

The Effect of Rare Earth Yttrium and Manganese Additive on Microstructure and Mechanical Properties of Aluminium Alloy

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Abstract

This research project investigates the impact of rare earth and additive, specifically yttrium (Y) and manganese (Mn), on the microstructure and mechanical properties of aluminium alloys. The incorporation of rare earth elements into aluminium alloys has been identified as a promising approach to enhance their performance for advanced engineering applications. In this study, various concentrations of yttrium and manganese were added to a base aluminium alloy (Al-Si) to observe the resulting changes in its properties. By examining the alloy's microscopic structure, it was discovered that adding both Yttrium (Y) and Manganese (Mn) not only made the structure finer but also helped spread the intermetallic particles more evenly. These improvements at the microscopic level led to better mechanical properties for the alloys. Hardness measurements also showed a noticeable increase, suggesting enhanced material toughness. Overall, the combination of yttrium and manganese in aluminium alloys significantly improves their microstructure and mechanical strength. This makes them suitable for demanding applications where high performance and durability are crucial, such as in aerospace, automotive, and marine engineering.

1. Introduction

Aluminium alloys find extensive applications across diverse industries such as automotive, aerospace, construction, and packaging, owing to their advantageous blend of lightweight characteristics, high strength, corrosion resistance, and cost-effectiveness. Aluminium alloys are engineered by adding specific elements like copper, magnesium, silicon, zinc, and manganese to pure aluminium, significantly enhancing its properties for specialised uses [1].

The addition of rare earth elements, such as yttrium, to aluminium alloys can improve their microstructure and mechanical properties. The REEs can form intermetallic compounds with the aluminium matrix, which can improve the high-temperature creep resistance and strengthen the alloy. This makes aluminium alloys with REEs attractive for use in harsh environments, such as marine and chemical processing applications. Yttrium (Y) addition to aluminium alloys, particularly the A5083 secondary aluminium alloy, has shown promising results in improving strength and performance [2].

The addition of manganese to aluminium alloys improves mechanical properties such as tensile strength and hardness. Manganese contributes to grain refinement and dispersion strengthening, particularly in alloys like Al-7Mg-0.15Ti, where Al₄Mn dispersoids inhibit grain growth during annealing [3].

2. Methodology

The project's methodology started with a metal casting process involving the aluminium alloy with yttrium and manganese, then pouring the molten mixture into a designated mould. The casting process will involve different weight percentages (wt%) added to aluminium alloy, which is AlSi+0wt.%, AlSi+0.3wt.%, AlSi+0.8wt.%, AlSi+1.2wt.%, AlSi+0.3wt.%+0.5wt.%, AlSi+0.8wt.%+0.5wt.%, and AlSi+1.2wt.%+0.5wt.%. After that, the analysis method will be divided into two parts, which are microstructure analysis and mechanical properties analysis. The microstructure analysis will be done by using Optical Microscopy (OM), Field-Emission Scanning Electron Microscopy (FESEM) with Energy Dispersive X-ray (EDX), and X-ray Diffraction (XRD). Next, the mechanical properties analysis was performed using the Vickers Hardness Tester to test the specimen toughness.

3. Result and Discussion

In this section, the result of the material's solidification will be shown and explained, along with the microstructure and mechanical properties of aluminium alloy mixed with rare earth Yttrium (Y) and Manganese as an additive. The microstructure was analysed using three methods, which are optical microscopy, FESEM with EDX, and XRD, while for the mechanical properties performed by test the toughness was tested using the Vickers Hardness Tester.

3.1 Optical Microscopy

Figure 1 and 2 shows the microstructure for the mixture aluminium alloy (Al-Si with Yttrium) and (Al-Si with Yttrium and Manganese). Figure 4.1(a), (b), (c), (d), (e), (f), and (g), the microstructure of the alloys exhibited a typical dendritic network structure, predominantly composed of dendritic α -Al matrix and hypoeutectic structure. From the grain size, the addition of Y in the base alloy of (Al-Si) affected the microstructure of the material uniformly. It clearly creates a greater branch uniformly when the Y is added, but when mixed with Mn, the microstructure becomes smaller with respect to the base alloy. From the optical microscopy, with a zoom of 200x, we can see the change in the grain of the material tested.

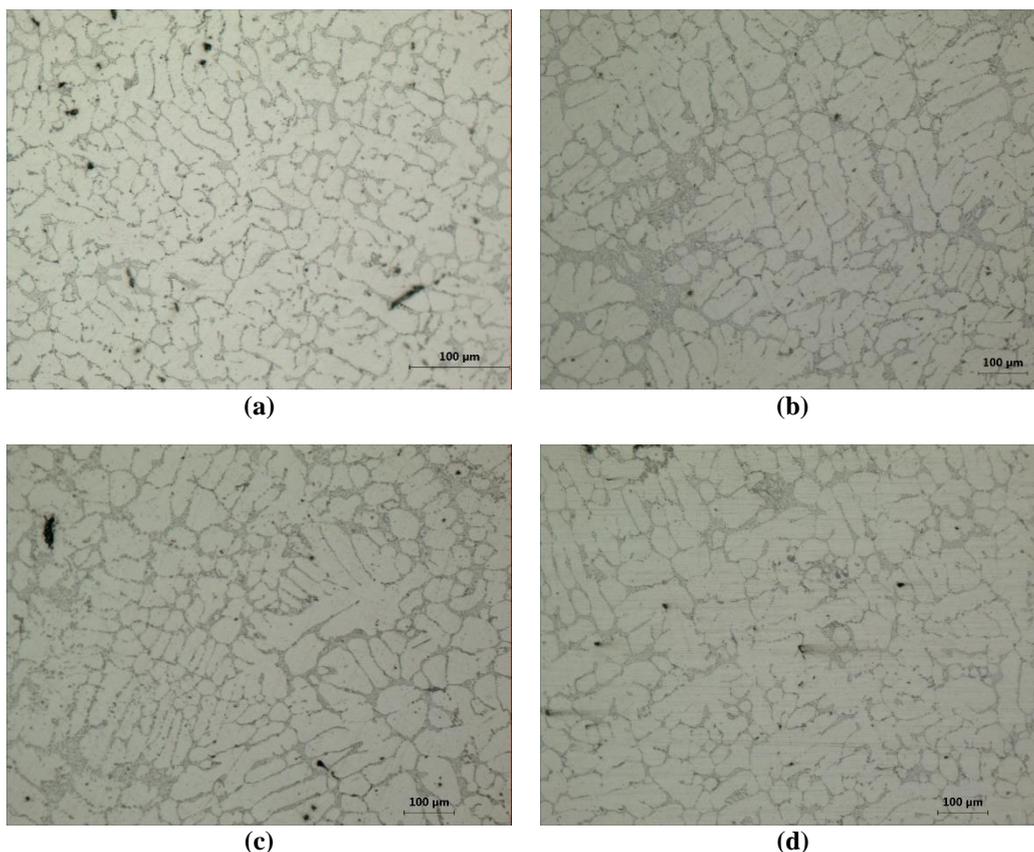


Fig 1 Optical microstructure observation (a)AlSi (b)AlSi(0.3%wt.Y) (c) AlSi(0.8%wt.Y) (d)AlSi(1.2%wt.Y)

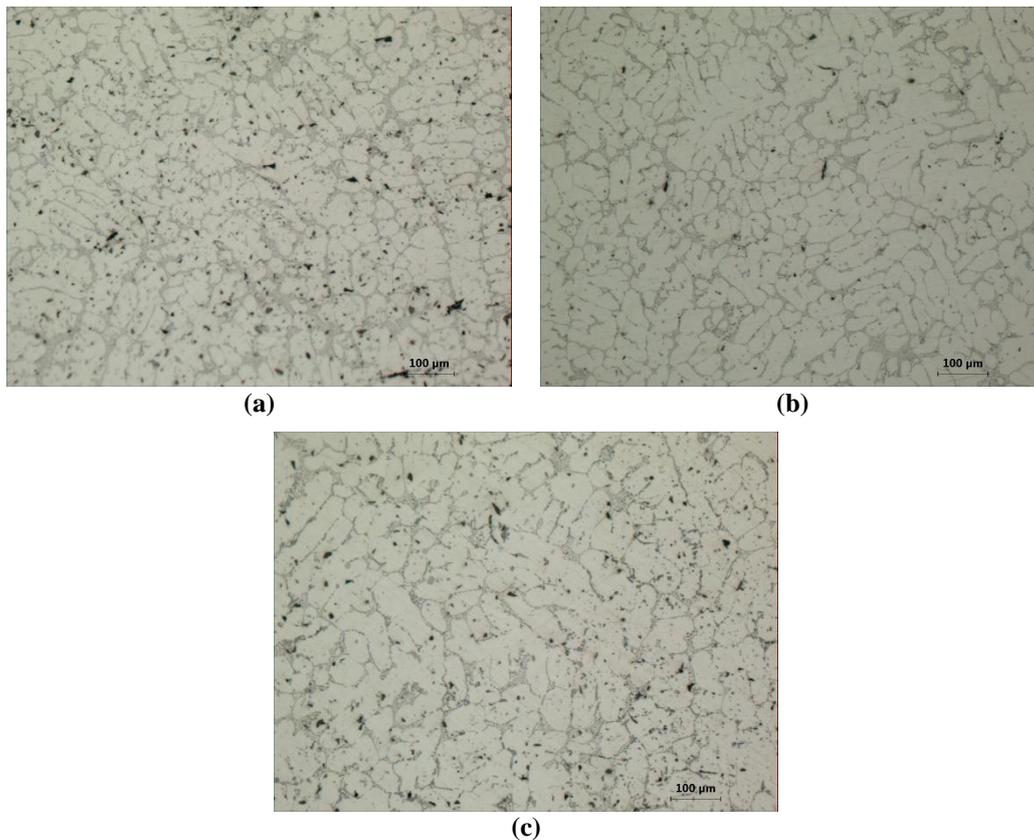


Fig 2 (a) *AlSi(0.3%wt.Y)(0.5%wt.Mn)* (b) *AlSi(0.8%wt.Y)(0.5%wt.Mn)* (c) *AlSi(1.2%wt.Y)(0.5%wt.Mn)*

3.2 FESEM with EDX Analysis

Based on the first sample, the sample contains Al and Si. The weight% in the mixture of aluminium alloy is Al is 90.90% and Si is 9.10%. For the second, a rare earth additive was added, which is Y. The weight% in the mixture of aluminium alloy is Al is 88.67%, Si is 10.35% and Y is 0.99%.

The third and fourth samples contained elements that were the same as those in the second sample, which are Al, Si, and Y. The weight% in the mixture of aluminium alloy is as follows: Al is 89.40%, Si is 9.81% and Y is 0.79% for the third sample, and Al is 89.85%, Si is 9.33% and Y is 0.83% for the fourth sample.

Another additive was added for samples 5, 6, and 7, which is Manganese (Mn), to improve toughness for the alloy. That made four elements contained Al, Si, Y, and Mn. The weight% in the mixture of aluminium alloy are Al is 90.15%, Si contained 7.61%, Y contained 1.73%, and Mn contained 0.51% for fifth sample, Al is 90.47%, Si contained 9.06%, Y contained 0.11% and Mn contained 0.37% for sixth sample and the last one Al is 89.41%, Si contained 9.23%, Y contained 0.28% and Mn contained 1.08%. For overall weight%, it does not fully describe how much weight percentage (wt%) is in the specimens; it just shows the weight% on the spectrum selected.

3.3 X-Ray diffraction (XRD) Analysis

X-Ray Diffraction (XRD) is used to analyse the crystallographic structure of materials by identifying peaks in intensity graphs that correspond to different crystal phases. This study examines the incorporation of yttrium (Y) and manganese (Mn) into an aluminium-silicon (Al-Si) alloy across seven samples with varying compositions. Sample 1, the presence of aluminium and silicon in the Al-Si alloy is confirmed by comparing XRD peaks with a reference database, showing aluminium as the primary phase and silicon as a minor phase, with no Y or Mn detected. Sample 2 shows the XRD pattern of Al-Si alloy with 0.3 wt% Y, indicating aluminium as the primary phase and an AlSi intermetallic phase, with a small peak at 35 Theta for Y. Sample 3 suggests a multiphase material with peaks for aluminium, silicon, and additional peaks likely due to Y at 47-48 and 56 Theta, with Y at 0.8 wt% possibly incorporated into the Al-Si matrix, causing peak shifts, and an unidentified peak at 69 Theta possibly due to oxygen or carbon. Sample 4, similar to Sample 3, with 1.2 wt% Y, shows matching peaks and the unknown peak at 69 Theta. Samples 5 and 6, no extra peaks due to Y and Mn are present, but sample 7 comes out with peaks matching the XRD pattern and an additional pattern for Manganese Silicide (MnSi).

3.4 Hardness Analysis

Fig. 3 shows the results of the hardness test for each specimen with various mix weight percentages of Yttrium and Manganese with the base aluminium alloy (Al-Si). The results display the specimen without any mixture of additives, indicating a hardness value of 74.1091 HV. Moreover, the hardness value for the second specimen, which is the mixture of Al-Si with 0.3%wt. is 74.4813, the value shows an increase, and it's a good sign because of the effectiveness of the mixture, but the hardness value of the third specimen should increase too, because of the increased weight percentage of Yttrium. The third specimen's hardness value decreases because at the indented point, there is not a large amount of Yttrium, so the value shows 72.059 HV. Other than that, the result for the fourth specimen also decreases, which is 68.5142 HV. For the start of the Manganese additive specimen, the value shows the lowest hardness value from all specimens, 66.9459 HV, and its increase for the sixth specimen at 72.2167 HV may be because the grain size shows an increase. Last but not least, the value for the mixture of Al-Si with 1.2%wt. Y and 0.5%wt. Mn got the highest value as predicted, 76.4477 HV, because this mixture was predicted to have the highest toughness among the others. The growth of grain size and the scattering of the intermetallic phase strongly develop the mechanical properties of the aluminium alloy.

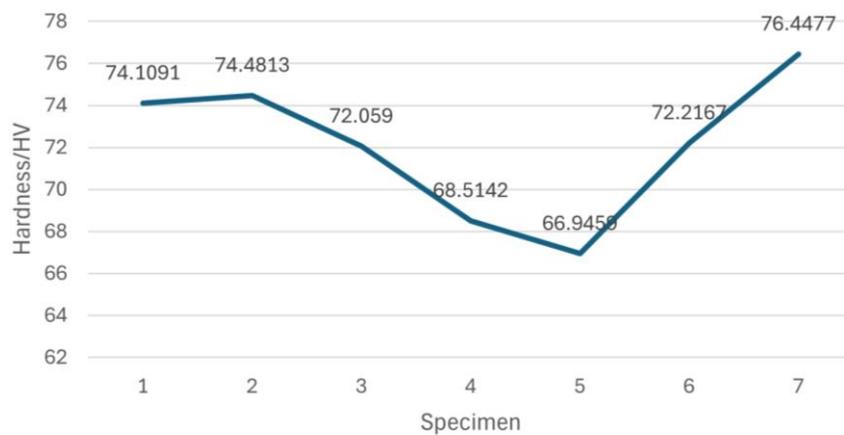


Fig 3. Hardness value (HV) for all specimens

Conclusion

The addition of Yttrium (Y) and Manganese (Mn) significantly influenced the microstructure and hardness of Al-Si alloys. Y promoted uniform dendritic growth, while the combined addition of Y and Mn refined the grain structure and facilitated intermetallic phase formation, particularly MnSi. Hardness testing confirmed that the Al-Si-1.2%Y-0.5%Mn alloy achieved the highest value (76.45 HV), indicating that the simultaneous addition of Y and Mn is more effective than Y alone in enhancing mechanical performance.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

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