Materials Science Forum
ISSN: 1662-9752, Vol. 978, pp 161-166
doi:10.4028/www.scientific.net/MSF.978.161

Submitted: 2019-01-18
Accepted: 2019-07-01
Online: 2020-02-19

# Tensile Toughness Characteristics of Cast Al-Zn-Mg Alloys Processed by Equal Channel Angular Pressing

G.K. Manjunath[1,a*], K. Udaya Bhat[2,b] and G.V. Preetham Kumar[2,c]

[1]School of Mechanical Engineering, REVA University, Kattigenahalli, Yelahanka, Bengaluru – 560064, Karnataka, India

[2]Department of Metallurgical & Materials Engineering, National Institute of Technology Karnataka, Srinivasnagar, Surathkal, Mangaluru - 575025, India

[a]manjugk2001@gmail.com, [b]udayabhatk@gmail.com, [c]pkphd@hotmail.com

**Keywords:** ECAP, Al-Zn-Mg alloy, Grain Size, Tensile toughness

**Abstract.** In the current study, consequence of ECAP on the toughness characteristics of the Al-Zn-Mg alloys was studied. Three set of Al-Zn-Mg alloys (5, 10 and 15% Zn and 2% Mg) were selected and ECAPed. Also, consequence of zinc on the toughness characteristics of the alloy, before and after ECAP was studied. After ECAP, grain size of the alloys decreased and significant rise in the strength and ductility of the alloys were noticed. Mainly, modulus of toughness of the alloys increased with successive ECAP passes. But, the modulus of toughness of the alloys decreased with rise in the zinc in the material.

## Introduction

Toughness is an important mechanical property of the material. Toughness of the material could be raised by rising the ductility and strength of the material. The strength and ductility of the alloys could be improved by reducing the grain size of the material through various severe plastic deformation (SPD) methods [1]. Amongst numerous SPD methods, equal channel angular pressing (ECAP) is an efficient and simple technique [2]. Aluminium and its alloys are acknowledged as suitable materials in engineering applications. Among various aluminium alloys, Al-Zn-Mg alloys have a wide acceptance in the fabrication of aerospace equipments where high strength to weight ratio is an important criterion [3]. Strength and toughness characteristics of these alloys could be improved by ECAP technique.

In literature, several reports were stated on the importance of ECAP processing on various material properties [4-5]. Since, Al-Zn-Mg alloys are identified as key materials for various engineering applications. The strength of the Al-Zn-Mg alloys could be enhanced by ECAP technique. It is necessary to understand the toughness characteristics of ECAPed Al-Zn-Mg alloys, so that these alloys could be utilized to suitable applications. To the author's knowledge no reports were stated on the effect of ECAP on the toughness characteristics of the Al-Zn-Mg alloys. In this regard, in the current investigation, toughness characteristics of the Al-Zn-Mg alloys were analyzed.

## Materials and Experiments

The alloys studied in the current investigation are Al-5Zn-2Mg, Al-10Zn-2Mg and Al-15Zn-2Mg alloys. These alloys were designated as Z5, Z10 and Z15 alloys, respectively. These alloy sets were prepared through casting process. The procedure for alloys preparation by casting process is presented in our past work [6]. Before ECAP, the as-cast alloy samples were treated with homogenization process at 753 K for 20 hours. For ECAP, homogenized samples were machined to Ø 16 mm and length 85 mm rods. Processing was carried out in a in a split type die and the channels of the die are interconnecting at 120º. Processing was carried out at 473 K in route $B_C$ and at a rate of 0.5 mm/sec.

Microstructure of the alloys was analyzed by using scanning electron microscopy (SEM) and transmission electron microscopy (TEM). Grain size of the alloys (before and after ECAP) was measured by linear intercept technique. To analyze the consequence of ECAP on the toughness characteristics of the alloys, tensile tests were carried out on the processed and unprocessed materials. From the tensile test data, engineering stress-strain curves were plotted. Modulus of toughness was estimated by estimating the area under the plastic region of the engineering stress-strain curve.

## Results and Discussion

### Microstructure Analysis

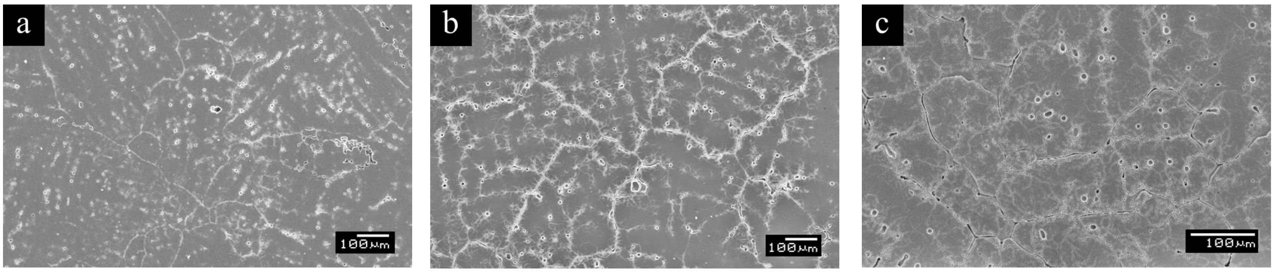


**Fig. 1:** SEM micrographs of the alloys in as-cast condition (a) Z5 alloy, (b) Z10 alloy and (c) Z15 alloy

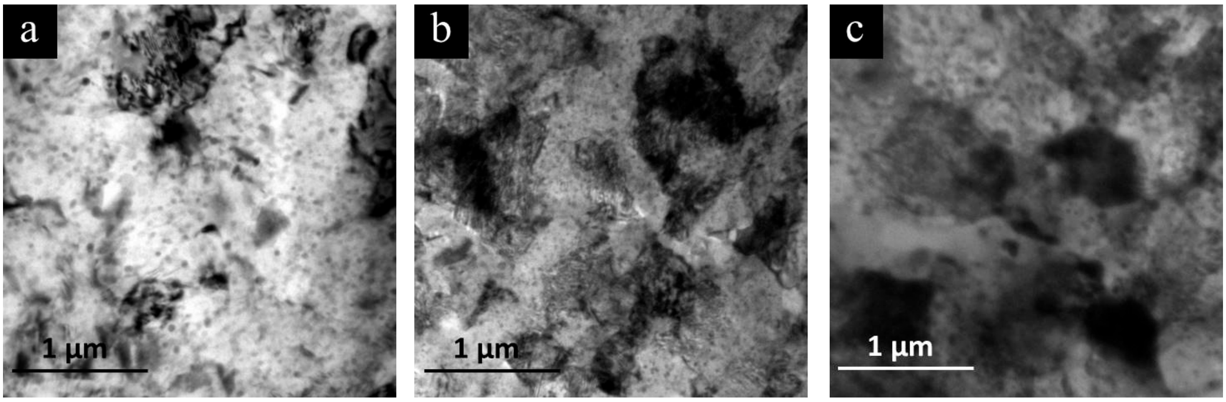


**Fig. 2:** TEM micrographs of the alloys after four ECAP passes (a) Z5 alloy, (b) Z10 alloy and (c) Z15 alloy

Figure 1 presents the SEM microstructure of all three alloys in as-cast state. In as-cast state, all three alloys exhibit typical dendritic configuration and secondary particles were noticed in the inter-dendritic spaces. The secondary particles in the inter-dendritic spaces were identified as $MgZn_2$ precipitates. It is observed that, with rise in the zinc in the material the quantity of secondary particles also raised. In as-cast state, in Z5 alloy, dendrites of 200±20 µm in size were noticed, as displayed in Fig. 1(a). In homogenized state, large grains of 180±20 µm in size were noticed. After ECAP, grain size is reduced to 30±10, 20±8, 10±6 and 5±3 µm in $1^{st}$, $2^{nd}$, $3^{rd}$ and $4^{th}$ passes, correspondingly [7]. In as-cast state, in Z10 alloy, dendrites of 280±40 µm in size were noticed, as displayed in Fig. 1(b). In homogenized state, large grains of 260±20 µm in size were noticed. After ECAP, grain size is reduced to 75±10, 40±8, 20±7 and 8±5 µm in $1^{st}$, $2^{nd}$, $3^{rd}$ and $4^{th}$ passes, correspondingly [7]. In as-cast state, in Z10 alloy, dendrites of 200±20 µm in size were noticed, as displayed in Fig. 1(c). In homogenized state, large grains of 180±18 µm in size were noticed. After ECAP, grain size is reduced to 50±15, 25±10, 15±5 and 10±5µm in $1^{st}$, $2^{nd}$, $3^{rd}$ and $4^{th}$ passes, correspondingly [7]. Figure 2 presents the TEM microstructure of all three alloys after four ECAP passes. In all three alloys, equiaxed grains were noticed. Also, large amount of dislocations was noticed.

## Toughness Characteristics

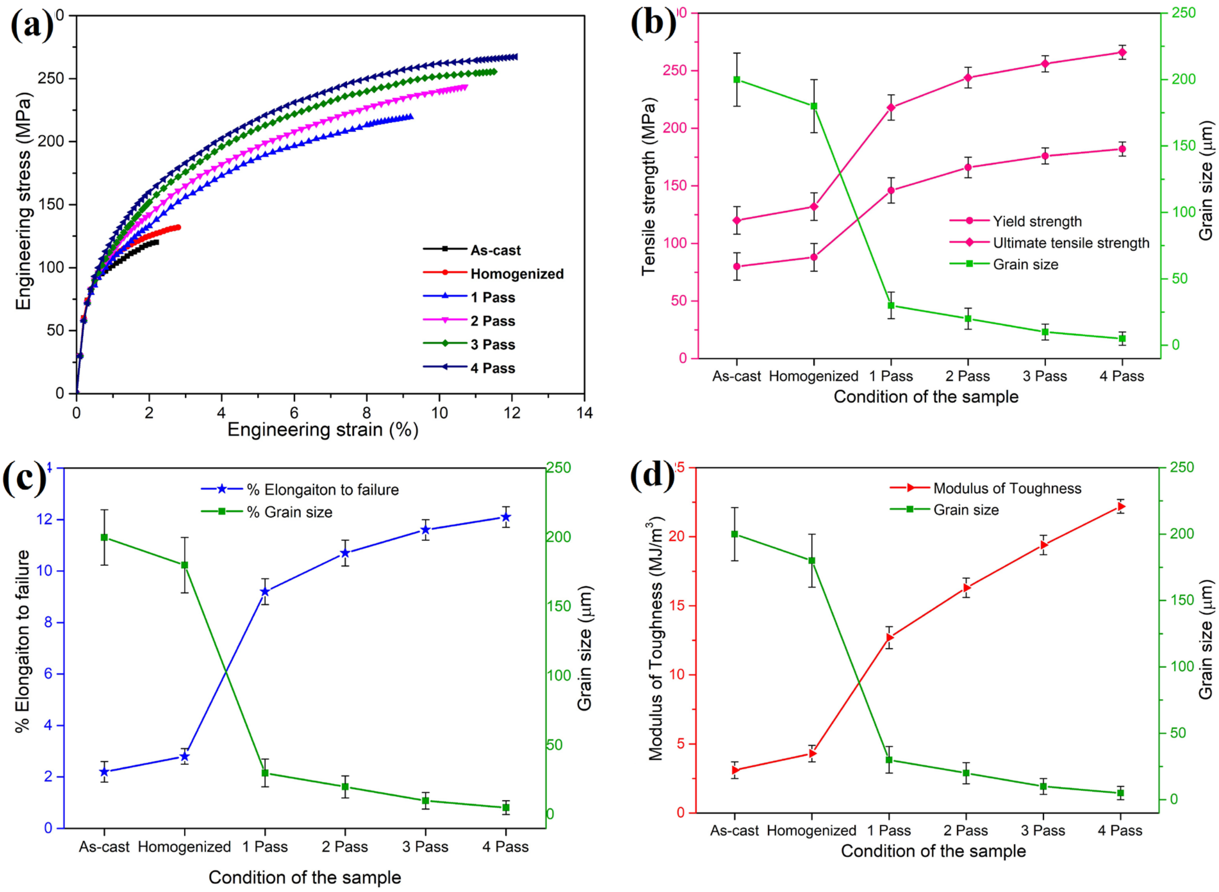


**Fig. 3:** (a) Engineering stress-strain diagram for Z5 alloy, (b) Variation of tensile strength and grain size (c) Variation of elongation to failure and grain size, and (d) Variation of modulus of toughness and grain size of the Z5 alloy processed under various conditions

Figure 3(a) displays the engineering stress-strain plot of the Z5 alloy under various conditions. In as-cast and homogenized state, alloy exhibits less strength and ductility in contrast to the processed samples, which is attributed to the occurrence of dendritic morphology and cast defects [8]. After ECAP, remarkable rise in the strength and elongation to failure of the alloy was noticed, which is owing to the decrease in the crystallite size of the material after ECAP. Figure 3(b) presents the variation of tensile strength and grain size of the Z5 alloy processed under various conditions. In as-cast and homogenized state, yield strength (YS) of the alloy is 80±12 and 88±12 MPa, correspondingly. After ECAP, YS of the alloy increased to 146±11, 166±9, 176±7 and 182±6 MPa in 1$^{st}$, 2$^{nd}$, 3$^{rd}$ and 4$^{th}$ passes, correspondingly. In as-cast and homogenized state, ultimate tensile strength (UTS) of the alloy is 120±12 and 132±12 MPa, correspondingly. After ECAP, UTS of the alloy increased to 218±11, 244±9, 256±7 and 266±6 MPa in 1$^{st}$, 2$^{nd}$, 3$^{rd}$ and 4$^{th}$ passes, correspondingly. Figure 3(c) presents the variation of ductility and grain size of the Z5 alloy processed under various conditions. In as-cast and homogenized state, ductility of the alloy is 2.2±0.4 and 2.8±0.3, correspondingly. After ECAP, ductility of the alloy increased to 9.2±0.5, 10.7±0.5, 11.6±0.4 and 12.1±0.4 % in 1$^{st}$, 2$^{nd}$, 3$^{rd}$ and 4$^{th}$ passes, correspondingly. Figure 3(d) presents the variation of modulus of toughness and grain size of the Z5 alloy processed under various conditions. In as-cast and homogenized state, modulus of toughness of the alloy is 3.1±0.6, 4.3±0.6 MJ/m$^3$, correspondingly. After ECAP, modulus of toughness of the alloy increased to 12.7±0.8, 16.3±0.7, 19.4±0.7 and 22.2±0.5 MJ/m$^3$ in 1$^{st}$, 2$^{nd}$, 3$^{rd}$ and 4$^{th}$ passes, correspondingly.

Figure 4(a) displays the engineering stress-strain plot of the Z10 alloy processed under various conditions. Similar to Z5 alloy, in as-cast and homogenized state, Z10 alloy exhibits less strength and ductility in contrast to the processed samples. After ECAP, remarkable rise in the strength and

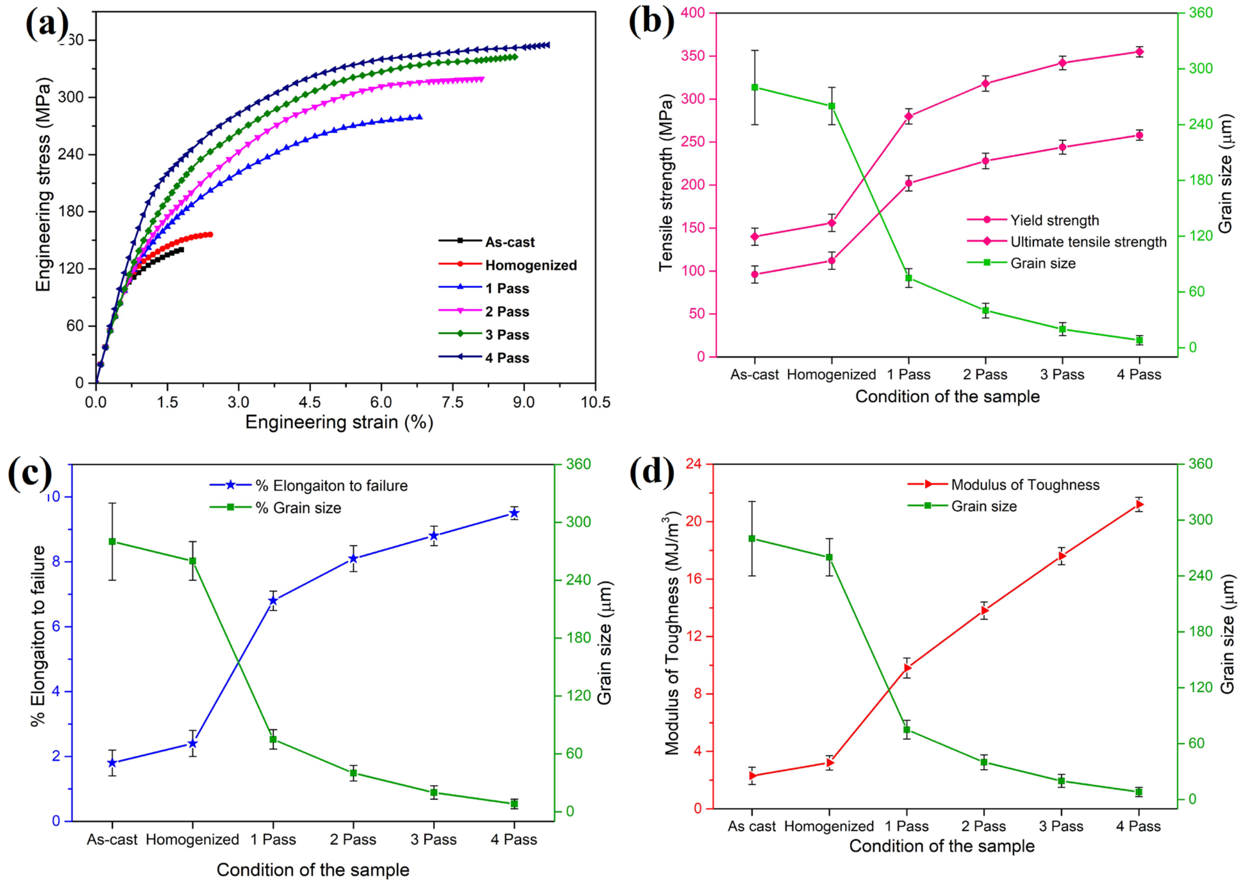


**Fig. 4:** (a) Engineering stress-strain diagram for Z10 alloy, (b) Variation of tensile strength and grain size (c) Variation of elongation to failure and grain size, and (d) Variation of modulus of toughness and grain size of the Z10 alloy processed under various conditions

elongation to failure of the alloy was noticed. Figure 4(b) presents the variation of tensile strength and grain size of the Z10 alloy processed under various conditions. In as-cast and homogenized state, yield strength (YS) of the alloy is 96±10 and 112±10 MPa, correspondingly. After ECAP, YS of the alloy increased to 202±9, 228±9, 244±8 and 258±6 MPa in 1$^{st}$, 2$^{nd}$, 3$^{rd}$ and 4$^{th}$ passes, correspondingly. In as-cast and homogenized state, ultimate tensile strength (UTS) of the alloy is 140±10 and 156±10 MPa, correspondingly. After ECAP, UTS of the alloy increased to 280±9, 318±9, 342±8 and 355±6 MPa in 1$^{st}$, 2$^{nd}$, 3$^{rd}$ and 4$^{th}$ passes, correspondingly. Figure 4(c) presents the variation of ductility and grain size of the Z10 alloy processed under various conditions. In as-cast and homogenized state, ductility of the alloy is 1.8±0.4 and 2.4±0.3, correspondingly. After ECAP, ductility of the alloy increased to 6.8±0.3, 8.1±0.4, 8.8±0.3 and 9.5±0.2 % in 1$^{st}$, 2$^{nd}$, 3$^{rd}$ and 4$^{th}$ passes, correspondingly. Figure 4(d) presents the variation of modulus of toughness and grain size of the Z10 alloy processed under various conditions. In as-cast and homogenized state, modulus of toughness of the alloy is 2.3±0.6, 3.2±0.5 MJ/m$^3$, correspondingly. After ECAP, modulus of toughness of the alloy increased to 9.8±0.7, 13.8±0.6, 17.6±0.6 and 21.2±0.5 MJ/m$^3$ in 1$^{st}$, 2$^{nd}$, 3$^{rd}$ and 4$^{th}$ passes, correspondingly.

Figure 5(a) displays the engineering stress-strain plot of the Z15 alloy processed under various conditions. Similar to Z5 and Z10 alloys, in as-cast and homogenized state, Z15 alloy exhibits less strength and ductility in contrast to the processed samples. After ECAP, remarkable rise in the strength and elongation to failure of the alloy was noticed. Figure 5(b) presents the variation of tensile strength and grain size of the Z10 alloy processed under various conditions. In as-cast and homogenized state, yield strength (YS) of the alloy is 125±12 and 138±11 MPa, correspondingly. After ECAP, YS of the alloy increased to 258±9, 285±7, 297±6 and 302±6 MPa in 1$^{st}$, 2$^{nd}$, 3$^{rd}$ and 4$^{th}$ passes, correspondingly. In as-cast and homogenized state, ultimate tensile strength (UTS) of the

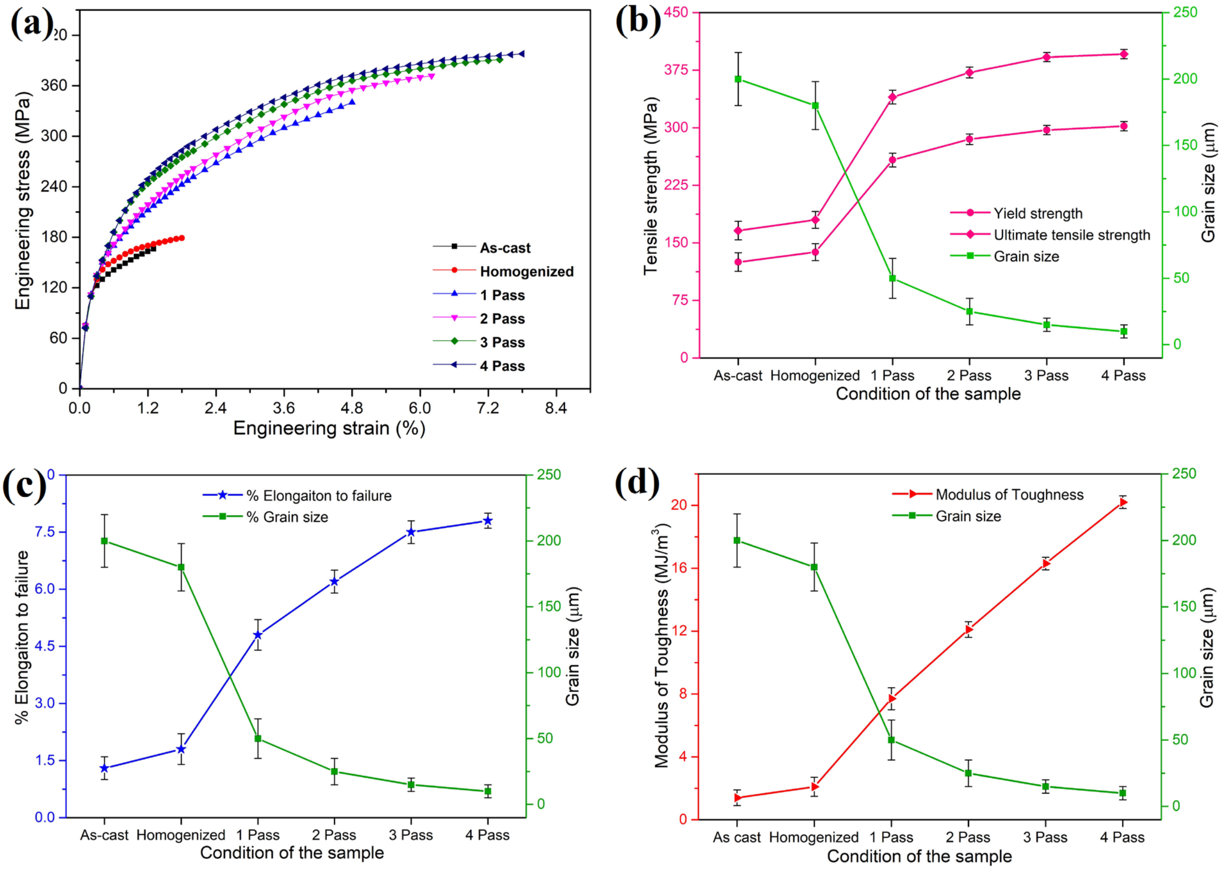


**Fig. 5:** (a) Engineering stress-strain diagram for Z15 alloy, (b) Variation of tensile strength and grain size (c) Variation of elongation to failure and grain size, and (d) Variation of modulus of toughness and grain size of the Z15 alloy processed under various conditions

alloy is 166±12 and 180±11 MPa, correspondingly. After ECAP, UTS of the alloy increased to 340±9, 372±7, 392±6 and 396±6 MPa in 1st, 2nd, 3rd and 4th passes, correspondingly. Figure 5(c) presents the variation of ductility and grain size of the Z15 alloy processed under various conditions. In as-cast and homogenized state, ductility of the alloy is 1.3±0.3 and 1.8±0.4, correspondingly. After ECAP, ductility of the alloy increased to 4.8±0.4, 6.2±0.3, 7.5±0.3 and 7.8±0.2 % in 1st, 2nd, 3rd and 4th passes, correspondingly. Figure 5(d) presents the variation of modulus of toughness and grain size of the Z15 alloy processed under various conditions. In as-cast and homogenized state, modulus of toughness of the alloy is 1.4±0.5, 2.1±0.6 MJ/m$^3$, correspondingly. After ECAP, modulus of toughness of the alloy increased to 7.7±0.7, 12.1±0.5, 16.3±0.4 and 20.2±0.4 MJ/m$^3$ in 1st, 2nd, 3rd and 4th passes, correspondingly.

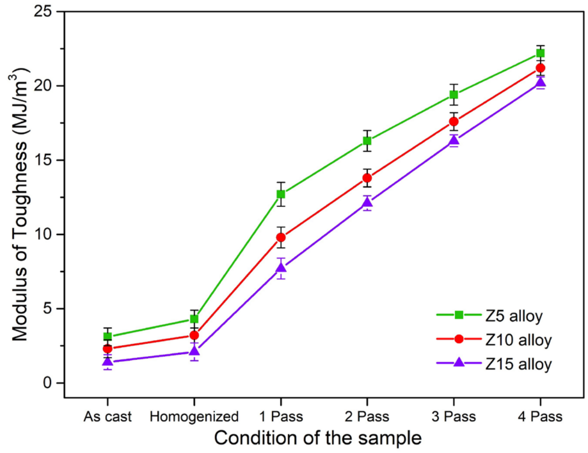


**Fig. 6:** Variation of modulus of toughness of the alloys processed under various conditions

It is observed that, with rise in the zinc in the material strength of the alloy raised. Even after ECAP, Z10 alloy exhibits more strength in contrast to Z5 alloy. Likewise, Z15 alloy exhibits more strength in contrast to Z5 and Z10 alloys. But, ductility of the alloy decreased with rise in the zinc in the alloy. Even though, after ECAP, ductility of the alloy increased, it decreased with rise in the zinc in the material.

Figure 6 displays the variation of modulus of toughness of all three alloys in various conditions. It is noticed that, in all conditions, Z5 alloy exhibits highest modulus of toughness in contrast to Z10 and Z15 alloys. This is attributed to the highest ductility obtained in Z5 alloy in contrast to Z10 and Z15 alloys, in all conditions. It is also noticed that, after $1^{st}$ pass, comparatively large modulus of toughness was observed in Z5 alloy in contrast to the Z10 and Z15 alloys. But, after $4^{th}$ passes, there is not much difference in the modulus of toughness of the alloys was noticed. Because, even though Z10 and Z15 alloys exhibits less ductility, even after ECAP, in contrast to Z5 alloy. But, these two alloys exhibits highest strength in contrast to Z5 alloy, in later passes. Hence, with subsequent passes, less difference in the modulus of toughness of the alloys was perceived.

## Summary

In the present work, consequence of ECAP on the toughness characteristics of the Al-Zn-Mg alloys was studied. Also, consequence of zinc on the toughness characteristics of the alloy, before and after ECAP was studied. After ECAP, modulus of toughness of the alloys was increased. With rise in the zinc in the material, modulus of toughness of the alloys decreased. But, with successive ECAP passes, not much difference in the modulus of toughness of the alloys was noticed.

## References

[1] Y. Cao, S. Ni, X. Liao, M. Song, Y. Zhu, Mater. Sci. Eng. R 133 (2018) 1–59.

[2] T. G. Langdon, Mater. Sci. Eng. A 462 (2007) 3–11.

[3] M. Kutz: *Mechanical Engineers Handbook: Materials and Mechanical Design* (John Wiley & Sons, New Jersey 2006)

[4] M. H. Shaeri, M. Shaeri, M. T. Salehi, S. H. Seyyedein, M. R. Abutalebi, Prog. Nat. Sci. Mater. Int. 25 (2015) 159–168.

[5] M. A. Afifi, Y. C. Wang, P. H. R. Pereira, Y. Huang, Y. Wang, X. Cheng, S. Li, T. G. Langdon, J. Alloys Compd.769 (2018) 631–639.

[6] G. K. Manjunath, P. Huilgol, G. V. Preetham Kumar, K. Udaya Bhat, Mater. Res. Express 6 (2019) 016511.

[7] G. K. Manjunath, K. Udaya Bhat, G. V. Preetham Kumar, Metallogr. Microstruct. Anal. 7 (2018) 77–87.

[8] G. B. Pourbahari, H. Mirzadeh, and M. Emamy, J. Mater. Eng. Perform. 27 (2018) 1327–1333.