Research Progress in Mechanical and Manufacturing Engineering Vol. 1 No. 1 (2020) 101-106
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RPMME

Homepage: http://penerbit.uthm.edu.my/periodicals/index.php/rpmme
e-ISSN : 2773-4765

Review of The Effect of Erbium and Neodymium on Microstructure and Mechanical Properties of Magnesium Alloy

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DOI: https://doi.org/10.30880/rpmme.2020.01.01.013
Received 28 Sept 2020; Accepted 29 Oct 2020; Available online 10 November 2020

Abstract: For this study, the effect of the rare earth element erbium (Er) and neodymium (Nd) on the microstructure and mechanical properties of the Mg alloy investigated. The case study method performed by referring to previous research and journal articles. In the references, the experiments were performed by using optical microscopy (OM) and scanning electron microscopy (SEM) with electron dispersive spectroscopy (EDS) showed the erbium and neodymium altered the grain size of the alloys. The grain size of the alloys by observation on optical microscopy promised a grain refinement. SEM/EDS results showed that Er and Nd addition gave a new formation of intermetallic phases along the grain boundaries and dissolved into the magnesium matrix. Both additives improved the ultimate tensile strength (UTS) and the hardness value of the Mg-Zn base alloys.

Keywords: Mg Alloys, Erbium, Neodymium, Microstructure, Mechanical Properties

1. Introduction

Magnesium alloys are alloys in which magnesium (Mg) is the predominant metal. The typical alloying elements are copper, aluminum, manganese, silicon, tin, and zinc. Magnesium are preferred as the weight- reduction material from its overall strength and the vibration damping capacity is also beneficial in application in which the internal forces of high-speed components must be reduced. Mostly the material being applied in aircraft and aerospace field, automotive parts and electronics appliances [1]. Zinc (Zn) is generally alloyed with aluminium, zirconium, rare earths, or thorium to deliver precipitation-hardenable magnesium composites having great quality. Otherwise, Rare earth (RE) metals are included into the Mg alloys either as mischmetal to decrease the expenses on manufacturing. Augmentations of the rare earths increment the quality at raised temperatures. They additionally diminish weld splitting and porosity since they are thinning the solidifying scope of the composites.

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AZ91 and AM50 are commonly used as the commercial magnesium alloy in the industry due to its outstanding mechanical properties and good castibility that limited to temperature below 120°C. In the previous study, the as-cast microstructure of magnesium ZRE1 alloy consists of α-Mg matrix and a $(Mg, Zn)_{12}RE$ intermetallic phase crystallized along the grain boundaries [2]. Erbium (Er) is a RE that dissolve in Mg (32.7 wt.%) at temperature of 584°C [3]. Add up erbium into a Mg–Zn–Zr alloy improves the deformability of the latter and prompts to the development of a fine and uniform microstructure. Moreover, erbium can increase the thermal stability and improve the mechanical properties of the alloy structure. Neodymium additions to magnesium have been shown to improve mechanical properties through precipitation and solid solution hardening. Addition of RE as a mixed metal can have the same effect as adding a single rare earth to the microstructure.

However, the addition of different RE into Mg-Zn system have different behaviours regarding to their microstructure and mechanical properties. Thus, the actual type and composition of RE addition is compulsory when accrediting the effect of RE addition to the alloy properties. In the present study, the microstructure and mechanical properties of Mg-Zn base alloy or magnesium Elektron ZRE1 alloy with addition of erbium and neodymium are identified.

2. Selection of References

The research method used for this study was case study by referring to past research and articles view. The selection of references were based on their objectives as similar to this study's objectives with other criteria such the year of publication, types of alloys used and type of experimental procedure conducted. All the publication for the selected references were taken for past ten (10) years from present and the type of the alloys used were mostly prioritized on the Mg-Zn system alloys with addition of Er and Nd as the scope of the study was pointed on. For type of experimental procedure, the case study review was mainly focused to the microstructure and mechanical properties of the specimens with proper testing and laboratory analysis by using the proper instruments.

2.1 Publication by year

The selected references were chosen in between year 2012 to 2017 with various sources such articles, journal articles and previous thesis. The objective of the study for all references were mostly related to this study and they were reliable as the references from the literature review. In Table 1 shows the distribution of the references by year with other descriptions; authors and type of references.

Table 1: Distribution of published references in year

No.	Author	Type of reference	Year
1	Shegaff. Z.M.	Thesis	2017
2	Farahin N.	Thesis	2017
3	Wang Jing, Liu Ruidong, Dong Xuguang, Yang Yuansheng	Journal article	2013
4	Xu Chunxiang, Wang Xing, Zhang Jinshan, Zhang Zhaoguang	Journal article	2014
5	M. Vlcek, J. Cizeka, B. Smola, I. Stulikova, I. Prochazka, R. Kuzel, A. Jager, P. Lejcek	Article	2012

2.2 Type of alloys

Magnesium alloys with Mg-Zn alloy system was preferred in this study as they were similar to magnesium Elektron ZRE1. Other magnesium alloys were plausible as long the main composition of the base alloy was magnesium (Mg) and zinc (Zn) element. From the collected references, the experimental procedure runs with the addition of RE into the base alloy were arranged by the element of rare earth used such erbium (Er) and neodymium (Nd) with different number of specimen and weight percentage (wt.%).

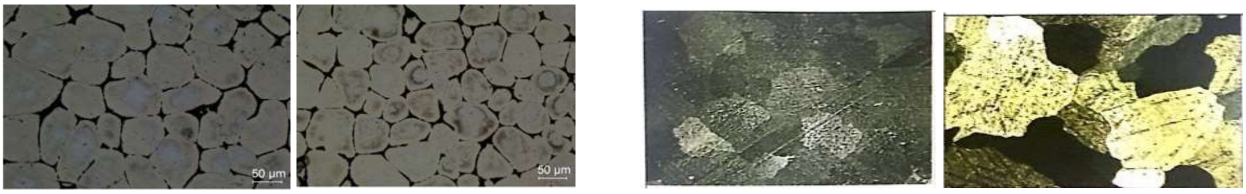
2.3 Analysis review and experimental procedure

The case study review was directly to the objectives of the study on analysis of the microstructure and mechanical properties of the base alloy after the addition of RE. Furthermore, mechanical properties of the specimen were tested by using tensile test and hardness test. This test determines either the mechanical properties of the base alloy had been improved or not after Er and Nd added. The microstructure analysis was using optical microscopy and SEM/EDS to obtain the qualitative and quantitative data such grain size measurement and determination of phases formed with their compositions along the grain boundaries.

3. Result and Discussion

3.1 Microstructure

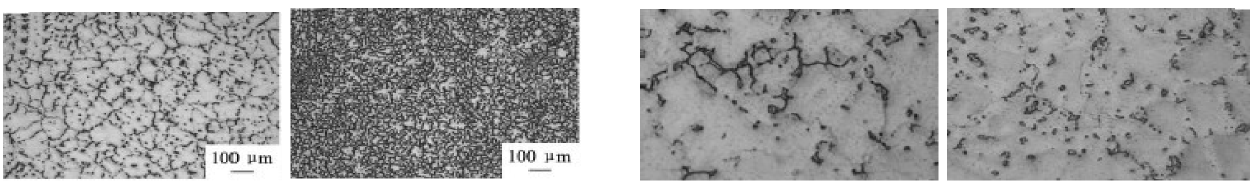
The analysis began with Er addition into Elektron ZRE1 and Elektron 21 alloy. For ZRE1 alloy, the pattern of the grain size decreased from 50.39 µm to 43.98 µm at 0.75 wt.% Er while for Elektron 21 alloy was 316.80 µm to 166.75 µm at 2.5 wt.%. Figure 1 shows the optical microscopic images for grains size comparison between the pure Elektron 21 and ZRE1 alloy with after addition of Er respectively.



(i) (ii) (iii) (iv)

Figure 1: (i) Pure ZRE1 alloy; (ii) ZRE1 alloy with 0.75 wt.% Er; (iii) Pure Elektron 21 alloy; (iv) Elektron 21 alloy with 2.5 wt.% Er

While for Nd addition, the images can be seen in Figure 2 where the formation of the grain boundaries was visible when the weight percentage (wt.%) of Nd additives were increased into the base alloy. Mg-Zn- Zr-Y alloy and ZK60 alloy give the same results after addition of wt.% Nd with the grain size decreases compared to its pure alloy.



(i) (ii) (iii) (iv)

Figure 2: (i) Pure Mg-Zn-Zr-Y alloy; (ii) Mg-Zn-Zr-Y alloy with 2.98 wt.% Nd; (iii) Pure Elektron ZK60 alloy; (iv) Elektron ZK60 alloy with 0.2 wt.% Nd

In terms of volume fraction, the overall experiment for Er and Nd addition give an elevated value from their pure base alloy. However, the increase volume fraction cannot be determined by the increases of wt.% RE as there were specific composition need to be selected for every RE addition into the base alloy. The SEM images for every samples for both Er and Nd additives for all base alloys showed the intermetallic compound was continuously distributed along the grain boundaries. According to Ahmad (2016), the decreasing of the RE's solubility in the Mg was affected by the combination of the alloying RE with the element [4]. The overall result of the experiments for both Er and Nd addition into the base alloys proved the statement by the weight percentage, wt.% of Mg element when the SEM images were analyzed in EDS analysis. Figure 3 represents the SEM image of Mg-Zn-Zr-Y alloy after addition of Nd and Table 2 shows its composition of the element by EDS analysis.

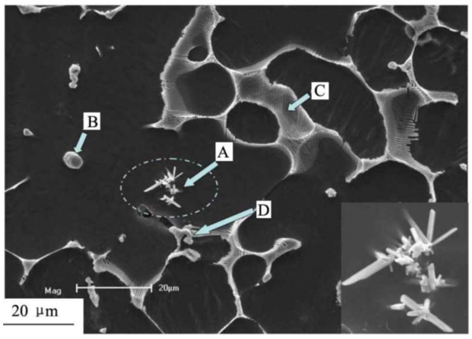


Figure 3: SEM images of Mg-Zn-Zr-Y alloy with 2.98 wt.% Nd additive

Table 2: EDS result for Mg-Zn-Zr-Y alloy

Position	Wt.%					
	Mg	Zn	Y	Nd	Zr	**Total**
A	33.161	12.464	-	-	54.375	**100**
B	21.337	61.639	6.065	10.959	-	**100**
C	70.53	18.964	5.403	5.103	-	**100**
D	55.025	39.437	-	5.538	-	**100**

The addition of Nd element in Mg-Zn-Zr-Y alloy with 2.98 wt.% promised the result where the grain boundaries were clearly formed at point B, C and D. The weight percentage of Nd in the region were 10.959, 5.103 and 5.538 wt.% respectively.

3.2 Mechanical properties

From the acquired result for all experiment, the RE metals alloying with Mg-Zn system alloys promised an improvement on the mechanical properties slightly as they increased the Ultimate Tensile Strength (UTS). Yufeng Zheng (2017) stated, an improvement of the mechanical properties increased when a third alloying element such Sr, Zr, Mn, Ca and Y was introduced into Mg-Zn based alloy [5]. For Elektron ZRE1 and Elektron 21, their results promised as expected with an improvement of UTS value after addition of Er from 153.09 MPa to 176.16 MPa and 126.35 MPa to 119.0 MPa respectively. Differ to Mg-Zn-Zr-Y alloys, Nd addition did not improve the UTS due to lack of wt.% Nd presence although an increment happenedin data and not exceed from its initial value. For ZK60, the the 0.2 wt.% gave a better result for the UTS but when 1.5 wt.% Y introduced into the alloying, the UTS drop immediately. According to Xu Chunxianget. al., the situation was happened due to Zn strengthening effect was debilitated in the matrix as the combination of Nd and Yb additives increased in Mg-Zn-Zr alloy system in ZK60 [6]. Figure 4 illustrated the overall experiment result from tensile test for both Er and Nd addition.

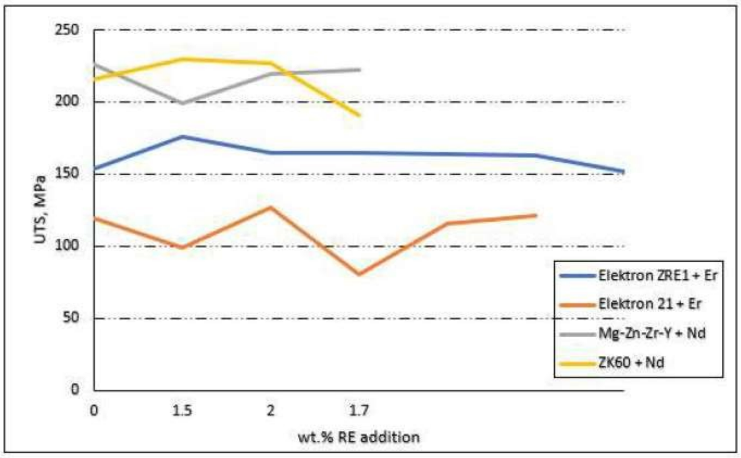


Figure 3: The overall UTS result for every Er and Nd addition into the base alloys

In Vickers's hardness test, Er and Nd gave the improvement to their base alloys respectively. Elektron ZRE1 alloy with Er addition had a highest value of hardness of 62.73 HV at 0.75 wt.% while the pure base alloy was 47 HV. On the other hand, Er alloying in Elektron 21 alloy shows a highest hardness value at 2.5 wt.% with average of 54.96 HV compared to origin with average of 48.33 HV. Nd additives allowed and increment on Mg-Y-Nd-Zr alloys at its hardest value at WE43+26Zn alloy with 25.82 wt.% Zn additives; presence of the 1.16 wt.% Nd. In the Figure 4, the overall graph pattern of presence of wt.% Nd in Mg-Y-Nd-Zr alloy were represented.

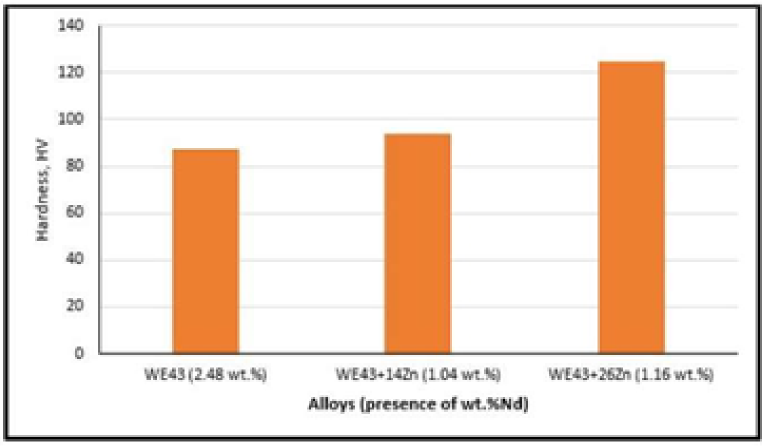


Figure 4: The presence of wt.% Nd with their hardness value

4. Conclusion

The effect of the addition of Er and Nd on microstructure and mechanical properties of Mg-Zn base alloy was investigated. From the case study analysis, the follows can be summarized:

a) Erbium and neodymium additives refined the microstructure of the Mg-Zn base alloys, grain size reduced and an increasing of volume fraction from its pure alloy
b) Addition of erbium and neodymium leads to the formation of additional intermetallic phases that distributed along the grain boundaries.
c) Erbium and neodymium additives did improve the mechanical properties of the Mg-Zn base alloys as the UTS and hardness value, HV increased. For neodymium, the expected result not occurred if the other RE was added such Y and Yb into the base alloy.
d) The preferred wt.% of Er and Nd should be added into base alloy were in range of 0.2 to 2.0 for further study.

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