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

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Abstract: The use of magnesium alloys in the manufacturing, automotive, and aerospace industries had led to research to investigate the effects of rare earth elements on these materials. The impact of the rare earth elements yttrium (Y) and neodymium (Nd) on the microstructure and mechanical properties of the magnesium alloy was investigated in this research. By referring to past research and academic publications, the case study method was used. In the selected references, from the experiments that were conducted using optical microscopy (OM), scanning electron microscopy (SEM) coupled with electron dispersive spectroscopy (EDS), the tensile test and Vickers Hardness test showed that the addition of yttrium and neodymium in different amounts improved the grain size and volume fraction, Ultimate Tensile Strength and hardness value of the magnesium alloys. Both additives improve the microstructure and mechanical properties of magnesium alloys, but different types of magnesium alloys have different compositions, which makes the optimum weight percentage of yttrium and neodymium additions differ too.

Keywords: Magnesium Alloy, Yttrium, Neodymium, Microstructure, Mechanical Properties

1. Introduction

Magnesium (Mg) is the lightest structural metal. Magnesium alloys are alloys of magnesium with other metals such as aluminium, zinc, and copper to improve their physical properties. Magnesium alloy ZRE1 is a magnesium based alloy containing zinc, rare earths and zirconium. A magnesium alloy can provide many benefits, such as significant weight reduction, high specific strength, good cast-ability, especially high-pressure die casting, in a suitable machine [1].

Cast alloys and wrought alloys are the two types of magnesium alloys available. Cast alloys are created by pouring molten liquid metal into a mould and allowing it to solidify into the desired shape. Magnesium cast alloys commonly contain varying proportions of aluminium, manganese, and zinc as primary alloying elements, but never more than 10%. Other alloying elements, including zirconium and rare-earth metals, have lately been employed to improve creep resistance.

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The addition of rare earth metals (RE) as alloying elements to magnesium alloys is one of the most common approaches to improving their mechanical properties and, in some cases, corrosion resistance. In recent years, the new Mg-RE series alloys have undergone considerable research due to their low density, high strength, creep resistance, excellent fire resistance and corrosion resistance.

Magnesium alloy with the addition of rare earth metals (RE), in this case, Yttrium (Y) and Neodymium (Nd) needs to be formed with mechanical properties and microstructure improvement.

2. Selection of References

Experimental data for the case study was gathered from different sources and journals related to the research topic. The types of specimens utilised in the reference studies have to be magnesium alloys with Yttrium and Neodymium added to them. The case study evaluation will focus on the mechanical properties and microstructure of the specimens that were obtained through proper testing and laboratory analysis using proper instruments for the experimental procedure of the reference research.

2.1 Publication by Year

Papers, journal articles, and former theses were used as sources for the references. Between 2006 and 2021, these references were published to guarantee that the information acquired was still accurate. Table 1 shows the references chosen were arranged by year of publication.

Table 1: Distribution of references in year

No	Author	Type of references	Years
1	Mingquan Zhang, Jinghuai Zhang, Ruizhi Wu, Hongwei Cui, Ertuan Zhao, Shujuan Liu, Pengfei Qin 1 and Qing Ji	Journal Article	2019
2	Tian-shun Dong, Xiao-dong Zheng, Tuo Wang, Jin-hai LIiu, and Guo-lu Li	Journal Article	2017
3	Long Liu, Fulai Yuan, Mingchun Zhao, Chengde Gao, Pei Feng, Youwen Yang, Sheng Yang and Cijun Shuai	Journal Article	2017
4	Xu Chun xiang, Wang Xing, Zhang Jinshan, Zhang Zhaoguang	Journal Article	2014
5	Wang Jing, Liu Ruidong, Dong Xuguang, Yang Yuansheng	Journal	2013

2.2 Types of alloy

The experimental procedure runs with the addition of RE into the base alloy was arranged by the element of rare earth used, such as yttrium (Y) and neodymium (Nd), with varying numbers of specimens and weight percentages (wt%) based on the references collected.

2.3 Experimental Procedure and Analysis Review

The objectives of the study on the investigation of the microstructure and mechanical properties of the base alloy following the addition of RE were specific and broad in the case study review. A tensile test and a hardness test were also used to assess the specimen's mechanical qualities. This test determines if the base alloy's mechanical properties have improved or not when Y and Nd are added. The microstructure study, on the other hand, used optical microscopy and SEM/EDS to determine grain size and the phases produced by the compositions at the grain boundaries.

3. Results and Discussion

The results and discussion section presents data and analysis of the study. This section can be organized based on the stated objectives, the chronological timeline, different case groupings, different experimental configurations, or any logical order as deemed appropriate.

3.1 Microstructure

From the obtained results of the experiment, the observation of Mg-11Li is presented in Figure 1. The pure base alloy of magnesium Mg-11Li was compared with the mixture of the Y additives and the base alloy with different weight percentages of Y. Without the Y additives, the average grain size of the Mg-11Li alloy was 410um. The addition of Y resulted in a decreased pattern of grain size at 4.32 and 7.74 wt%, with grain sizes of 140 and 87 um, respectively.

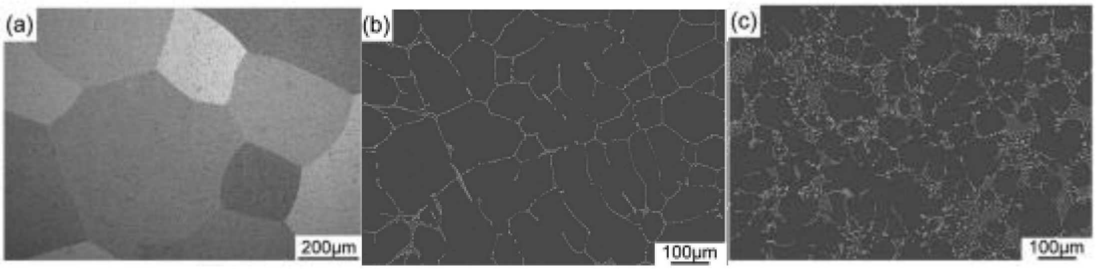
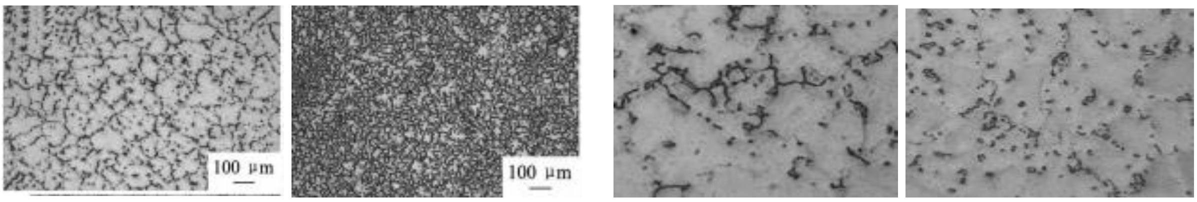


Figure 1: (a) Base alloy (b) 4.32wt% Y (c) 7.74wt% [2]

When the weight percentage (wt%) of Nd additions in the base alloy was increased, the formation of dendrited-shaped structures was very visible, as shown in Figure 2. When there is 0.2 wt% of Nd, the grain boundaries are clearly formed, as in the ZK60 alloy. When wt% Nd is added to Mg-Zn-Zr-Y alloy and ZK60 alloy, the grain size decreases when compared to the pure alloy. In terms of volume fraction, the overall experiment for Y and Nd addition gives an elevated value for their pure base alloy. However, increases in wt% RE do not determine the increase in volume fraction because each RE addition to the base alloy requires a different composition.



(a) (b) (c) (d)

Figure 2: (a) Pure Mg-Zn-Zr-Y alloy; (b) Mg-Zn-Zr-Y alloy with 2.98 wt.% Nd; (c) Pure Elektron ZK60 alloy; (d) Elektron ZK60 alloy with 0.2 wt.% Nd [3][4]

The SEM images for every sample for both Y and Nd additives for all base alloys showed the intermetallic compound was continuously distributed along the grain boundaries. The alloying of the RE with the element influenced the decrease in the RE's solubility in Mg. When the SEM images were analyzed in EDS, the overall result of the experiments for both Y and Nd addition to the base alloys proved the statement about the weight percentage, wt., of the Mg element. Figure 3 represents the SEM image of the Mg-Zn-Zr-Y alloy after the addition of Nd and Table 2 shows the composition of the element by EDS analysis.

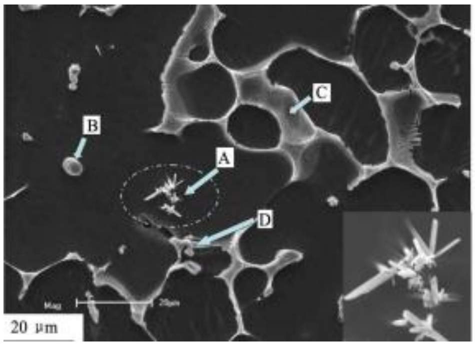


Figure 3: SEM image of Mg-Zn-Zr-Y alloy with 2.98 wt% Nd [4]

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

Point	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	39.467	-	5.538	-	**100**

3.2 Mechanical Properties

The RE metals alloyed with Mg system alloys promised a slight improvement in mechanical properties while increasing the Ultimate Tensile Strength (UTS). In the Mg-11Li alloy experiment, the Y additives influence the average of UTS at specific wt% values, where the base alloy is 145 MPa and the addition of wt% Y, which is 4 wt% Y and 8 wt% Y, shows 224 MPa and 243 MPa, respectively. As the weight% of Y additives in the samples increased, the pattern of the average UTS increased.

Unfortunately, the Nd alloying to Mg-12Li-3Al alloy did not have the expected outcome where the UTS was decreased compared to the base alloy. The data shows that the UTS value for the Mg-ZnZr-Y alloy decreased by 1.12 wt% but was slowly evaluated for 2.02 wt% and 2.98 wt% samples and did not exceed the UTS of the base alloy's composition. For ZK60 alloy, 0.2 wt% Nd addition gave the better mechanical properties as the UTS higher than the origin alloy with 226.9 MPa compared to 215.4 MPa and same as 1.5 wt% Yb addition with UTS of 229.3 MPa. The outcome was different when both Nd and Yb additives were alloyed with the ZK60 alloy. The UTS decreased to 190.6 MPa. The situation happened due to the Zn strengthening effect that was debilitated in the matrix as the combination of Nd and Yb additives increased in the Mg-Zn-Zr alloy system in ZK60 [4]. Figure 4 illustrates the overall results of the tensile test for both Er and Nd addition.

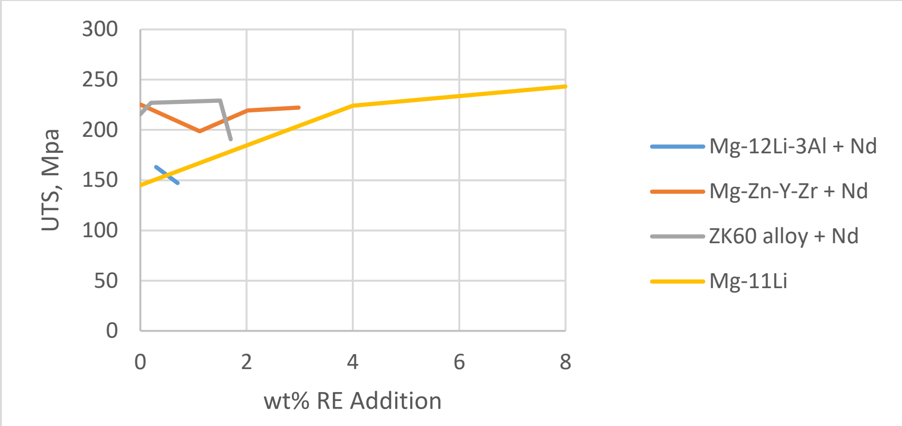


Figure 4: Figure 4.9: The UTS and different weight of Nd and Y addition into base alloy

For the Vicker's hardness test, the AZ61 alloy with Y addition had the greatest hardness value of 105 HV at 2 wt%, compared to 91 HV for the pure base alloy. The average hardness value increases until it reaches 3 wt%. The hardness value of Y has dropped from 103 MPa to 98 MPa at 4 wt% Y.

As a result of the experiments for Nd addition from the references, Tian-Shun Dong (2017) [5] showed that the hardness of the base alloys was improved, with the greatest hardness value of 0.7 at 55 MPa. The pattern of the average value of hardness increased as the wt% of Nd additives in the samples increased. Figure 5 shows the comparison of the weight of Nd and Y added to the base alloy.

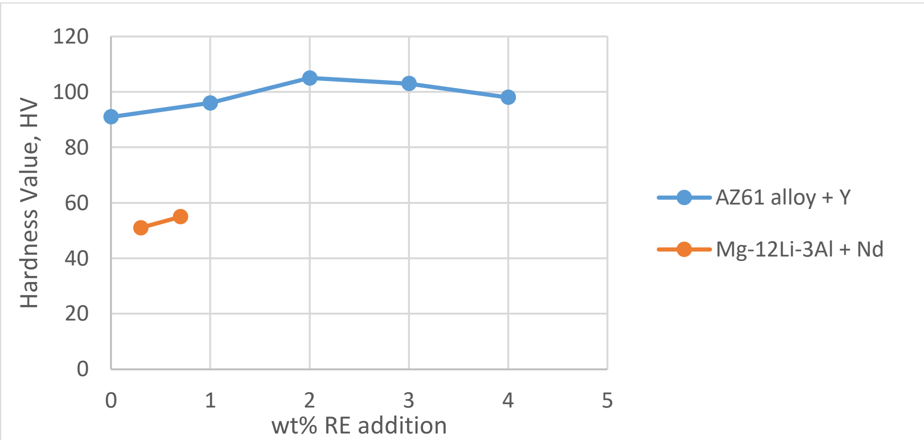


Figure 5: The comparison of weight Nd and Y addition into base alloy

4. Conclusion

The effect of the addition of Y and Nd on the microstructure and mechanical properties of the magnesium base alloy was investigated. From the case study analysis, it can be summarized that yttrium and neodymium additives refined the microstructure of the magnesium base alloys, reducing grain size and increasing the volume fraction of the pure alloy. The addition of yttrium and neodymium leads to the formation of additional intermetallic phases that are distributed along the grain boundaries. In addition, yttrium and neodymium additives did improve the mechanical properties of the magnesium base alloys as the UTS and hardness value, HV increased. If the other RE adds such Y and Yb to the base alloy, the expected result does not occur for neodymium.

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