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Material Characterization of Magnesium Elektron ZRE1 Alloy with Praseodymium (Pr) and Erbium (Er) Additions

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Abstract: The application of magnesium (Mg) is limited due to its poor mechanical and microstructural properties. The additions of rare earth elements to the Mg-Zn-Zr alloys will result in a much better properties of Mg alloy. In this study, the additions of erbium and praseodymium to magnesium elektron ZRE1 will be discussed thoroughly. This study will discuss the effects of praseodymium (Pr) and erbium (Er) on the microstructure and mechanical properties of Mg elektron ZRE1 alloy. Mg elektron ZRE1 alloy was used as main material while Elektron 21, Mg-Gd-Zn and MEZ alloys were used for comparison purposes. As for main rare earth (RE) additives, Praseodymium (Pr) and erbium (Er) were used. Yttrium (Y), gadolinium (Gd) and cerium (Ce) were also used to get more accurate results. This research focused on the case study where results and data from previous research will be analysed and compared to achieve the objectives. RE additions reduce the grain size of alloy and increase its volume fraction. UTS and hardness value were also increased with the additions of RE. The study carried out has shown that the additions of Pr and Er can positively influenced the mechanical and microstructure properties of Mg elektron ZRE1 alloy. Due to the potential of ZRE1 alloy in application such as industrial application, further study should be widely done on this alloy.

Keywords: Magnesium elektron ZRE1 alloy, rare earth elements, mechanical properties, microstructure properties

1. Introduction

Magnesium is used widely in the application of various industries such as automotive, electronics, aerospace and telecommunication industries. Its attractive traits include the low-density property, high specific strength, great machinability and superior castability [1]. An improved property of Mg is achieved by means of alloying [2]. The metals that are mixed with Mg are usually aluminium, zinc, manganese, silicon, copper, RE elements and zirconium. Mg alloys represent some of the best solidification characteristics such as excellent fluidity and possess low susceptibility towards hydrogen porosity [3].

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For the purpose of developing light construction alloys for the application at elevated and high temperatures, Mg is alloyed with RE elements. RE elements also help in improving corrosion and creep resistance. They are useful metallic elements which improve the binding energy of Mg atoms and decrease the diffusion velocity of atoms [4]. Mg alloys that contain RE elements is an important class of Mg alloys that are developed specifically for applications at elevated temperature [5]. Mg elektron ZRE1 is one of the Mg-Zn-RE-Zr alloys ever found. However, the level of strength and hardness of elektron ZRE1 are considered low [6]. Elektron ZRE1 inherits one significant problem where atomic structure of Mg alloy is not stable enough when compared to Mg alloy and steel. The purpose of adding rare earth elements is to stabilize atomic structure with the formation of intermetallic components.

Besides, the additions of RE elements generally reduce the grain size of the Mg elektron alloy and thus improving the mechanical properties of Mg alloys. The presence of zirconium in magnesium elektron ZRE1 is also useful during solidification process as solid particles that are rich with zirconium provides sites for heterogenous nucleation of Mg grains. This is due to the fact that the lattice parameters of zirconium are nearly similar to Mg. The solid particles which are rich with zirconium and responsible for providing sites for heterogenous nucleation are produced during the freezing of melt [7].

To create or produce an improved version of Mg alloys, the effects of the additions of alloying elements must be first understood. Adding RE elements into the Mg alloys can significantly improve its mechanical and microstructure properties. Some of its benefits include the increment of tensile strength and also the resistance of alloys towards corrosion. Even though Mg alloy castings usually have defects such as misruns and micro-shrinkage, defects can always be repaired with welding and overlay welding techniques [8]. Through this study, the capability of two types of RE elements which are Er and Pr in improving the mechanical and microstructure properties will be approved.

2. Materials and Methods

Due to the COVID-19 pandemic, Movement Control Order (MCO) was enforced by the government to the public. Hence, no experiments were conducted, and this research focused on the case study instead. Results and data from previous research will be analysed and compared in order to achieve the objectives of this research.

2.1 Materials

The comparison that can be made in this section is based on different samples of Mg alloys which are Mg elektron ZRE1, Elektron 21, Mg-Gd-Zn and MEZ alloys. Even if the focus of this research is towards magnesium ZRE1 alloy, the other three Mg alloys are expected to give the same result. This is because they also contain the elements of Mg and Zn without the presence of Al, which is a similar characteristic to Mg ZRE1 alloy. This research focuses on two RE which are erbium and praseodymium. However, since yttrium, gadolinium and cerium which were added in the form of cerium-rich misch metal are also RE elements, they were also taken into consideration for comparison purposes.

2.2 Methods

The effects of the additions of Pr and Er on Mg ZRE1 alloy were found out by comparing the results from previous research. Based on one of the case studies collected, permanent steel mould castings were used to cast the specimens needed to conduct the experiment [6]. Different percentages of RE were added separately to Mg alloys resulting in different samples produced. After the specimens were successfully casted, analysis and testing on the mechanical and microstructure properties of the specimens were then carried out. Mechanical testing included were tensile and hardness tests while microstructure analysis focused on the grain size and phases formed by specimens.

3. Results and Discussion

This section will include analysis and comparison of analysis from previous research together with attachment of data.

3.1 Microstructure Analysis

The overall results of average grain sizes and volume fraction of magnesium alloy taken from previous researches are tabulated in Table 1.

Table 1: Average Grain Sizes and Volume Fraction of Magnesium Alloy

Mg Alloy	Additives	% of Additives (wt.%)	Average Grain Sizes	Volume Fraction	Reference
ZRE1	Er	0	50.39	28	[6]
		0.25	44.74	31.33	
		0.50	42.88	31.83	
		0.75	42.98	32.16	
		1.00	44.74	34.33	
		1.25	45.79	36.16	
		1.75	45.67	35.5	
ZRE1	Pr	0	50.5	28	[6]
		0.25	38.9	37.16	
		0.50	42	38	
		0.75	42.3	40.83	
		1.00	42.57	42.66	
		1.25	44.06	43.52	
		1.75	55.67	46.39	
ZRE1	Y	0	50.39	36.62	[6]
		0.25	49.26	44.42	
		0.50	45.31	44.00	
		0.75	41.16	44.31	
		1.00	38.29	44.21	
		1.25	42.46	44.40	
		1.75	43.41	48.5	
Elektron 21	Er	0	316.80	28.6	[9]
		0.50	206.98	31.0	
		1.00	216.99	28.5	
		1.5	261.12	21.0	
		2.0	240.78	27.0	
		2.5	166.75	29.5	
Mg-Gd-Zn	Gd	2	16	-	[10]
		3	12	-	
M1	Ce	0	26.9	-	[11]
MEZ1.15		0.1	24.6	-	
MEZ1.2.5		0.19	23.5	-	

From Table 1, it can be seen that the overall RE additions caused the grain sizes of alloys to decrease and volume fractions to increase. These trends continue to show positive effect to the alloys. However, grain sizes started to increase after RE additions exceeded certain values. Volume fraction of alloys also started to decrease after certain additions of RE were done. This may be due to the less effect the RE brought to the alloys.

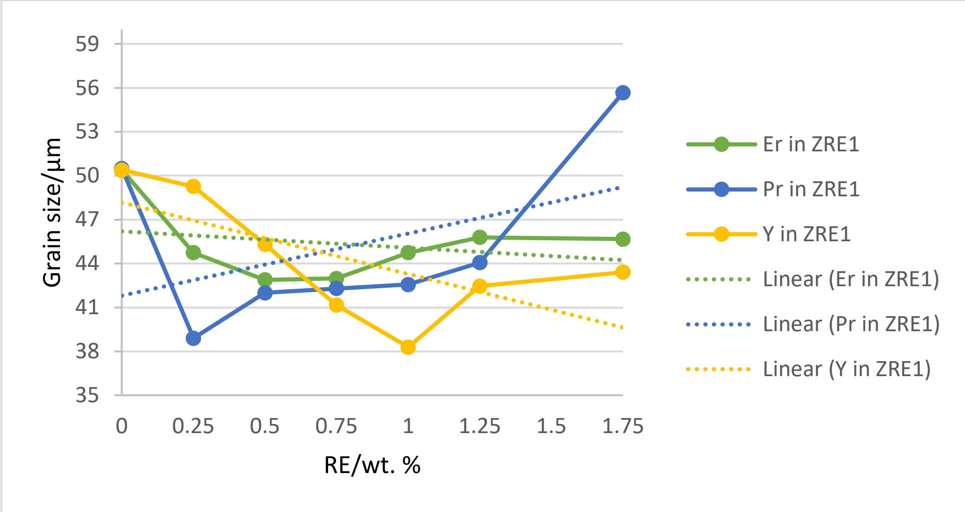

Figure 1: Effect of the additions of RE on the grain sizes of ZRE1 magnesium alloy

For a clearer view of the effect of RE additions into the alloy, Figure 1 shows the comparison of grain sizes of alloys. From the linear lines of the graph, the addition of Er and Pr into the base alloy caused a decrease in grain sizes of alloys. However, the linear line for the addition of Y shows an increase of the overall grain sizes of alloy. This indicated that Y did not give enough positive effect to the grain sizes of alloy and caused the linear graph to decrease.

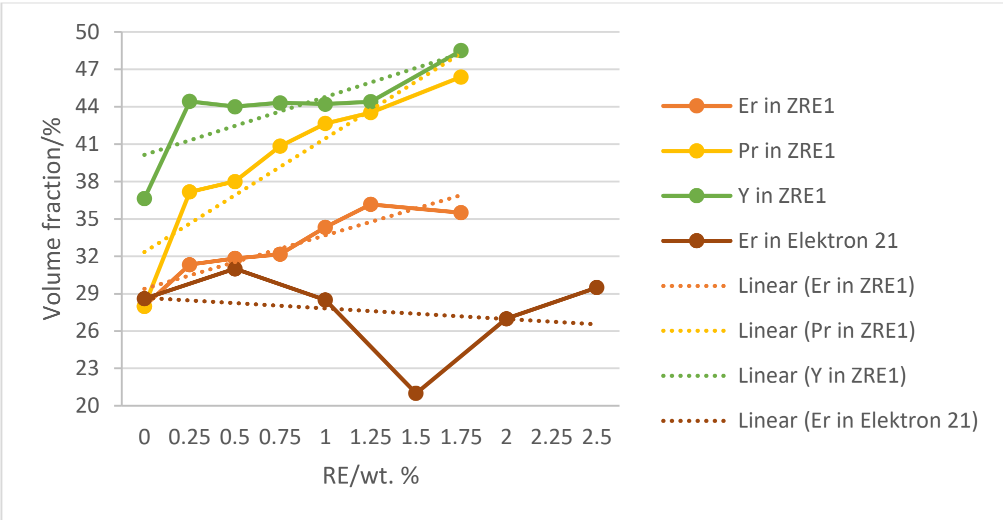

Figure 2: Volume fraction of magnesium alloys

For a better view of the effect of RE additions to the volume fraction of alloys, a graph in Figure 2 was constructed from the data of ZRE1 and Elektron 21 alloys. The linear lines for the addition of Er, Pr and Y into ZRE1 alloy shows an increasing pattern. As for the addition of Er in Elektron 21, the linear line decreased towards the end of the addition indicating the less positive effect RE brought to the volume fraction of alloy.

To observe and prove the presence of RE elements in the alloys, specimens were observed with a specified equipment. The equipment used was the Scanning Electron Microscope (SEM) which was coupled with Electron Dispersive Spectrometer (EDS). Figure 3 shows an example of SEM micrograph of specimen.

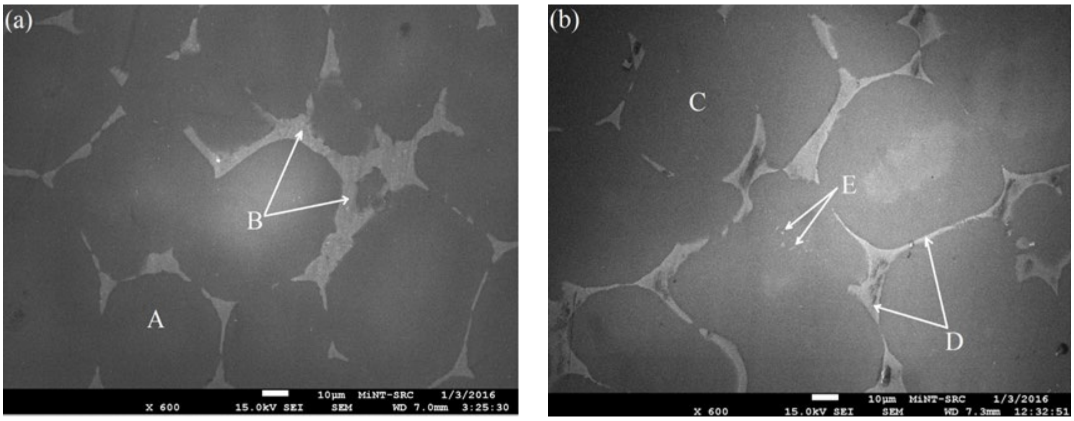

Figure 3: SEM micrographs for ZRE1 base alloy and ZRE1 alloy treated with 1.75 wt.% Er [6]

3.2 Mechanical Testing

As to find out the mechanical properties of alloys, tensile test and hardness test were carried out. Table 2 shows the comparison of ultimate tensile strength and hardness values of alloys with different percentages of RE additives.

Table 2: Average UTS and Hardness Value, HV of alloys

Mg Alloy	Additives	% of Additives (wt.%)	Average UTS (MPa)	Hardness, HV	Reference
ZRE1	Er	0	153.09	47.00	[6]
		0.25	176.16	56.91	
		0.50	164.23	58.62	
		0.75	164.67	62.73	
		1.00	163.43	59.66	
		1.25	157.33	58.83	
		1.75	152	58.39	
ZRE1	Pr	0	153.09	47.00	[6]
		0.25	154.37	50.00	
		0.50	165.78	51.78	
		0.75	166.30	52.66	
		1.00	167.48	53.00	
		1.25	168.82	55.15	
		1.75	160.17	58.00	
ZRE1	Y	0	153.09	47.00	[6]
		0.25	152.94	52.00	
		0.50	152.82	50.00	
		0.75	160.82	55.00	
		1.00	164.78	58.84	
		1.25	180.00	54.00	
		1.75	173.20	59.00	
Elektron 21	Er	0	119.00	48.33	[9]
		0.50	98.95	54.51	
		1.00	126.35	50.63	
		1.5	79.92	50.39	
		2.0	115.32	51.87	
		2.5	121.48	54.96	
Mg-Gd-Zn	Gd	2	224.33	-	[10]
		3	220.40	-	
M1	Ce	0	-	-	[10]
MEZ1.15		0.1	-	-	
MEZ1.2.5		0.19	-	-	

For the ease of comparing the pattern of UTS for each alloy, a graph in Figure 4 was plotted. Based on the Figure 4, the linear lines for the UTS values of ZRE1 alloy shows an increasing trend when Pr and Y were added. The addition of RE seemed to give positive results to the alloy. However, linear line for UTS value decreased when Er was used as an additive to the alloy. This was due to the less of effect that element Er brought to the tensile properties of the alloy.

From Table 2, it can be seen that RE addition helped in improving the hardness value of the alloys. Although the results showed that a certain addition of RE could decrease the hardness value, it was observed that the value will eventually increase again after the addition of RE was proceeded. As shown in Figure 5, all the linear lines show an increasing trend of the graph. This proved that the hardness value of magnesium alloys can be increased with the addition of RE which are Er, Pr and Y.

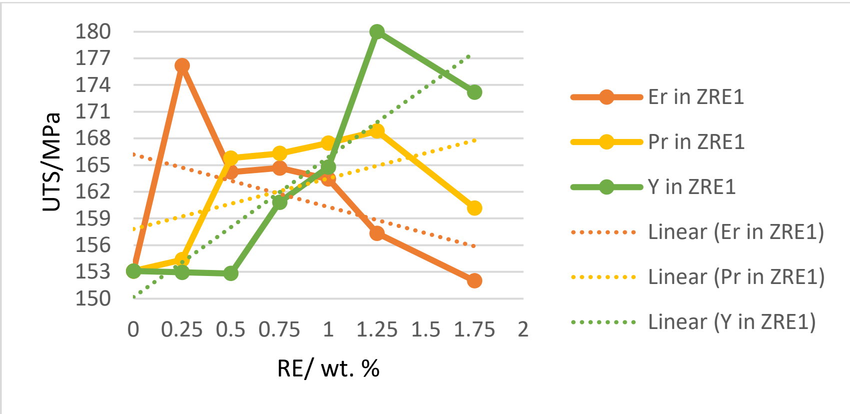

Figure 4: Effect of RE additions on UTS values for ZRE1 alloys

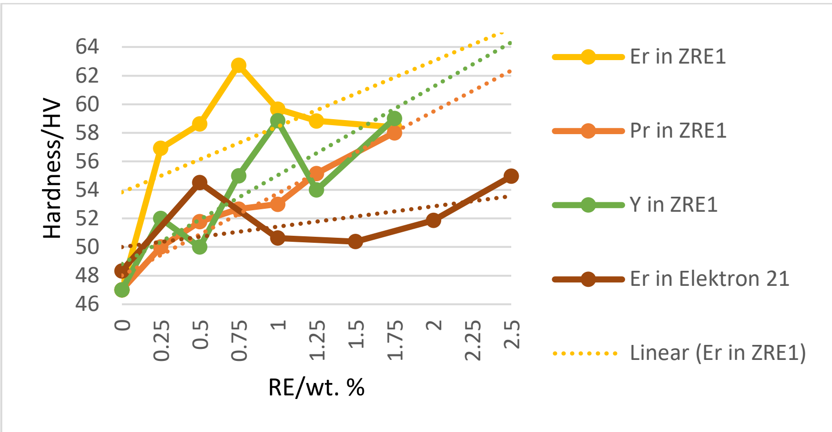

Figure 5: Effect of RE additions on the hardness values of magnesium alloys

4. Conclusion

From the analysis of result, it could be seen that the addition of RE elements positively influenced the mechanical and microstructure properties of magnesium alloys. Although the RE elements used in the previous research were not the same to the element focused in this research, it was assumed that they will give similar results. This was due to the fact that all of them are RE elements. A certain addition of RE gave positive results to the microstructure and mechanical properties of magnesium alloys. Hence, the objectives of this research were achieved, in which the effects of praseodymium and erbium to magnesium elektron ZRE1 alloy were successfully analysed. Pr and Er positively affect the microstructure and mechanical properties of magnesium elektron ZRE1 alloy. For microstructure properties, grain size decreases while volume fraction increases. As for mechanical properties, UTS value and hardness value increase with the addition of Pr and Er.

For future work recommendation, the addition of other RE elements such as ytterbium (Yb), neodymium (Nd) and terbium (Tb) into ZRE1 alloy should be considered. This should be done to further prove the effect of RE on the improvement of mechanical and microstructure of magnesium elektron ZRE1 alloy. The next recommendation is that the pouring temperature should be accurately followed to make sure that the elements react perfectly, and a more precise result can be achieved.

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