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THE EFFECT OF HOLMIUM ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF LIGHT METAL ALLOY

R. Ahmad[*a], M. H. S. Rashid[a], Sulaiman Hasan[a], Z. Harun[a], M. S. Yusof[a], Suhaimi Hassan[a], M.M. Rahman[b]

[a]Department of Manufacturing Engineering, Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussein Onn Malaysia, Malaysia, 86400 Batu Pahat, Johor
[b]Faculty of Mechanical Engineering, Universiti Malaysia Pahang, Pekan, Pahang, Malaysia
E-mail: roslee@uthm.edu.my

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Abstract

The thesis project investigates the effect of Holmium addition on the microstructure and mechanical properties of cast ZRE1 magnesium alloy. In the advancement of automotive and aerospace industries, the next generation of light metal alloy is magnesium due to its manufacturing abilities and lightweight material. The main limitation of Mg alloys is the ability to improve its mechanical properties. Rare earth elements were used as alloying elements for improving the mechanical properties and producing a new Mg-RE alloy with modified structure and strength. In this studies, it demonstrates the addition of RE at specific amount, which could be considered as main alloy element that may lead to extend limitation of RE application. The amount of Holmium (Ho) at 0.2, 0.4 and 0.6 wt. % were added separately to ZRE1 magnesium alloy. The Optical Microsope, FESEM coupled with EDX, and XRD were used to investigate the microstructure and mechanical properties, including tensile and hardness tests. The results showed that the Ho content at 0.2wt. % increased the ultimate tensile strength and yield strength compared to others Ho composition. Finally, the hardness value was increased and the additive had a significant improvement of mechanical properties, thus the ZRE1 magnesium alloy has been improved with Holmium addition.

Keywords-- Holmium, Magnesium alloy, microstructure, mechanical

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INTRODUCTION

The characteristics of magnesium alloy are lightweight and it has high weight to strength ratio and with low in density. It can be seen a lot of usage in structural and non-structural applications. Magnesium has relatively good in electrical conductivity and thermal conductivity, with high thermal conductivity values, and very high damping capacity, which is the ability to absorb elasticity vibrations [1]. It mostly used in applications of die casting manufacturing, which is applicable automotive, industrial, materials handling, and aerospace equipment. The applications used in automotive is to build the air intake grills, brake pad, support beam, and car body. For automotive industry, it is used to operate high speeds parts and it must be lightweight to lower the force of inertia and momentum. Next, in the materials handling it includes on the grain shovels and dock plate. However, the magnesium is most important in aerospace development due to its lightweight applications, which is applicable in the bullet train, aeroplane's beam, helicopters and gearbox for commercial and military aircraft [2,3]. The magnesium is well known for its alloys that is widely used in automotive and it can reduce the motor vehicles weight.

Magnesium with rare earth zinc zirconium alloys has a good characteristics in casting due to the addition of rare earth elements that promotes low micro porosity and improve fluidity. The properties of Mg-RE alloys are enhanced by adding zirconium to refine grain size and further increase in strength occurs if zinc is present as well [5]. In solidification process, thermal analysis technique is a very useful tool to investigate the characteristics of alloys

MATERIALS AND METHOD

The casting of specimens used a permanent steel crucible mould steel castings. The alloy is prepared by adding Holmium (Ho) with different percentage (0.2, 0.4, 0.6 wt. %) separately into cast ZRE1 magnesium alloy. Testing and analysis to the specimen include microstructure and mechanical properties. The microstructure analysis was focusing on the grain size and phases formed and for mechanical properties, the focus was to obtain tensile and hardness properties. The result obtains from microstructure was correlated with mechanical properties result. The chemical composition of the commercial ZRE1 magnesium alloy was shown in Table 1.

Table 1. The chemical composition of ZRE1 magnesium alloy

Element	Magnesium, Mg	Zinc, Zn	Rare earth, RE	Zirconium, Zr
Percentage (wt. %)	Remaining	2.0-3.0	2.5-4.0	0.4-1.0

The Magnesium ZRE1 alloy was melt in electrical resistance furnace with a steel crucible. The 0.2, 0.4, and 0.6 wt. % Holmium addtion were added separately in order to measure the microstructure and mechanical properties of each of specimen. In order, to mix holmium (Ho) with the melted Magnesium ZrRE1 alloy, the rare earth additive must be cut into small pieces and was added after the base alloy melt at approximately 730°c.

Then, fiberfrax was used to close the opening of the mould for directional radial solidification process and to prevent the heat convection to the surrounding air. The specimen from the solidification process was cut into a small specimen in size of 15x15x10mm in diameter and then used for metallographic examination.

The specimen is prepare for microstructure analysis by wet grinding on a silicon carbide papers 500/800 and a final grinding is done by 1200/2400/4000 grit papers, water used as a cooling fluid, follow by rough polishing with a diamond paste of 3 & 1 microns and the fine polishing with 0.3 micron α-alumina. Then, it was rinsed with distilled water to wash of any residue on the specimen following by dying with compress air. Finally, the specimen etched with 3% nitric acid in ethanol and kept it dry without touching the specimen.

Structure

Optical micrographs were taken from base alloy and based alloy treated with Holmium (Ho) as shown in Figure 1 respectively. From the microstructure, it can be seen that the microstructure consist of α-Mg matrix and secondary phase crystallised along the grain boundaries. It is clears that the addition of RE has changed the microstructure of base alloy. The massive morphology at the between grain show as the second phase grain boundary.

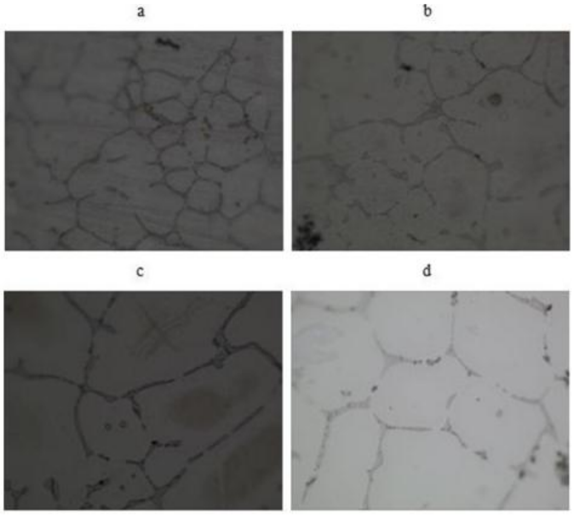
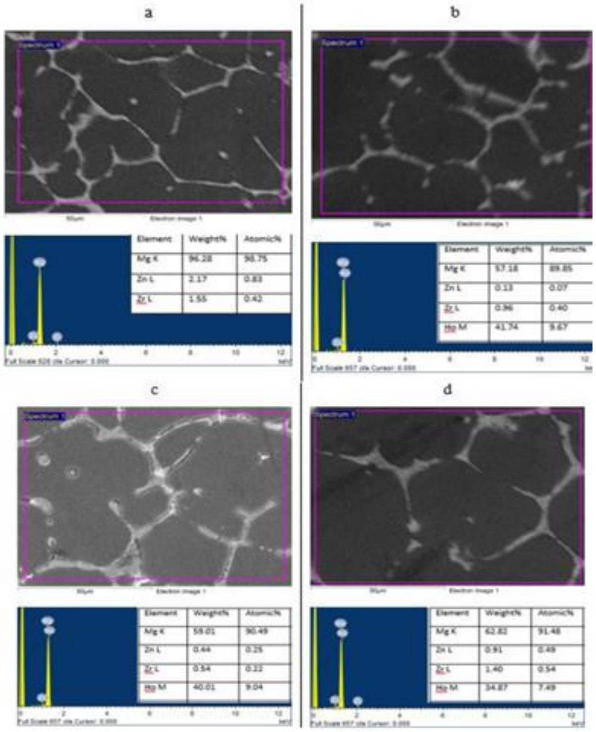


Figure 1. Microstructure image of (a) base alloy; (b) 0.2wt.% Ho; (c) 0.4wt.% Ho ;(d) 0.6wt.% Ho

For XRD analyser were performed on 4 specimen to identify the phases that existing in the ZRE1 base alloy and treated with Holmium (Ho) were shown in Figure 2. For the base Zre1 alloy it can be clearly show that it consist the α-Mg matrix phase and Mg-Zn secondary intermetallic phase. The α-Mg matrix phase was found as hexagonal structure and its crystallographic parameter are (a 3.20936- b 3.20936- c 5.21120). These crystallographic parameter has a similar phases that obtained by others RE in Mg-Zn-Zr alloy composition [6]. However, XRD analyser detected some amount of MgZn and ZnZr phases which has been dissolved inside Mg matrix of base alloy [7]. The Zn_2Zr has a cubic crystal structure with a (a 7.39580- b 7.39580- c 7.39580) of crystallographic parameters.

In the addition of Holmium (Ho) onto ZRE1 alloy, the phases that has been detected within the sensitivity limit of XRD machine at the same peak point of the secondary phase of base alloy may be indicate a new secondary phase that has been transformed of base alloy. The new MgZn intermetallic phases has a cubic crystal structure with a crystallographic parameters of (a 8.53000- b 8.53000- c 8.53000). A HoZn phase has been found at the same peaks of MgZn, which is it shows that both phases were combined together and crystallised at grain boundaries. It is similar to the previous studies result, where the RE were formed as secondary intermetallic phases in MgZnRE phase [12]. The solid solution of RE atoms and the second phase of hardening due to Mg-Zn-RE intermetallic compound are for strengthening the Mg alloys [13]. The addition of RE produce an intermetallic phases were formed to improve the strength of alloys and can lead to improve in grain boundary. It produced where the HoZnphase and MgZn phase were crystallized in grain boundaries and the atomic bonding between the intermetallic secondary phases and the matrix interface which leads by obstructing dislocation slip of Mg-Zn-RE alloys that can improve its strength.

In Figure 2 shows the result from FESEM micrographs and EDX micro analyser of ZRE1 base alloy (a), treated with content of Holmium (Ho) at 0.2 wt. % (b), 0.4 wt.% (c) and 0.6 wt. % (d). FESEM shows an observations of the base alloy microstructure which is consist of α-Mg grains in the spectrum which is it has been surrounded by the crystallisation of second phase along the grain boundaries and a massive morphology.



(a)

Element	Weight%	Atomic%
Mg K	96.28	98.75
Zn L	2.17	0.83
Zr L	1.55	0.42

(b)

Element	Weight%	Atomic%
Mg K	57.18	89.85
Zn L	0.13	0.07
Zr L	0.96	0.40
Ho M	41.74	9.67

(c)

Element	Weight%	Atomic%
Mg K	59.01	90.49
Zn L	0.44	0.25
Zr L	0.54	0.22
Ho M	40.01	9.04

(d)

Element	Weight%	Atomic%
Mg K	62.82	91.48
Zn L	0.91	0.49
Zr L	1.40	0.54
Ho M	34.87	7.49

Figure 2. FESEM micrographs and EDX microanalysis of (a) base alloy, (b) base alloy treated with 0.2 wt. % Ho, (c) base alloy treated with 0.4 wt. % Ho, (d) base alloy treated with 0.6 wt. % Ho

The EDX spectrum regions showed composition of α-Mg matrix and the secondary phase of base alloy, the result showed that the second phase was composed of magnesium, zinc and small amount of zirconium. For the following ZRE1 treated with holmium at 0.2 wt. % in Figure 4.4-b showed two intermetallic phases crystallised along the grain boundaries, the EDX results showed that the phases consists of Mg-Zn-Zr-Ho phase this means that Ho combined with the intermetallic phase and form a new phase which is detected in XRD as HoZn phase. Moreover, the Mg-Zn-Ho intermetallic second phase is detected in the spectrum as the Ho atomic composition at 9.67wt. %. There are studies that confirm the formation of Mg-Zn-RE phase which is included rare earth element and combined with Mg and Zn will form new Mg-ZN-RE phase [8].

The addition of Ho has significant effect on UTS at 0.2 wt. % then decreased at 0.4 and 0.6 wt. % Holmium addition. The UTS of ZRE1 base alloy and ZRE1 treated with Ho at 0.2wt. % were obtained 114.69 Mpa and 116.97 Mpa respectively, then at 0.4 and 0.6 wt. % Ho addition it decreased linearly until 103.89 Mpa.

In addition, increasing the amount of Ho content to 0.2 wt. % will lead to increase the volume fraction of the secondary intermetallic phase and ultimate strength will improved as well as yield strength. The strengthening of alloy will not affect until there are some changes in size, shape, property, and amount of rare earth addition element onto the base alloy. The yield strength slightly increased at the same addition of Ho content at 0.2 wt. % which it has obtain 69.985 Mpa compared to 64.349 Mpa for ZRE1 base alloy. As the Ho content increased the yield strength has slightly decreased at 0.4 wt. % then increase back at 0.6 wt. %, the yield strength improve by 65.691 Mpa due to the decreasing of grain boundary and volume fraction. The yield strength is represent as the ductility of the alloy [18]. Ho content has led the reduction on the alloy elongation (mm) showed the results in Figure 4.11, the base alloy has obtain the highest elongation at 3.88 mm due to its grain boundary. For the holmium addition on the ZRE1 magnesium alloy with content at 0.2, 0.4 and 0.6 wt. % it has linearly decreased due to its closely packed grain boundary and high in volume fraction of intermetallic phase. These addition has been obtained an elongation starting 3.25, 2.61 and 2.17 mm for the treated ZRE1 base alloy with holmium respectively. Alloying element on the Mg alloys can effects its mechanical properties, furthermore, by improving on grain refinement, age hardening, dispersion hardening and solid solution it can obtained the new strength of cast magnesium [9].

Table 2. The Summary of the microstructure and mechanical properties of base alloy and base alloy treated with Holmium addition

Alloy	Grain size/ µm	Volume fraction/ %	UTS/ Mpa	YS/ Mpa	El/mm	Hardness/ HV
ZRE1	40.3	29.1	114.69	64.389	3.88	59.6
ZRE1-0.2wt. % Ho	48.5	37.4	116.97	69.985	3.25	62.4
ZRE1-0.4wt. % Ho	53.6	42.2	110.87	64.062	2.61	63.8
ZRE1-0.6wt. % Ho	55.4	49.6	103.89	65.691	2.17	65.3

From Table 2, the level content of Ho to 0.6 wt. %, the hardness showed the maximum deflection at 65.3 HV it may from the change of size in volume fraction intermetallic secondary phase. In hardness, the increase of volume fraction of secondary phase can lead to improvement in hardness. The increase of grain size, Volume fraction and the distribution of intermetallic phase are strongly will improve the mechanical properties of Mg alloys [12].

CONCLUSIONS

The addition of holmium has affect on microstructure and mechanical properties on ZRE1 magnesium alloy have been investigated. The rare earth holmium at low concentration which is at 0.2 wt. % has the most effective on the solidification parameter and grain refinement compared to 0.4 and 0.6 wt. %. The addition of Ho alloying element result to an increase in the volume fraction of intermetallic compounds, and its α-Mg is the primary grains which became more surrounded by the network of Ho element that can lead to more strong grain refinement. The addition of Ho led to form an effect to the MgZnRE phase which the Zr almost dissolve in the α-Mg matrix. An intermetallic phase plays an important role in improving the mechanical properties and for phase identification in order to understand its strengthening mechanism of the modified alloy. Holmium addition has became more effective on the ultimate tensile strength and yield strength which it has improved the treated ZRE1 magnesium base alloy. But for the elongation of the alloys the holmium addition has been reduce its capability compared to base alloy. The hardness value of the alloys increased as the addition of holmium content increases. The maximum hardness value is achieve at 0.6 wt. % Ho compared to the others holmium contents. These addition has showed improvement in hardness value and tensile strength. The mechanical properties of magnesium alloys are strongly affected by the addition of rare earth element in term of microstructure which is grain size, volume fraction and distribution of intermetallic phase.

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