Research Progress in Mechanical and Manufacturing Engineering Vol. 4 No. 1 (2023) 359-364
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RPMME

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

Effect of Yttrium on Microstructure and Hardness Properties of Aluminium LM30 Alloy

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DOI: https://doi.org/10.30880/rpmme.2023.04.01.041
Received 23 June 2022; Accepted 23 June 2022; Available online 01 June 2023

Abstract: The application of aluminium alloy in the automotive and aircraft industries has strengthened the need to investigate the influence of rare earth elements on aluminium alloys. A lightweight vehicle is one way for increasing a vehicle's fuel efficiency and performance. Despite the increased interest in aluminium alloys, their applicability is still restricted in comparison to steel. The effect of Yttrium alloying addition elements on the microstructure and hardness properties of cast LM30 (Al-Si17Cu4Mg) alloy was studied. The purpose of this research is to investigate the variations that occurred in Si morphology as well as their effect on the hardness value. The experimental results indicate that the Yttrium affected the silicon eutectic morphology of Al-Si17Cu4Mg alloy when 1.0 wt. % was added to the alloy and the acicular structure of Si was modified into a fine fibrous structure. The hardness measurements revealed that the hardness values of the based alloy were higher with the Yttrium addition.

Keywords: Al Alloys, Yttrium, Microstructure, Hardness Properties

1. Introduction

There has been an enormous increase in aluminium production as a result of the increased use of aluminium packaging, transportation, construction, and electrical engineering [1]. Aluminium is a versatile material that can be used in a wide range of applications. In addition to its economical and attractive metallic material, aluminium is widely used as structural metal apart from steel. The interest sparked by the industries is mainly because aluminium is a lightweight material. A lightweight vehicle is one way for increasing a vehicle's fuel efficiency and performance.

Micro-alloying is a standard approach for increasing the mechanical behaviour of aluminium alloys to achieve excellent high-temperature performance, low cost, and relatively high strength. The rare-earth element which is all metal also called rare earth metal is used as an alloying agent to improve the properties of aluminium alloy. Aluminium LM30 alloy or Al-Si17Cu4Mg is additionally referred to as hypereutectic aluminium alloy whose composition is including aluminium and its major element which is Silicon. The reason for combining the entire element is to intensify the mechanical properties. Additionally, aluminium alloys are more castable than other cast metals like steel. Despite the increased interest in aluminium alloys, their applicability is still restricted in comparison to steel.

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There are numerous methods for improving a material's mechanical properties, including element modifications, heat treatment, and others. Alloying is one approach to achieving the modification of an element to increase the mechanical characteristics of aluminium alloys. An appropriate alloying element can aid in the improvement of aluminium alloys' mechanical and hardness properties. Other rare earth elements, such as Yttrium, have been found to improve the strength of Al-Zn-Mg-Cu alloy at high temperatures by reducing the grain size of the as-cast alloy, resulting in a better nucleation ratio, during artificial aging. [1,2]. However, a few studies have been conducted on the LM30 alloy to observe the effect on microstructure and hardness properties. Thus, it is critical to investigate the microstructure and hardness properties of LM30 aluminium alloy in addition to Yttrium.

2. Methodology

The main material used to manufacture the sample is aluminium LM30 alloy, and the chemical composition is expressed in weight percent, wt. %. LM30 alloy is melted into the crucible furnace and yttrium (Y) additive is added at a temperature around 730°C±. As the yttrium is added during the melting process, the yttrium is stirred to ensure homogeneity of the composition. The melted alloys were poured into the preheated steel mould. The chemical compositions of the aluminium LM30 that are used in this study is displayed in Table 1 below.

Table 1: The chemical composition of LM30 aluminium alloy

Element	Cu	Si	Mg	Fe	Mn	Ni	Zn	Pb	Sn	Ti
Percentage, %	4.0-5.0	16.0-18.0	0.4-0.7	1.1	0.3	0.1	0.2	0.1	0.1	0.2

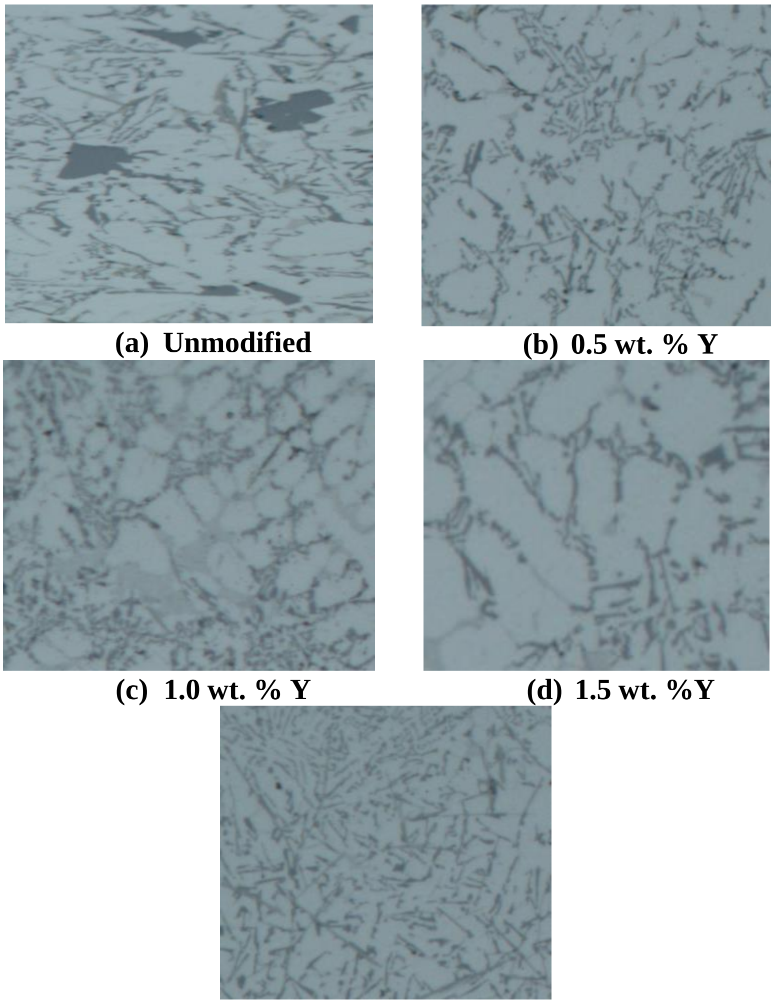
Microstructural analysis of as-cast samples was performed to determine the modification effect of Y addition. The samples for microstructural were ground and polished before being inspected under an optical microscope at various magnifications to observe the change of the compounds with and without Y addition. Keller's reagent is used as an etchant to reveal the microstructure of polishing samples. The Vickers hardness tester was used, and the test load and dwell time were HV0.1 and 10s, respectively. To minimize inaccuracy, at least 5 points were measured for each specimen, and the average value was determined.

3. Results and Discussion

The microstructure of LM30 alloy with different compositions of Yttrium (Y) is shown in Figure 1. From the microstructure, it can be seen that the microstructure consists of α-Al phase as well as eutectic Si phases. From Figure 1, it can be seen that the addition of Yttrium (Y) has modified the microstructure of the base alloy. The microstructure of the eutectic silicon transforms the eutectic Si from a coarse acicular structure to a more fine fibrous structure as the composition of the Yttrium increases. Figure 1 (a) and (b) show that coarse acicular structures existed in the microstructure of the unmodified alloy and a short-rod structure appears as the addition of Y is 0.5 wt. %. In addition, when the amount of Yttrium added increases to 1.0 wt. %, the more fine fibrous eutectic Si structure appears, as shown in Figure 1(c). As the content of Yttrium increase until 1.5 wt. %, the structure of eutectic Si particles turns to rod-like morphology as shown in Figure 1 (d). However, when the amount of Y added is raised to 2.0 wt. %, the eutectic Si of needle-like structure starts to appear.

From the experimental results, it can be seen that 1.0 wt. % of Y has a good modification effect on the eutectic silicon alloy. This result obtained has shown similarity to other rare-earth. When 1.0 wt.% of Ce is added to Al-17%Si and had shown a favorable influence on the primary silicon and eutectic silicon of the alloy [3]. Similar studies also show that the addition of 1.0 wt.% of Ce alters the LM30 alloy with Ce exhibiting well distributes and finer primary silicon morphology [4].

The microstructure of the AlSi17 alloy with 2.0wt. % Y as presented in Figure1 (e) demonstrates that the higher yttrium content does not result in the grain refinement of the alloy. The Y addition had three effects roles which are reducing the length of needle-like phases (AlSi17), transforming the eutectic silicon particles from the coarse acicular structure into a fine fibrous form, and refining the α-aluminium dendrites.



(a) Unmodified **(b) 0.5 wt. % Y**

(c) 1.0 wt. % Y **(d) 1.5 wt. %Y**

(e) 2.0 wt. % Y

Figure 1: Microstructure Analysis

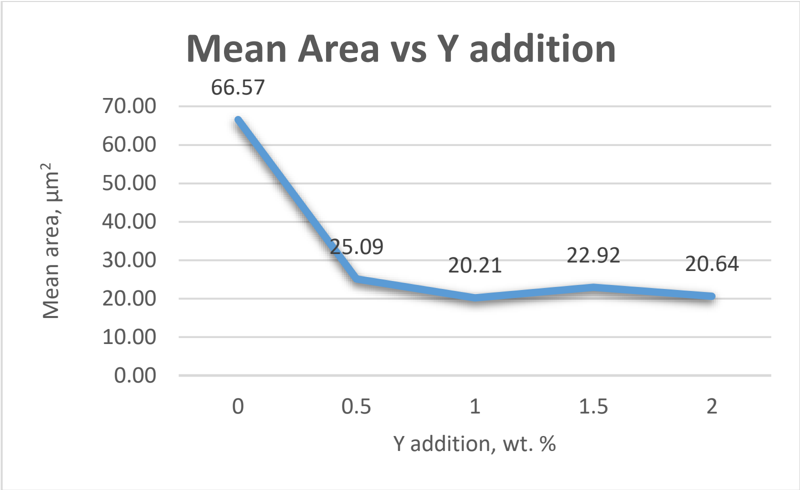


Figure 2: Graph of Mean Area, µm^2 versus Y addition, wt. %

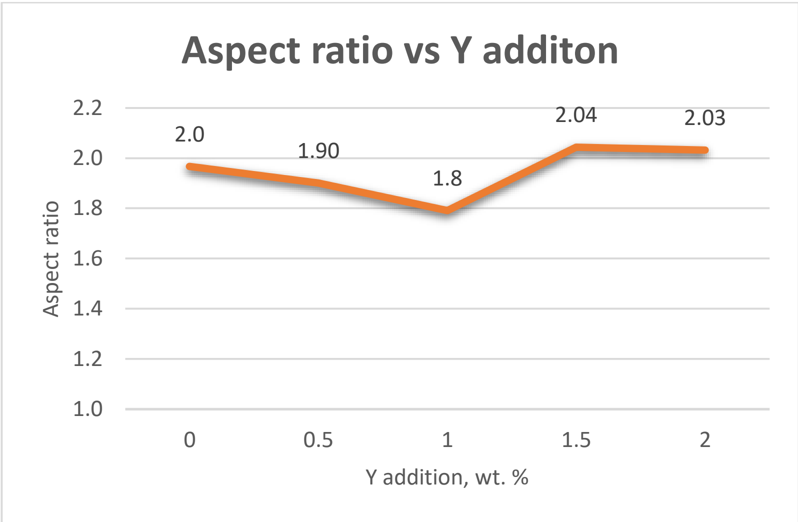


Figure 3: Graph of Aspect Ratio versus Y addition, wt. %

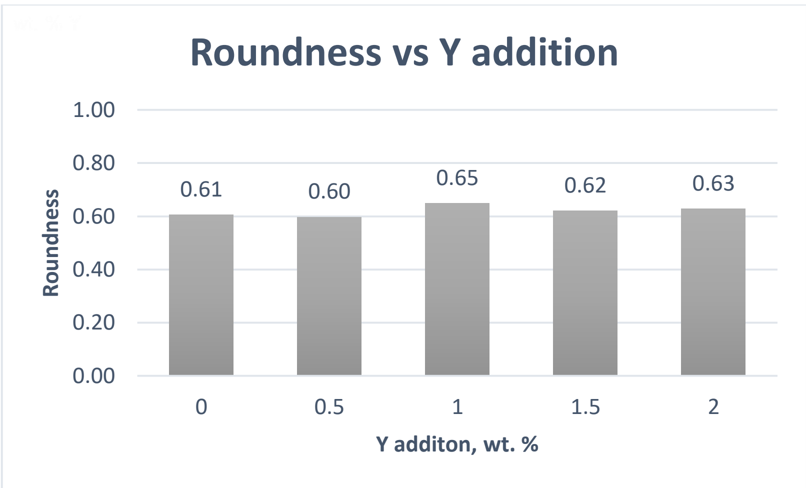


Figure 4: Graph of Roundness versus Y addition, wt. %

Figure 2 and 3 demonstrates the relationship between the mean area μm^2 and the proportion of Y addition as well as the relationship between the aspect ratio and the proportion of Y added to the LM30 aluminium alloy. The mean area, and aspect ratio of unmodified alloy are 66.57 μm^2 and 2.0 respectively. The discrepancy between the mean area and aspect ratio values indicates that silicon underwent a change, whose value is 25.09 μm^2 and the aspect ratio declined to 1.90. The formed silica microstructure becomes discontinuous and smaller. This can be seen in Figure 1 (b) when Yttrium is added at 0.5 wt. % the eutectic Si particles exhibited a short rod structure, and the edges and corners of the eutectic Si become smooth and round. When 1.0 wt. % of Y was added to the LM30 aluminium alloy, the mean area decreased from 66.57 μm^2 to 21.21 μm^2, while the aspect ratio decreased from 2.0 to 1.8. As the amount of Y addition increases, the aspect ratio value decreases. This determines the size of eutectic silicon particles dropped. Figure 4 shows the chart of roundness versus the percentage of Y addition. It can be noted that the roundness increased as the concentration of Y increased. The highest roundness value is when 1.0 wt. % of Y is added to LM30 alloy which is up to 0.65. It is believed that a small amount of rare earth addition to Al-Si alloys is sufficient to alter their microstructure.

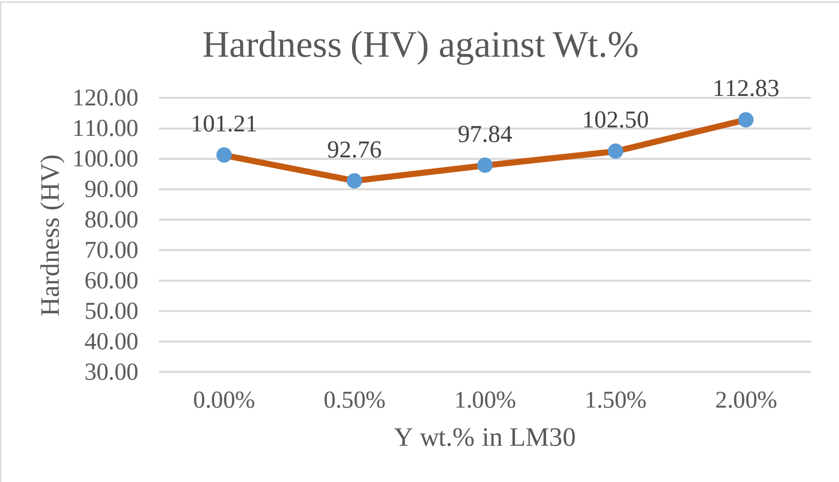


Figure 5: The effect of Y addition on the hardness values of LM30 aluminium alloy

Figure 5 shows the hardness values of the unmodified alloy and the modified alloy with the addition of Y addition. The hardness value is slightly decreased from 101.21 HV for the unmodified alloy to 92.76 HV for 0.5 wt. % Y. This may be attributed to a change in the morphology of eutectic Si particles, and the decrease in eutectic temperature during solidification may have contributed to a reduction in hardness. The reduction in hardness is associated with an increase in molecular dispersion among particles, which makes disengagement bowing considerably less difficult [5]. The hardness value shows an increasing trend until 2.0 wt. %. At 2.0 wt. %, the hardness value shows the greatest value among the others which is 112.83 HV The increase in hardening response may be a result of the solid solution strengthening and grain refinement [1]. A similar study has been conducted on Al-Si with the addition of rare earth Erbium, two factors can account for the improvement in microhardness in modified alloys. The first is the refinement and dissolution of eutectic Si, and the second is the precipitation of Al_3Er particles [6]. Therefore, it found that the addition of wt. % Y on LM30 alloy increases the hardness of the aluminium.

4. Conclusion

The purpose of this research to investigate the effect of yttrium addition on the microstructure and hardness properties of the aluminium LM30 alloy was achieved. The 1.0wt. %.of Y addition in LM30 aluminium alloy give the best modification which refined the eutectic silicon structure from coarse acicular structure to fine fibrous modified structure. The Y addition had three effects roles which are reducing the length of needle-like phases (Al17Si), transforming the eutectic silicon particles from the coarse acicular structure into a fine fibrous form, and refining the α-aluminium dendrites. The hardness value of the alloys improved as the mixture of yttrium content increased. The maximum hardness value is achieved at 2.0 wt. % Y compared to the other yttrium contents. The hardness properties of aluminium alloys are strongly affected as a result of the mixture of the rare earth element in terms of microstructure which is the refinement and dissolution of eutectic Si particles.

Acknowledgement

The authors would also like to thank the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia for its support.

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