Effect of Mo Addition on the Effect of Mo Addition to ZA22 Alloy Grain Refined by Ti on its Metallurgical and Mechanical Characteristics

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Abstract— Since the production of zinc alloys with higher aluminum contents, they were getting increasingly in demand in industrial and engineering applications of these newly developed alloys have high strength and hardness, improved creep and wear resistances and lower density. However, they have the disadvantage in solidifying in dendritic structure with large grain size which adversely affects their mechanical strength, toughness and surface quality. Hence, it is of prime importance to grain refine their structure to avoid these discrepancies. Grain refinement of metals and alloys by some rare earth elements has engaged the materials researchers for the last seven decades and is now well established. In this paper the effect of molybdenum addition to zinc 22% wt. aluminum grain refined by Ti was carried out. The effect of the addition on the metallurgical and mechanical characteristics of the alloy was investigated and the obtained results are presented and discussed.

Index Terms— Grain refinement, Zinc 22%aluminum alloy, ZA22 Titanium, Molybdenum, Titanium, Molybdenum, Cast condition, Metallurgical, Mechanical characteristics.

1 Introduction

Zinc-based alloys in general and ZA22 in particular have high strength and hardness in addition to good wear and corrosion resistances. They demonstrate a great potential for various applications. They have been used in many applications such as mobile phone antennae, portable computers, disk drives, radiofrequency circuits, transformer cores, high quality filters, precision interlocking gears, heat sinks, shutter mechanisms in cameras, and many other electrical and electronics consumer applications, [4]. Moreover, they are widely used in the automobile and aeronautical industries. For the latter where the parts are subjected to multidirectional service requests, for example they must provide an optimal combination of mechanical strength, plasticity, toughness, fatigue resistance and good resistance to stress corrosion cracking, SSC, [5]. Their demand has increased in the last few decades after the major advancement in the zinc industry in developing zinc alloys with higher aluminum contents. These new zinc– aluminum based alloys have high strength and hardness, improved creep and wear resistance and lower density. Although they were developed originally for sand and gravity casting, they are now being used in growing amounts for pressure die casting. Because they possess excellent casting and mechanical properties, have been increasingly used to replace traditional alloys such as aluminum, bronze, brass and cast iron in many industrial applications, [6]. Moreover, the mechanical properties of zinc-based alloys make them attractive substitutes for cast iron and copper alloys in many structural and pressure-tight applications. These zinc-based alloys have a distinct cost advantage over copper-based alloys, [7]. Against all these advantages they have a common disadvantage that they solidify form the molten liquid state into dendritic structure with large grain size which tends to adversely affect their mechanical characteristics and surface quality. It is therefore very necessary to grain refine their grains and modify their structures to avoid the discrepancies of solidification. Different methods are available for grain refinement of metals and alloys e.g. grain refinement by rare earth elements and severe plastic deformation, SPD, methods. The SPD is relatively a new technique and beyond the scope of this paper. The grain refinement by rare earth elements was discovered by Cibula in 1950 and is now well established and the literature on the subject is voluminous, Refs., [3-16]. Review of its applications to aluminum and its alloys is reviewed by the author in 2001, [11]. Although grain refinement has been in use for grain refinement of aluminum and its alloys it was not applied to zinc aluminum alloys except after mid-seventies, [4]. Since then researchers of material science started to investigate the effect of addition of different elements to different zinc aluminum alloys and their effect on the metallurgical and mechanical characteristics, [4-16]. Despite the number of published papers on the subject, it is far from being complete and further investigations required. Review of the grain refinement of zinc based alloys is reported in Ref., [12]. The different methods of grain refinement of metals and alloys are recently published in, Ref., [13]. Zinc-based alloys have high strength and hardness, so they are very good materials for manufacturing parts which needs to be machined, pressed and stamped. They have been used in many applications, including mobile phone antennae, portable computers, disk drives, radiofrequency circuits, transformer cores, high quality filters, precision interlocking gears, heat sinks, shutter mechanisms in cameras, and many other electrical and electronics consumer applications, [1 and 2]. They are widely used in aeronautical industry where alloys are subject to multidirectional service requests as they must provide an optimal combination of mechanical strength, plasticity, toughness, fatigue resistance and good resistance to

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stress corrosion, [5]. The major advancement in the zinc industry over the past years has been the development of zinc alloys with higher aluminum contents. These new zinc– aluminum based alloys have high strength and hardness, improved creep and wear resistance and lower density, and, although developed originally for sand and gravity casting, they are now being used in growing amounts for pressure die casting. These alloys, which possess excellent casting and mechanical properties, have been increasingly used to replace traditional alloys such as aluminum, bronze, brass and cast iron in many industrial applications, [6].

2 Materials, Equipment and Experimental Procedures

2.1 Materials

Different materials were used in this research work namely: granular pure zinc, high purity aluminum, titanium, and molybdenum powders. The chemical compositions of the granular zinc and aluminum as determined by the scanning electron microscope, SEM, are shown in Tables 1 and 2 respectively. 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) for five hours to get rid of the oxide layer.

These materials were used in manufacturing the base alloy, ZA22, the binary 10.4 % Ti and the binary Al-7.6 %Mo master alloys. These were then used to prepare the different ZA22 microalloys. Their chemical compositions as determined by the scanning electrical microscope are shown in Table 3.

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.

It is worth menioning that the base alloy, the binary master alloys and the different microalloys were prepared following the same procedure as reported in Ref., [16].

TABLE 3
Chemical composition of the different ZA22 microalloys

No	Alloy	Mo%	Ti%	B%	Al%	Zn%
1	ZA	0	0	0	21.91	Ball
2	ZA-Mo	0.094	0	0	21.98	Ball
3	ZA-Ti	0.15	0	0	21.97	Ball
4	ZA-Ti-Mo	0.094	0.141	0	21.95	Ball
5	ZA-Ti-B	0	0.048	0.0096	21.99	Ball
6	ZA-Ti-B-Mo	0.047	0.047	0.0093	21.96	Ball

2.2 Equipment and experimental procedures

The experimental procedure was started by manufacturing the base alloy, ZA22, followed by manufacturing the binary Al-10.7%Ti and Zn-6.47Al alloy which are used for preparation of the different microalloys namely ZA22-Ti, ZA22-Mo and ZA22-Ti-Mo in addition to the main ZA22 alloy. After the preparation, their chemical composition was determined using the scanning electron microscope, SEM. Followed by preparing the main basic alloy, ZA22 followed by manufacturing the master alloys which were then used in manufacturing the different microalloys. The following tests were carried out on specimens of appropriate dimensions: Vickers micro-hardness, HV, optical microscopic examination for determining the mechanical behavior the, compression test, the grain size and the general microstructure of the base alloy, master alloys and each microalloy. The compression tests were performed on the Instrun Universal testing machine of 250 KN capacity at 10mm/minute cross head speed and the autographic records obtained for each specimen. The autographic records were used for determining the mechanical behavior.

Finally, the metallurgical, microhardness and mechanical tests were carried out on appropriate machined specimens form ZA22 and each of its microalloys. Their metallurgical examination was carried out on 10 mm diameter cylindrical specimens cold mounted on Araldite, polished with successive grits of silicon carbide papers and polished with 1 micron diamond paste. Finally each specimen was etched in a solution consisting of: 100ml distilled water, 20 grams CrO_3, 1-5grams Na_2SO_4 for 20 seconds. The general microstructure was examined using an optical microscope.

2.3 Metallurgical examination

To determine the grain size and the general microstructure of ZA22 and its mcroalloys, cylindrical specimens of 10 mm diameter and 10 mm height were machined from each, mounted on araldite, then ground using successive grit numbers of silicon carbide paper, followed by fine polishing with one micron diamond paste, and finally etched using (5% HNO3 + 3% HCl+4% HF+88% H2O) solution for 20 seconds and the Metallurgical examination using was carried out using the optical microscope type (NIKON108). Finally, the Photomicrograph of each specimen was obtained at a magnification of X500.

2.4 Mechanical tests

The mechanical behavior of the base metal, ZA22 and all its microalloys. Cylindrical specimens of 10 mm diameter and height were machined from ZA22 and each micro alloy for determining their mechanical behavior using the autographic records of the compression tests which were carried out on the Instrun Universal testing machine at cross head speed of 10 mm/ minute.

The Vickers micro harness tests were carried out using the digital micro hardness tester (model HWDM-3). Ten readings were taken on the surface of each specimen from which the average HV microhardness was determined.

3 Results and Discussion

3.1 Effect of Mo addition on the metallurgical aspects of ZA22 grain refined by Ti

Examination of the general microstructure of the etched specimens it appeared that there are not clear boundaries among the grains; hence it was not possible to determine the grain size quantitatively due to the difficulty in counting the grains using intersect line method for ZA22 and its microalloys, although different etching times were tried. Therefore, only qualitative description is possible. The effect of addition of Ti or Mo alone or together on the microstructure is shown in the photomicrographs of Figs.1(a),(b),(c) and (d) of ZA22, ZA22-Ti, ZA22-Mo and ZA22l-Ti-Mo, respectively. It can be seen from figure 1(b) that the addition of Ti to ZA22 resulted in refining of grains, the grains are smaller in size and the distance between them is larger. In figure 10 (c) that addition of Mo to ZA22 resulted in refining the grains as columnar type structure, also the addition both Ti and Mo to gather resulted in further more refining than Ti or Mo as alone.

Effect of Mo addition on the hardness and mechanical characteristics of ZA22 Grain refined by Ti. It can be seen from the histogram of Fig.2 that addition of either Ti or Mo alone or both together resulted in enhancement of the hardness. The maximum increase is at Ti addition being 5.4 % followed by Mo addition (2.5 %) and very little increase, 0.7 % when both are added together.

Figure 3 shows the effect of Mo addition on the general mechanical behavior of ZA22 and the ZA22 grain refined by Mo and Ti micro-alloys represented by the true stress versus true strain curve of each of them. It can be seen from these curves that addition of Mo to ZA22 resulted in deterioration of its general mechanical behavior, e.g. a reduction in flow stress at 20% strain from 451 MPa to 349 MPa has occurred, whereas addition of Ti either alone or in the presence of Mo resulted in enhancement of its mechanical behavior. The enhancement is being more pronounced in the case of addition of Ti alone. These are explicitly illustrated from the results shown in Table 6 where the strength coefficient of the ZA22 has decreased by (7.4%) in case of Mo addition but increased by 37% in case of Ti addition and 14% by adding Ti+Mo.

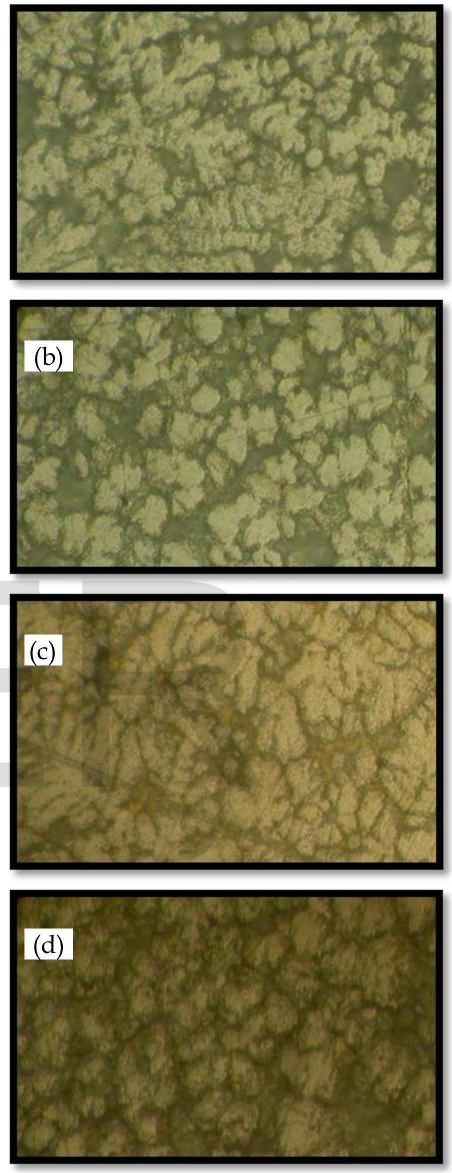
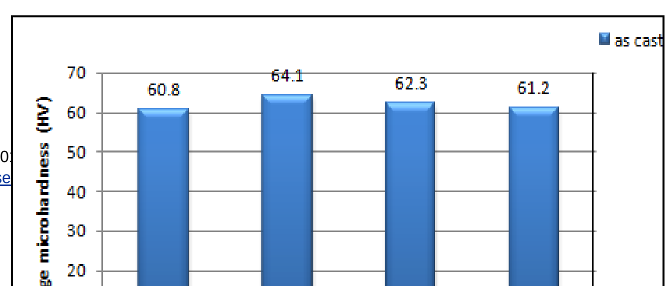


Fig. 1: Photomicrographs of ZA22 and its Micro Alloys: (a) ZA22, (b) ZA22-Ti, (c) ZA22-Mo, (d), ZA22-Ti-Mo

Regarding the work hardening index, it can also be seen from Table 7: that it has increased by 29% in case of Mo addition followed by 19.3% in case of Ti-Mo addition and finally by 18.75% in case Ti addition. The mechanical properties are given in Table 3.



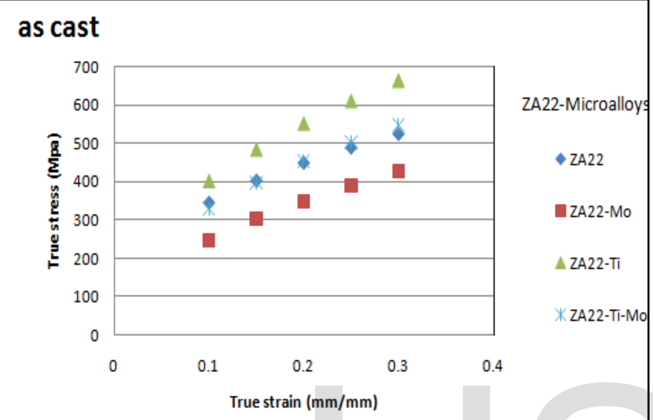


Fig.3. Effect of Mo addition on the true stress-- true strain of ZA22 and its different microalloys

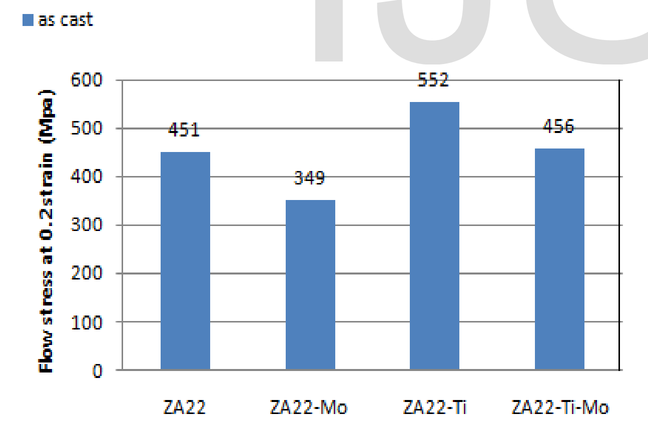


Fig.4. Histogram of the flow stress at 0.2 strain of ZA22 and its different mcroalloys

4 Conclusion

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

i). Addition of Mo to ZA22 or to ZA22 grain refined by Ti resulted in a little increase of its Vickers microhardness with a maximum value of 5.26% in case of Ti addition alone and of a minimum value of 0.66% in case of Mo addition to ZA22 grain refined by Ti.

ii). Addition of Mo to ZA22 or ZA22 grain refined by Ti in deterioration of its mechanical behavior and very slight enhancement when they Mo was added to ZA22 grain refined by Ti. However, when Ti was added alone a very pronounced increase in its mechanical behavior represented by 37.6% increase in its strength coefficient and 22.4% in its flow stress at 20% strain. Furthermore, an increase of 28.9 % in its strain hardening index.

iii). The increase in its strain hardening index improves its ductility and formability. This in turn will reduce the number of stages required for forming the alloy at large process strain, in excess of the plastic instability strain which makes the alloy cost effective and widens its applications in industry.

iv). Addition of Mo to ZA22 refined by Ti resulted in reduction of its flow stress and strength coefficient by 22.62% and 7.4% respectively but resulted in pronounced increase in its strain hardening index by 37.1%. This, as mentioned in the previous point makes the alloy cost effective and widens its applications in industry.

TABLE4
MECHANICAL CHARECTERISTICS OF ZA22 AND ITS DIFFERENT MICROALLOYS

Micro Alloys	Flow stress (MPa) at strain= 20 %	Strain hardening index (n)	Strength coefficient (K) MPa	General equation of mechanical behavior
ZA22	451	0.384	836.4	$\bar{\sigma} = 836.4\varepsilon^{0.384}$
ZA22-Ti	552	0.456	1150.8	$\bar{\sigma} = 1150.8\varepsilon^{0.456}$
ZA22- Mo	349	0.495	774.5	$\bar{\sigma} = 774.5\varepsilon^{0.495}$
ZA22-Ti-Mo	456	0.458	953	$\bar{\sigma} = 953\varepsilon^{0.458}$

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