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Comparison between Mo Addition to Zinc Aluminum Alloy, ZA22, Grain Refined by Ti and Ti-B after Pressing by the Equal Channel Angular Press, ECAP

Adnan I. O. Zaid, Ahmad O. Mostafa

Abstract— Zinc aluminum alloys in general and ZA22 in particular are in increasing demand in engineering and industrial applications especially in the automobile and aircraft industries. In this paper comparison between the effect of molybdenum addition to ZA22 grain refined by Ti and Ti-B after pressing by the ECAP process regarding its metallurgical and mechanical characteristics is investigated and the obtained results are presented and discussed.

Index Terms— Equal channel angular pressing, ECAP, Grain refinement, Molybdenum addition, Titanium, Titanium-Boron.

1 INTRODUCTION

Zinc aluminum alloys in general and ZA22 alloy in particular are widely used in manufacturing several components in the automobile and aircraft industries because of their unique and useful properties, such as strength, toughness, rigidity, bearing load capacity, economical and clean cast ability, good corrosion resistance, ease of manufacturing in different sizes and weights with good surface quality .Their inherent corrosion resistance give them the advantage over cast iron and their clean and low melting point in addition to their low price they replaced copper and its alloys in many applications, [1-5]. Against these advantages they have the disadvantage of solidification in large grains dendritic structure which affects their mechanical characteristics and surface quality. Their phase diagram is shown in Figure 1.

Therefore, to overcome this discrepancy, they are normally treated either by addition of some rare earth elements e.g. Ti, Ti-B, V, etc. or refining their structure by subjecting them to severe plastic deformation, SPD. The grain refinement by addition of Ti or Ti-B to their melt prior to solidification is used since early fifties after Cibula's findings in1950- 1951, [6 ,7] and now it is well established and the literature on it is voluminous, [8-20]. Other relatively recent methods which engaged researchers in the last two decades for producing fine grain size in metals and their alloys are the severe plastic deformation processes, SPD, which in turn will result in enhancement of their mechanical characteristics and surface quality. The equal channel angular pressing, ECAP, is the mostly used among the different SPD methods, [21- 29].

In this paper comparison between the addition of Mo to ZA22 grain refined by Ti or Ti-B after ECAP on its metallurgical structure and mechanical characteristics is investigated and the results are presented and discussed.

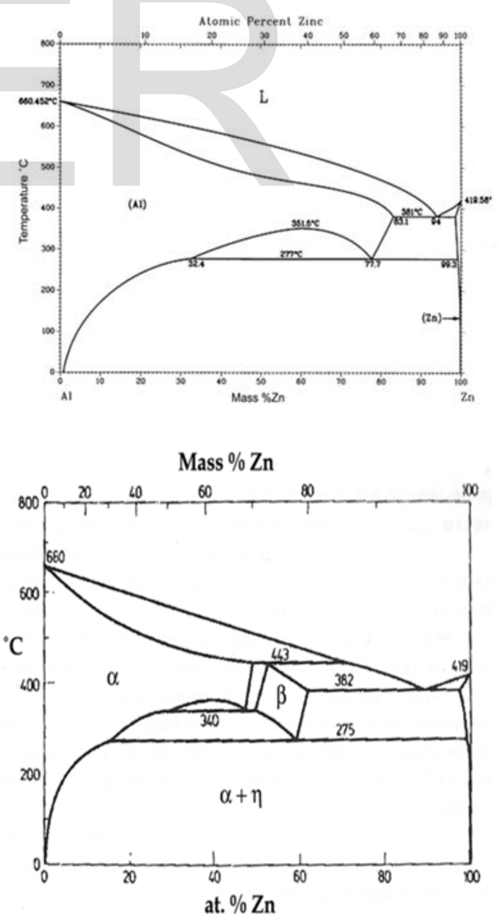

Fig. 1. The phase diagram of zinc aluminum alloys

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2 Materials, Equipment and Experimental Procedure

2.1 Materials

Pure aluminum and pure granular zinc of the chemical compositions shown in Tables 1 and 2 respectively, were used in manufacturing the main zinc- 22% aluminum alloy ,referred to later as ZA22, main alloy. High purity molybdenum, titanium and high purity aluminum were used in manufacturing the following binary master alloys: Al- Mo and Al-Ti. The ternary master alloy Al-Ti-B was commercially available and was supplied by the Arab Company for manufacturing aluminum (ARAL). These three master alloys were used as grain refiners for the ZA22 main alloy and for the manufacturing of the different ZA22 micro alloys. Pure graphite crucibles graphite rods were used in manufacturing the main alloy ZA22, master alloy and the different ZA22 micro-alloys, and pure graphite rods were used for stirring.

TABLE 1
Chemical composition of zinc

Element	Wt %
Pb	0.003
Fe	0.002
Cu	0.004
Al	0.005
Sn	0.002
Cd	0.002
Zn	Bal

TABLE 2
The chemical composition of commercially pure aluminum

Element	Wt %
Fe	0.09
Si	0.05
Cu	0.005
Mg	0.004
Ti	0.004
V	0.008
Zn	0.005
Mn	0.001
Na	0.005
Al	Bal.

The commercially pure aluminum was obtained from Jordan Electricity Authority in the form of bundles of wires. They were cut into small pieces and pickled by immersing them in 95% distilled water and 5% concentrated HCl to get rid of the oxide layer and other contaminations. Tool steel H13 of the composition shown in Table 3 was used in manufacturing the equal channel angular pressing die, ECAP. It was heat treated following the treatment cycle recommended by the suppliers, hardened and tempered to obtain a final hardness of 52 RC.

TABLE 3
Chemical composition of tool steel H13

Element	Wt%
C	0.45
Si	0.8
Cr	5.5
Ni	0.3
Mo	1.7
Cu	0.25
V	1.2
Mn	0.2
Fe	Reminder

2.2 Preparation of the Master Alloys

Three master alloys were used to obtain the different micro alloys namely: the ternary Al-5%Ti-1%B This alloy is used in aluminum factories as a grain refiner of commercially pure aluminum. It was obtained from ARAL (Arab Aluminum factory in Amman) in the form of rod about 10 mm diameter. The chemical composition of this alloy shown in Table 4.

TABLE 4
Chemical composition of the Al-4.9 %Ti-1%B ternary

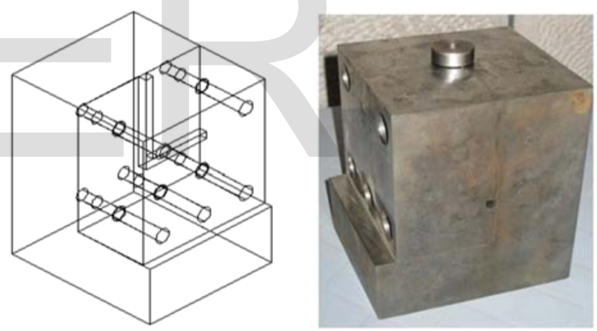
(a) (b)

Fig. 2. a) Schematic drawing of the ECAP die, and b) Photograph of the ECAP die.

2.3 Equipment and Experimental Procedure

The experimental procedure started by designing and manufacturing the ECAP die shown in figure 2.

3 Results and Discussion

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3.1 Effect of Mo addition on the metallurgical aspects of ZA22 grains refined by Ti +B after pressing by the ECAP process

Zinc aluminum alloys normally solidify in dendritic structure with large grain size which tends to affect their mechanical strength, toughness and surface equality. The addition of Mo to ZA22 has changed its structure from dendritic large grains structure into equ-axial with smaller grains .Its effect and the effect of Ti-B are explicitly shown in the photomicrographs of figure 3 (a),(b),(c)and (d). For ZA22, ZA22-Ti-B, ZA22-Mo and ZA22l-Ti-B-Mo, respectively. In general, it can be seen that addition of either Mo or Ti-B or both together resulted in refining of the structure, being more pronounced in case of T-B addition Fig. 3.b. Furthermore, it can be seen from figure 2c that the grains has gathered in colonies whereas in addition of both Mo and Ti+B petal like. Assessment of the effect of the addition of different grain refiners on the ECAP process is investigated through the autographic record of each micro alloy i.e. (punch load-punch displacement) from which the maximum pressing force is obtained.

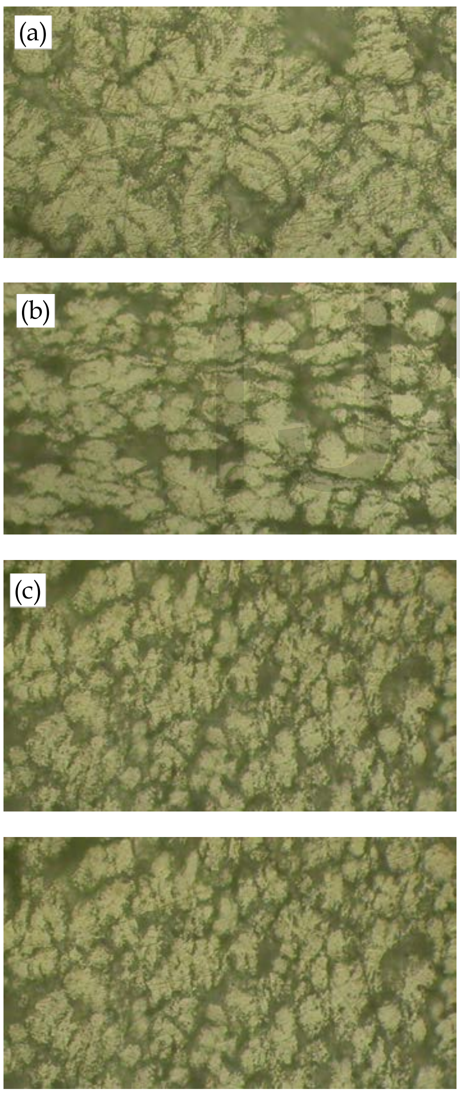

Fig. 3. : Photomicrographs of ZA22 and its Micro Alloys: (a) ZA22, (b) ZA22-Ti,(c) ZA22-Mo, (d) ZA22l-Ti-Mo, after ECAP process, X 500.

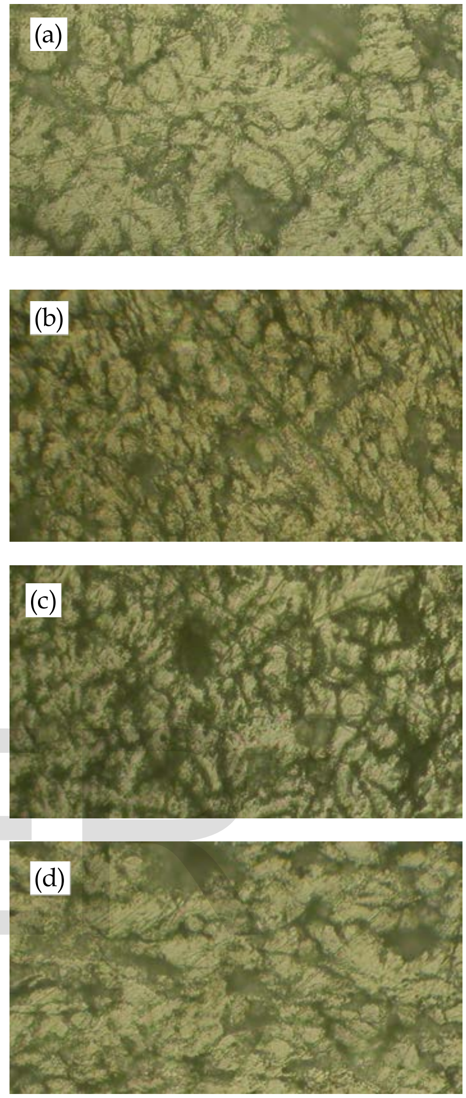

Fig. 4. : Photomicrographs of ZA22 and its Micro Alloys: (a) ZA22, (b) ZA22-Ti-B, (c) ZA22-Mo, (d) ZA22l-Ti-B-Mo, after ECAP process.

3.2 Effect of Mo addition on the metallurgical aspects of ZA22 alloy grain refined by Ti after ECAP process

The effect of addition of Ti or Mo alone or together on the microstructure is explicitly shown in the photomicrographs of figures 3 (a),(b),(c)and (d) for ZA22, ZA22-Ti, ZA22-Mo andZA22-Ti-Mo, respectively. It can be seen from figure 3 (b) that the addition of Ti to ZA22 s resulted in refining of its structure. .After ECAP it resulted in further refinement. Similar effect is produced by addition of Mo to the ZA22 after ECAP figure.3 (c) where further refinement occurred by the ECAP process. The best refinement was achieved by addition of both of them Ti-Mo after ECAP process, Figure 3 (d).

3.3 Effect of the ECAP process on the hardness and mechanical characteristics of ZA22 and its micro alloys

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It can be seen from the histogram of figure 5 that the ECAP process resulted in decreasing of the hardness of ZA22 and its five micro alloys. This is expected as a result of super plastic behavior and softening.

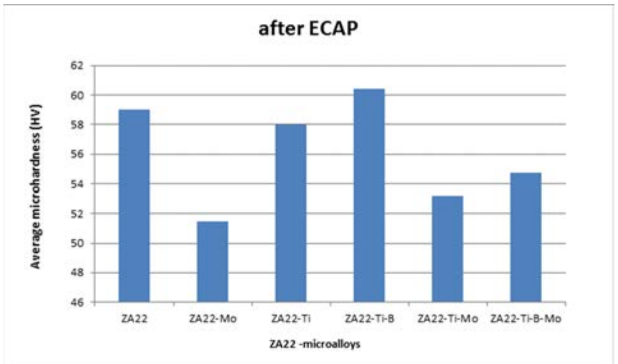

Fig. 5. Effect of Mo addition to ZA22 grain refined by Ti and Ti-B on its Vickers microhardness after pressing by ECAP.

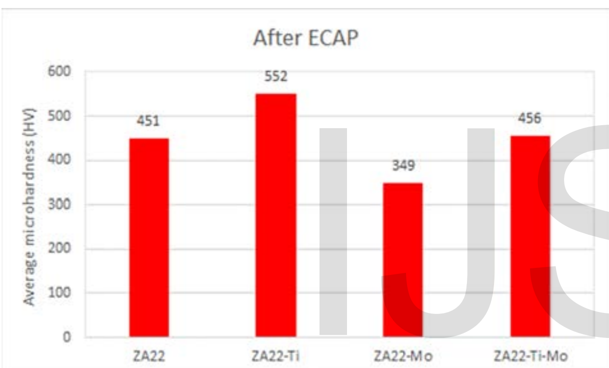

Fig. 6 (a). Effect of Mo addition to ZA22 grain refined by Ti on its flow stress.

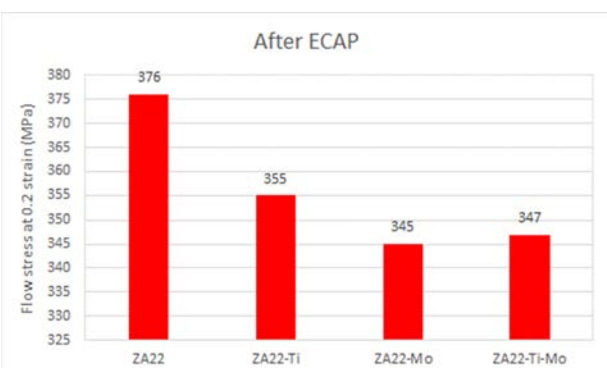

Fig. 6 (b). Effect of Mo addition to ZA22 grain refined by Ti-B on its flow stress.

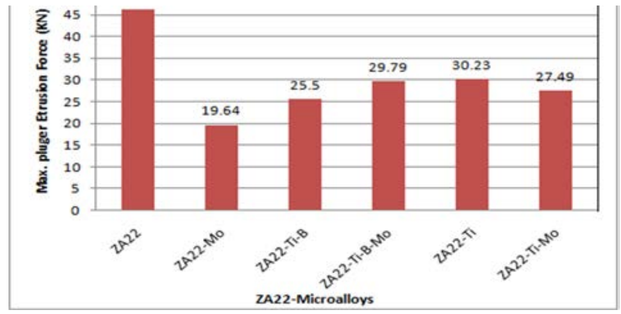

Fig. 7. Effect of molybdenum addition on the maximum ECAP force of ZA22 and ZA22 grain refined either by Ti or Ti-B

Micro Alloys	Flow stress (MPa) at strain=20%	Strain hardening index (n)	Strength coefficient (K) MPa	General equation of mechanical behavior
ZA22	376	0.617	1016	$\bar{\sigma}=861\bar{\varepsilon}^{0.566}$
ZA22-Mo	345	0.651	985.1	$\bar{\sigma}=985.1\bar{\varepsilon}^{0.650}$
ZA22-Ti	355	0.757	1199.5	$\bar{\sigma}=1199.5\bar{\varepsilon}^{0.757}$
ZA22-Ti	361	0.675	1069.3	$\bar{\sigma}=1067\bar{\varepsilon}^{0.675}$
ZA22-Ti-Mo	347	0.699	.37010	$\bar{\sigma}=1070.3\bar{\varepsilon}^{0.699}$
ZA22-Ti-B-Mo	318	0.719	1012.7	$\bar{\sigma}=1012.7\bar{\varepsilon}^{0.719}$

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Figure 6 gives comparison between the mechanical behavior of ZA22 and its five micro alloys namely ZA22-Ti, ZA22-Mo, ZA22-Ti- Mo, ZA22-Ti-B and ZA22-Ti-B-Mo for the as cast conditions and after ECAP process. From which it can be explicitly seen that the addition of either Ti or Mo or both Ti-Mo together resulted in decrease of the ZA22 mechanical behavior suggesting softening of the alloy microstructure. Comparison of the flow stress at 20 % strain of ZA22 and its different micro alloys is shown in figures 6 (a) and 6 (b).

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It can be seen from these two figures that the ECAP process has resulted in decrease of the flow stress at 20 % strain of the ZA22. The maximum decrease is 55.5 % and occurred in the ZA22-Ti micro alloy, followed by ZA22-Ti-B-Mo micro alloy with decrease of 28.9 %. It can be seen from the summary of the results of the mechanical behavior in figures 6 (a) and 6 (b) together with the mechanical characteristics of ZA22 and its five micro alloys in Table 5 after pressing by the ECAP process, it can be concluded that all the parameters related to the mechanical behavior decreased except the work hardening index, n which was increased.

It can be observed from the histogram of figure 7 that the Mo addition to ZA22 grain refined by either Ti or Ti-B resulted in reduction of the maximum ECAP force. The maximum reduction is 57.46 % at Mo addition followed by Ti-B addition with 44.77 % reduction and 40.46 % for Ti-Mo addition, 35.48 % for Mo-Ti-B addition and finally the least reduction is when Ti was added alone, being 34.5%.

Briefly the following two figures 8 and 9 illustrate explicitly the reduction of the maximum ECAP force by the addition of Mo to ZA22 grain refined by Ti or Ti-B either alone or both together. Also addition Ti-B or Mo alone or both of them together resulted in reduction of its consumed work through ECAP process, as shown in figure 9.

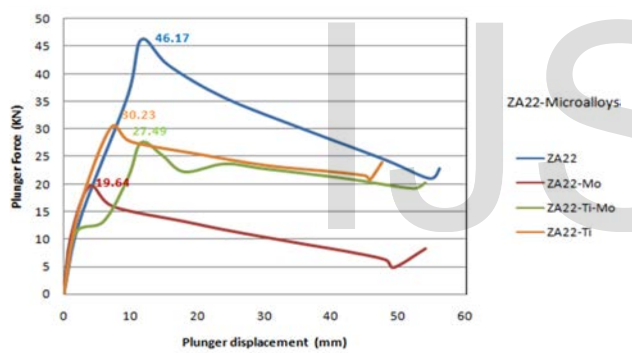

Fig. 8. Plunger force with the plunger displacement (ECAP autographic records) for ZA22 grain refined by Ti.

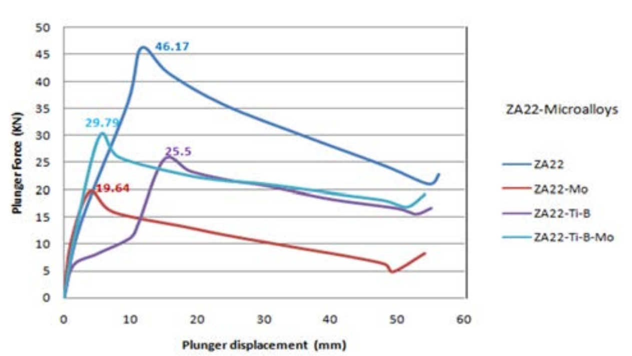

Fig. 9. Plunger force with the plunger displacement (ECAP autographic records) for ZA22 grain refined by Ti-B

Finally, it can be seen from the histogram of figure 10 that the addition of Mo to ZA22 grain refined by either Ti or Ti-B

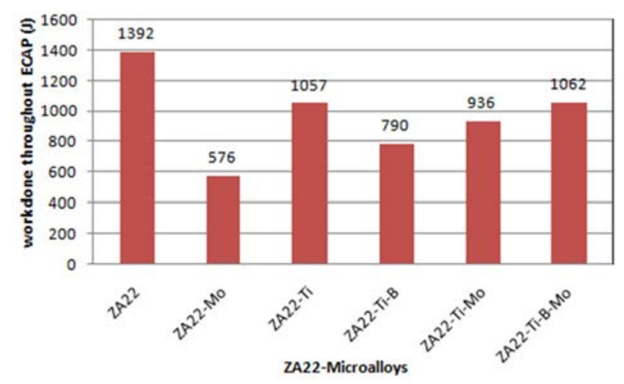

Fig. 10. The consumed work (J) throughout ECAP process for ZA22 and its micro alloys.

has resulted in decreasing of the consumed work by the ECAP process. This is expected as a result of super plastic behavior. The maximum decrease in the consumed work is 58.6 % in case of addition of Mo alone to ZA22 followed by Ti-B addition with 43 % decrease, then Ti-Mo by 32.8 % and finally by 24 % and 23.7 % in case o Ti and Ti-B-Mo respectively.

Conclusion

From the results obtained throughout this investigation the following points are concluded:

i) Addition of molybdenum, Mo, to the ZA22 alloy, resulted in reduction of its grains i.e. fining them.

ii) Addition of Mo to ZA22 grain refined by Ti or Ti-B resulted in increase of its micro hardness in the cast condition.

iii) Addition of Mo to ZA22 grain refined by Ti or Ti-B in as cast condition resulted in deterioration of its mechanical behavior i.e. its reduced the true stress-true strain (σ-ε) curve, flow stress where decreased by 22.6% at 20% strain was achieved in Mo addition, whereas it improved its work hardening index, n, and its ductility, i.e. improves formability and hence reduces the number of stages required for forming the alloy at large process strains in excess of the plastic instability strain.

iv) Addition of Ti to ZA22 resulted in improvement of its mechanical behavior i.e. its true stress-true strain (σ-ε) curve, increase of flow stress by 22.4 % at 20% strain was achieved, increase of work hardening index, n, by 18.75% but resulted in decrease of its ductility.

v) Addition of Mo to ZA22 or ZA22 grain refined by Ti or Ti-B resulted in decrease of extrusion force and energy at the same extrusion dimension specimen. This is attributed to the decrease in the mechanical strength in case of Mo addition to ZA22 or ZA22 grain refined by Ti or Ti-B. Similarly, it resulted in decrease of the work consumed per unit volume.

vi). The ECAP process resulted in grain refining of ZA22 and ZA22 grain refined by Ti or Ti-B as was illustrated in the micrographics pervious assessment.

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vii) The ECAP process resulted in decrease of hardness and flow stress of ZA22 and its micro alloys but resulted in increase of their strength factor, K and work hardening index n, i.e. improvement of their formability and reducing the number of stages required for forming at strain beyond the plastic instability and all its investigated micro alloys.

viii) Concluded in the last point is an indication of superplastic behavior in the ZA22and its different micro alloys at room temperature. Previously, this alloy and the ZA27 alloy cannot reach superplastic behavior except at temperature in the range of 300℃ - 400℃ this achievement makes the forming of this alloy cost-effective.

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