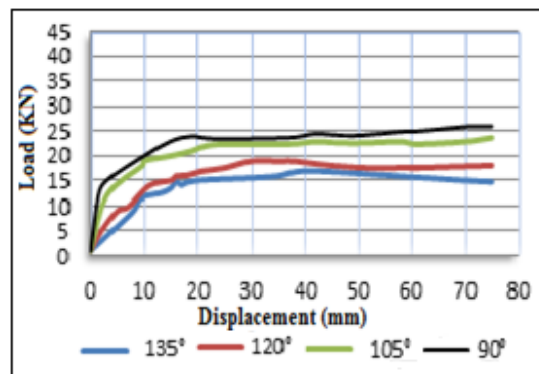
**Figure 7.** GDC before extrusion

**Figure 8.** NRC before extrusion

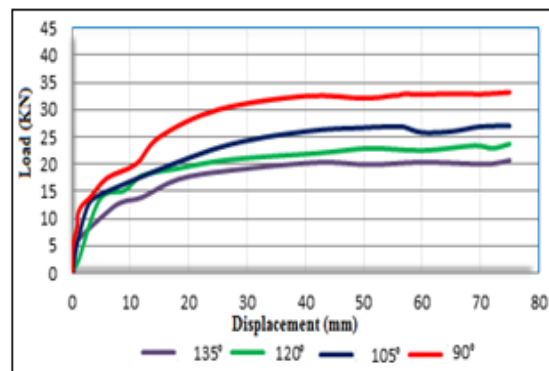


### 3.3 Evaluation the effect of die angle on load of ECAE process

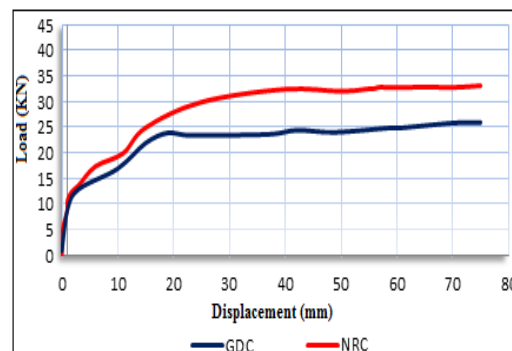
The results show that the force required for ECAE increased with decreasing the angle of extrusion for both types of ZA-27 alloy. Both NRC & GDC require maximum force at die angle  $90^\circ$  and the force decreases gradually with increases die angle as shown in Figure 9 and Figure 10. All the tests were done at temperature at  $100^\circ$ . The explanation of this result, when die angle decreases the shear force that material encountered through forming increases and lead to increase load of extrusion. Specimens produced by NRC method require load more than GDC for all die angles because of the shape and the size of grain which is small and equiaxed for NRC. Figure 11 shows the comparison of extrusion load between two casting method of alloy at  $90^\circ$  die angle, and it is clear that the higher load appear at NRC method.



**Figure 9.** Extrusion load – displacement relationship for GDC



**Figure 10.** Extrusion load – displacement relationship for NRC

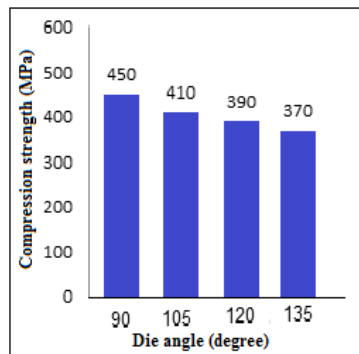


**Figure 11.** Extrusion load – displacement relationship for GDC & NRC at  $90^\circ$

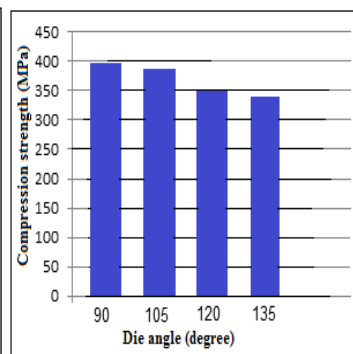


### 3.4 Effect of casting techniques on compression strength

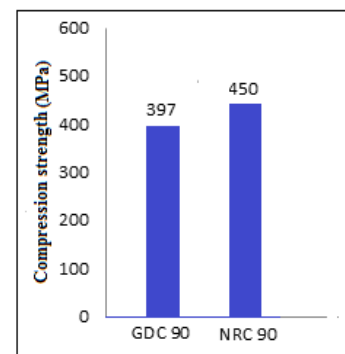
To compare between compression strength of (GDC and NRC) as extruded samples for the four die angle (135, 120, 105 and 90°), compression tests were performed at room temperature. The results of compression test are showed in the figures (12, 13, and 14). The improvement of this property occurs at die angle of 90° for both alloys. NRC method gave better results than GDC method and the reason belongs to the refinement of grain at this angle especially with NRC method.



**Figure12.** Relationship Comparison between compression strength and strength for die angle NRC die angle.



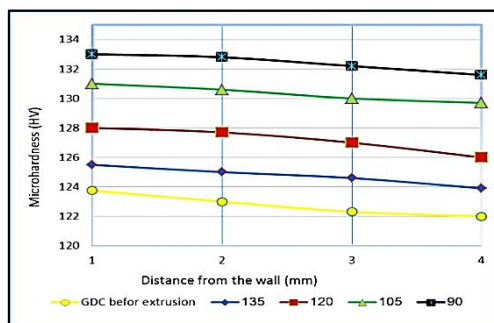
**Figure13.** Relationship compression strength and die angle for GDC.



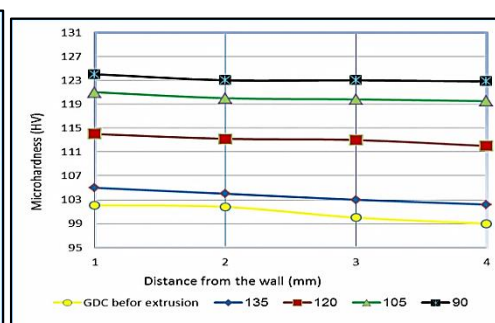
**Figure14.** Relationship compression GDC & NRC at 90°

### 3.5 Effect of casting techniques on microhardness

Vickers micro hardness measurement (MHV) at four positions was recorded from the outer edge to the center for NRC casting and GDC casting samples produced by ECAE with four angles. The results show that the values of micro hardness decreased from the wall toward the center of specimen for both types of alloy as shown in Figure 15 and Figure 16 and the reason is the wall of specimen subjected to high cooling and result in fine grain lead to increase the hardness. From the above figures, it can be noticed that the values of hardness of specimens produces by NRC more than those produced by GDC and 90° die angle gave the best value. The improvement of hardness for NRC and 90° die angle belongs to the refinement of grain of microstructure at that casting method and die method.



**Figure 15.** Vickers Microhardness for Extruded NRC for Extruded Specimens.



**Figure 16.** Vickers Microhardness GDC Specimens.

### 3.6 Effect of extrusion die angle on microstructure

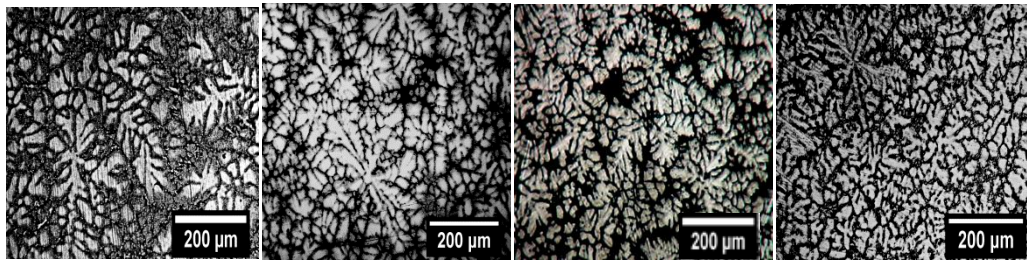
It is so clear from the table 10 and table 11 that the technique of equal channel could successfully refine the grain of eutectoid ( $\eta + \alpha$ ) phase to average  $2.37\mu\text{m}$ ,  $4.91\mu\text{m}$  near the wall and centre respectively. This phase has grain size before the processing reaches to  $32\mu\text{m}$  in average for GDC and  $28\mu\text{m}$  for NRC. The  $\alpha$ -Al phase has various shapes that appear fine equalized in NRC and fine dendritic shape in GDC, this phase has grain size before the processing reaches to  $41\mu\text{m}$  in average for GDC and  $26\mu\text{m}$  for NRC. Figure 17 and Figure 18 show microstructure of GDC and NRC respectively, and it can be noticed that  $90^\circ$  die angle revealed more equilibrium distribution of eutectoid ( $\eta + \alpha$ ) phase which leads to improve in compression strength more than other angles. Also, the grains near the walls were always smaller than near center, this is because of undergoing higher cooling rate when the processing is done.

**Table 7.** Grain size of dendritic arm space (DAS) and phases for GDC with different extrusion angle.

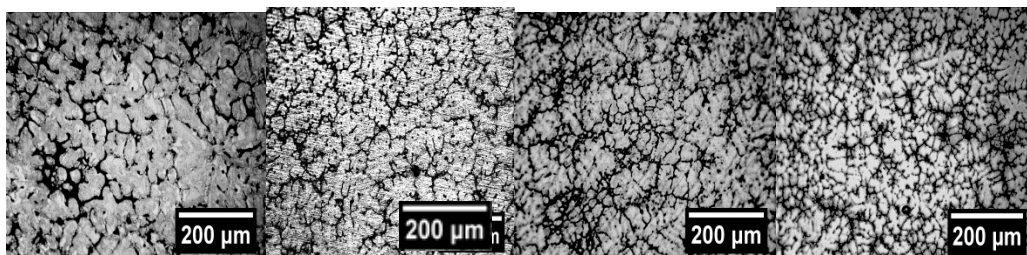
Die angle	$90^\circ$	$105^\circ$	$120^\circ$	$135^\circ$
<b>Grain size (<math>\mu\text{m}</math>)</b>				
<b>DAS (near the wall)</b>	6.14	7.55	9.88	10.67
<b>DAS (at the center)</b>	9.09	10.75	11.45	14.32
<b><math>\alpha</math>-Al phase(near the wall)</b>	21.98	25.04	28.51	31.11
<b><math>\alpha</math>-Al phase(at the center)</b>	22.03	27.55	30.04	32.09
<b>Eutectoid (<math>\eta + \alpha</math>)(near the wall)</b>	10.08	13.88	14.13	16.55
<b>Eutectoid (<math>\eta + \alpha</math>)(at the center)</b>	10.12	15.75	17.98	19.09

**Table 8.** Grain size of phases for NRC with different extrusion angle

Die angle	$90^\circ$	$105^\circ$	$120^\circ$	$135^\circ$
<b>Grain size (<math>\mu\text{m}</math>)</b>				
<b><math>\alpha</math>-Al phase(near the wall)</b>	5.03	6.87	8.66	11.04
<b><math>\alpha</math>-Al phase(at the center)</b>	5.89	8.23	9.9	13.69
<b>Eutectoid (<math>\eta + \alpha</math>)(near the wall)</b>	19.09	19.89	21.97	24.30
<b>Eutectoid (<math>\eta + \alpha</math>)(at the center)</b>	19.90	22.88	25.34	27.67



**Figure 17.** Microstructure of GDC specimens after angular extrusion with different die angles



**Figure 18.** Microstructure of NRC specimens after angular extrusion with different die angles

#### 4. Conclusions:

1. The ECAE was successfully applied to ZA-27 alloy manufactured by two methods NRC and GDC to produce specimens without defects.
2. Die angle of ECAE has main effect in improvement of compression strength and hardness of alloy for both casting method of alloy.
3. Die angle of 90° gave the best of compression strength and hardness of alloy for both two casting method compare with other angles but required higher load in ECAE process.
4. NRC method revealed improvement of compression strength and hardness better than GDC method after ECAE process.
5. Refinement of grains of microstructure of alloy for two casting method occurs at 90° angle that the size of grains became uniform from the wall to the center of specimen.

#### Reference

- [1] Srinivas B, Srinivasu CH, Banda Mahesh and Aqheel 2012 *Journal of Advance Materials Manufacturing & Characterization* **3** 291-296.
- [2] Gadirl E And Gunduz M 2000 *Journal of Materials Science* **35** 3837-3848.
- [3] Dey AK, Poddar P, Singh KK and Sahoo KL 2006 *Materials Science and Engineering* **435** 521-529.
- [4] Abood AN and Habeb TS 2008 *Journal of Zankoy Sulaimani* **11** 89-99.
- [5] Palash Poddar and Sahoo KL 2012 *Materials Science and Engineering* **556** 891-905.
- [6] Berbon PB, Furukawa M, Horita Z, Nemoto M and Langdon TG 1999 *Journal of Metallurgical and Materials Transactions* **30** 1989-1997.
- [7] Gencaga Purcek, Onur Saray, Karaman I and Haouaoui M 2009 *Metallurgical and Materials Transactions* **40** 2772-2782.
- [8] Saray O, Purcek G and Karaman I 2010 *Adv. Mater. Sci* **25**. 42-51.
- [9] Thiyaneshwaran N and P. Sureshkumar 2013 *International Journal of Engineering Research & Technology (IJERT)* **2** 17-24.
- [10] Nashith A, Sanjid P, Shamsudheen M, Rasheeqe R, Ramis MK And Shebeer AR 2014 *International Journal of Materials Engineering* **4** 119-122, 2014.
- [11] Patricia Ponce-Peña, Edgar Lopez-Chipres, Edgar Garcia-Sanchez, Miguel Angel Escobedo-Bretado, Brenda Xiomara Ochoa Salazar and Maria Azucena Gonzalez-Lozano 2015 *Optimized Design of an ECAP Die Using the Finite Element Method for Obtaining Nanostructured Materials* Advances in Materials Science and Engineering.
- [12] Mohammed A J 2015 *Role of Die Profile in Forward Extrusion on Zn-Al Alloy* Ms.C University of Technology.
- [13] Nazari Tiji, Asgari A, Gholipour H and Djavanroodi F 2016 *Journal of Engineering Manufacture* 1-7.