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

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Abstract: The application of aluminium alloy in automotive and aerospace industries has supported the need to study the effect of rare earth elements on alluminium alloys. In this study, the effect of the rare earth element erbium (Er) and neodymium (Nd) on the microstructure and mechanical properties of the Aluminium alloy was reviewed. The case study method was conducted by referring from previous researches and journal articles. In the selected references, from the experiments that were conducted using optical microscopy (OM), scanning electron microscopy coupled with electron dispersive spectroscopy, Tensile test and Vickers Hardness test showed that the addition of erbium and neodymium in different amounts improved the grain size, Ultimate Tensile Strength and hardness value of the aluminium alloys. Both additives improved the microstructure and mechanical properties of aluminium alloys but different types of aluminium alloys have different compositions which makes the optimum weight percentage of erbium and neodymium addition to differ too.

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

1. Introduction

Aluminium alloys are alloys which composition mainly consist of aluminium (Al). The typical alloying elements are magnesium, copper, manganese, silicon and zinc. Aluminium alloys are known for its application in automotive and aerospace industries since it is lightweight, has a high strength to density ratio, high corrosion resistance, low thermal expansion coefficient, high wear resistance and good castability. In aerospace industries, aluminium alloys are used a lot in the construction of the body of the aircraft since aluminium alloys are lightweight and have high strength. While in automotive industries, to reduce the weight of engine while at the same time improving the mechanism of the motion of the moving parts, the engine components such as blocks, cylinders, pistons and some of the moving parts are mostly composed of aluminium alloys.

There are a few factors that affect the microstructure and mechanical properties of aluminium alloys which includes alloy-composition, impurity elements, microstructure, addition of modifiers or refiners and also other variables that has to be controlled during the casting process. The focus of the review is

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on the addition of rare earth elements erbium and neodymium on aluminium alloys. Erbium (Er) is a rare earth element that dissolves in the pure Al-Si alloy that is heated at 800°C [1]. It was found out that the addition of Er has enhanced the mechanical properties of the aluminium alloy due to the formation of secondary Al3Er precipitates [2]. Optimal amount of addition of Er will change the size and shape of the eutectic silicon, thus refining the microstructure of Aluminium alloys. In the other hand, neodymium (Nd) can also refine the primary silicon of hypereutectic of Al-Si alloy effectively [3]. Addition of Nd in Aluminium alloys has a huge impact on the mechanical properties of the alloy which includes huge improvement of tensile strength and elongation. The optimal amount of Nd addition will significantly reduce the size of the primary silicon in Aluminium alloys.

Despite that, different rare earth element combined with Al-Si alloys will produce different results regarding their microstructure and mechanical features. Therefore, identifying the actual type and composition of rare earth addition is an absolute must when attributing the effect of rare earth addition to the alloy properties.

2. Selection of References

The research method used for this study is case study where the study was done by referring to past researches and journal articles. The selections of references were based on the similarity of their objectives with this study’s objectives and other criteria such the year of publication, types of alloys used, types of rare earth element used and type of experimental procedure conducted. The publication date for the selected references was made sure to be not more than ten years from present and the alloys used were made sure to be aluminium alloys. For type of experimental procedure, the case study review was focused to the microstructure and mechanical properties of the specimens with proper testing and laboratory analysis by using the proper instruments and methods.

2.1 Publication by year

The selected references were chosen in between year 2010 to 2019 and the objective of the study for all references were related to this study. Table 1 shows the references selected which was sorted by year of publication.

Table 1: References selected sorted by year of publication

No.	Author	Type of reference	Year
1	R. Ahmad, N. Wahab, S. Hasan et al.	Journal article	2019
2	S. Kord, Mohammad Alipour, M. H. Siadati, Masumeh Kord, and Praveennath G. Koppad	Journal article	2018
3	Qi Tang, Jianhua Zhao, Tao Wang, Jing Chen, Ke He	Journal article	2018
4	Zhi Hu, Xian-ming Ruan, Hong Yan	Journal article	2015
5	Z.M. Shi n, Q. Wang, G. Zhao, R.Y. Zhang	Journal article	2015
6	Shi Weixi, Gao Bo, Tu Ganfeng, Li Shiwei, Hao Yi, Yu Fuxiao	Journal article	2010

2.2 Type of alloys

Alloys that are mainly composed of aluminium (Al) are preffered in this study since the target of the study is to investigate the effect of rare earth addition towards aluminium alloys. From the selected references, the experimental procedure runs with the addition of RE into the base alloy were arranged by the element of rare earth used which is erbium (Er) and neodymium (Nd) with different number of specimen and weight percentage (wt.%).

2.3 Analysis review and experimental procedure

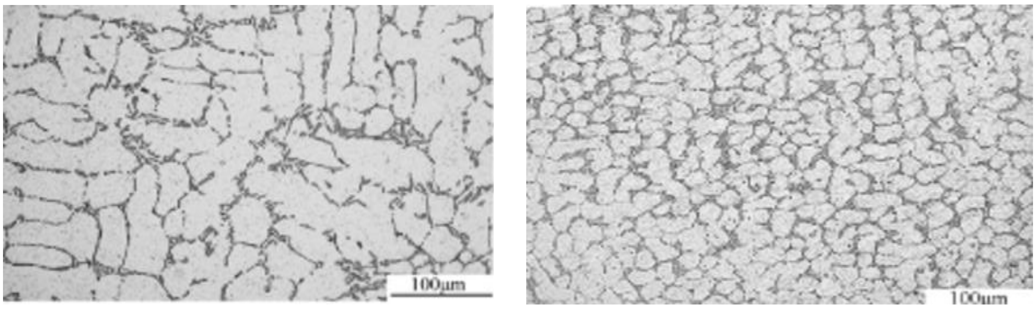
The case study was focused directly to the objectives of the study on analysis of the microstructure and mechanical properties of the base alloy after the addition of rare earth elements. The mechanical properties of the specimen were tested by using tensile test and hardness test. This test determines whether the mechanical properties of the base alloy has improved or not after undergoing Er and Nd addition. The microstructure analysis was done by using observations from optical microscopy and SEM/EDS to obtain the qualitative and quantitative data which is grain size measurement and determination of phases formed with their compositions along the grain boundaries.

3. Results and Discussion

The results that will be presented and discussed includes the Optical Microscope observations, observations obtained from SEM/EDM coupling, data from tensile test and data from Vickers Hardness test.

3.1 Microstructure

The analysis began with Er addition into A356 and Al–Zn–Mg–Cu alloys. For A356 alloy, the average grain size reduced from 85.6 μm to 22.2 μm at 0.3 wt.% of Er. Meanwhile, the average grain size of Al–Zn–Mg–Cu alloy reduced from about 530 μm to about 60 μm at 2.0 wt.% of Er. Figure 1 shows the optical microscopic image for grain comparison of pure A356 alloy and after the addition of 0.3 wt.% of Er. In the other hand, Figure 2 shows the graph of average graian size for Al–Zn–Mg–Cu against the weight percentage of Er.



(i) (ii)

Figure 1: (i) Pure A356 alloy; (ii) A356 alloy with 0.3wt.% Er

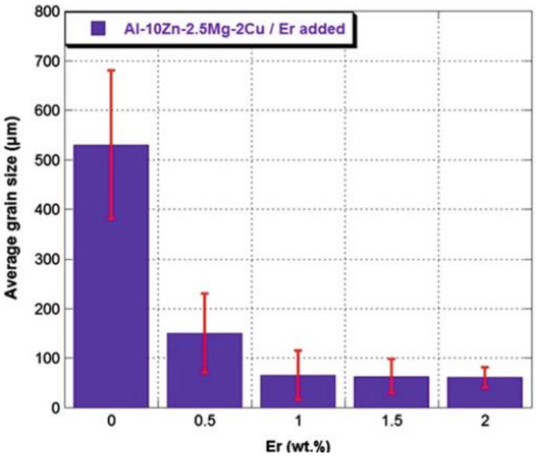
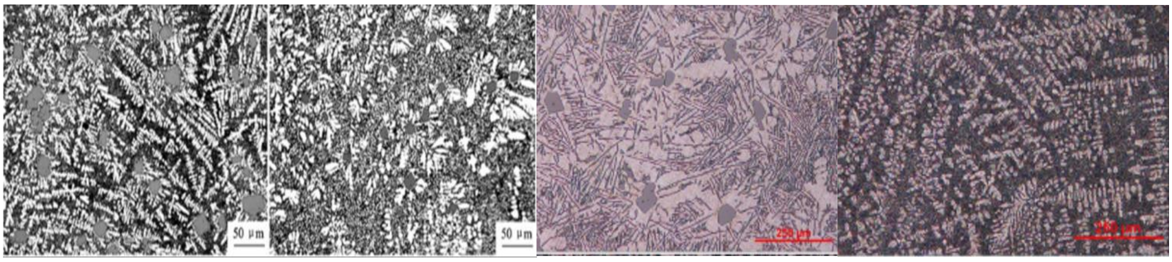


Figure 2: The graph of average grain size of Al–Zn–Mg–Cu against the weight percentage of Er

For Nd addition, the images can be seen in Figure 3 where the grain size of the microstructure of Al-15Si alloy and Al−12Si alloy is smaller with the addition of Nd.



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

Figure 3: (i) Pure Al-15Si alloy; (ii) Al-15Si alloy with 0.03 wt.% Nd; (iii) Pure Al−12Si alloy; (iv) Al−12Si alloy 0.3 wt.% Nd

The SEM images for every samples for both Er and Nd additives on all base alloys showed the intermetallic compound was continuously distributed along the grain boundaries. 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 Er and Nd elements when the SEM images were analyzed in EDS analysis. Figure 4 shows the SEM image of A356 alloy after addition of Er and Table 2 shows its composition of the element by EDS analysis.

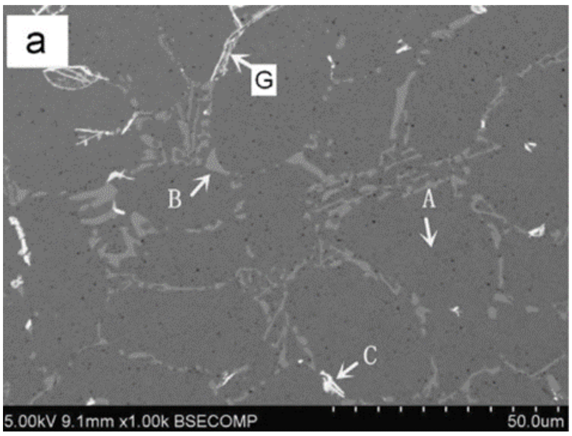


Figure 4: SEM micrographs of A356 alloy with 0.3 wt.% Er

Table 2: EDS results of points A, B and C in Figure 4.5.

Point	wt.%				
	Al	Si	Mg	Er	Fe
A	98.29	1.71	-	-	-
B	64.85	35.42	-	-	-
C	59.24	19.58	7.18	7.32	6.67

The EDS analysis on the addition of Er element in A356 alloy with 0.3 wt.% shows that the grain boundaries were formed at point C. The weight percentage of Er in the region is 7.32 wt.%.

3.2 Mechanical properties

Based on the obtained results for all experiments, the addition of Erbium and Neodymium into aluminium alloys promised an improvement on the mechanical properties as it increased the Ultimate Tensile Strength of the aluminium alloys. In the research carried out by Shi et, al using A356 alloy as the base alloy, it was stated that the addition of Er affected the value of average Ultimate Tensile Strength of the base alloy with the specific values of weight percentage of Er where the average UTS of the pure base alloy is about 235 MPa while the average UTS of the base alloy with 0.3 wt.% Er is about 350 MPa. Figure 5 shows the graph of UTS against weight percentage of Er in A356 alloy.

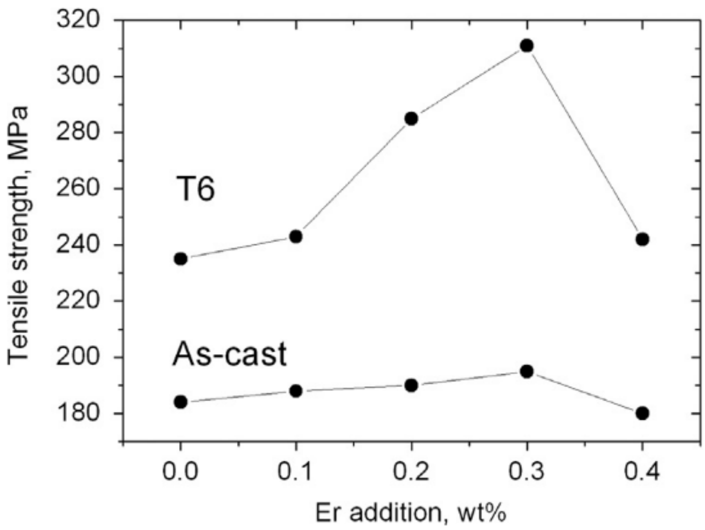


Figure 5: The Ultimate Tensile Strength (MPa) against weight percentage of Er in the A356 alloy

For the addition of Nd to the aluminium alloys, the Al–12Si alloy showed increase of UTS value at the peak of about 250 MPa with 0.3 wt.% of Nd compared to the pure base alloy with UTS value of about 150 MPa. Figure 6 shows the graph of UTS against weight percentage of Nd in Al–12Si alloy.

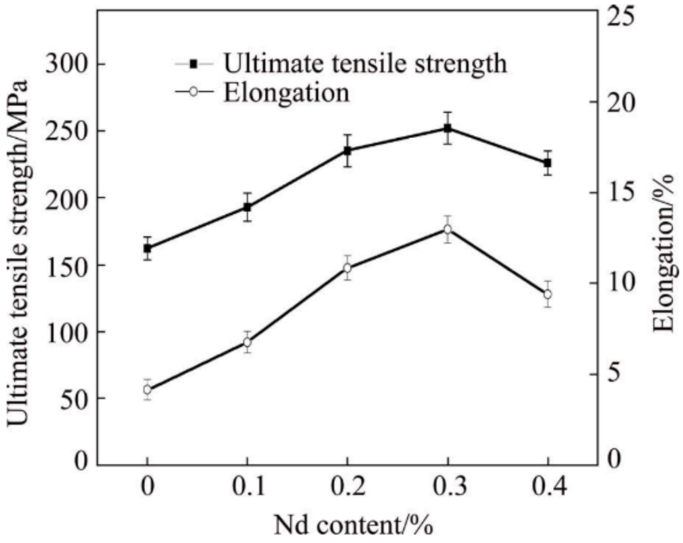


Figure 6: The average Ultimate Tensile Strength (MPa) with different weight percentage of Nd in the Al−12Si alloy

In Vickers Hardness test, only Er addition can be analyzed since the references for Nd addition on Vickers Hardness test was not found. For the Er addition, the addition of Er gave slight improvement to the hardness value of A356 and LM24 alloy. The A356 alloy with 0.4 wt.% Er had the highest hardness value which is about 71 HV while the pure A356 alloy has the hardness value of about 67 HV. As for the LM24 alloy, the base alloy with 1.0 wt.% Er had the highest hardness value which is about 87 HV while the pure base alloy has the hardness value of about 84 HV. Figure 7 shows a graph of hardness value of A356 and LM24 alloy with different weight percentage of Er.

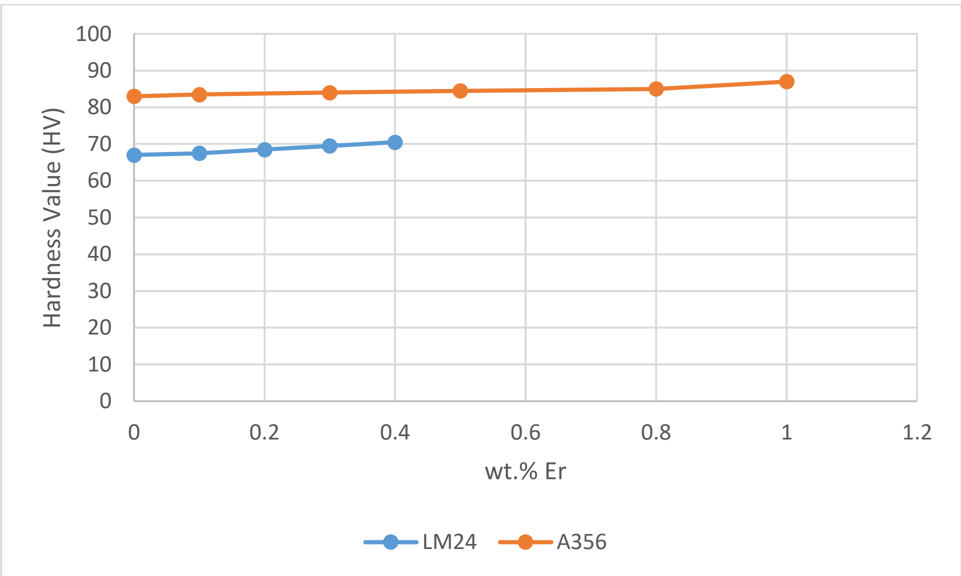


Figure 7: The comparison of Hardness value of A356 alloy and LM24 alloy with the addition of Er

Even though the addition of Er only gave a slight improve to the hardness value for both of the alloys, the graph did not show any sign of declining on the hardness value.

4. Conclusion

The effect of the addition of Er and Nd on microstructure and mechanical properties of Aluminium base alloy was investigated. From the case study analysis, the conclusion can be summarized as the points below:

a) Erbium and neodymium additives refined the microstructure of the aluminium base alloys by reducing the average grain size.
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 improved the UTS of the aluminium base alloys.
d) Erbium additives slightly improved the hardness value of aluminium base alloys.

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