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Effect of Yttrium on the Microstructure of Gravity Die Cast A356 Alloy

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Abstract -The efficiency of yttrium on grain refinement of gravity die cast A356 aluminium alloy is investigated in this work. The amount of yttrium added to A356 was specified at 0, 0.3 and 0.6 wt%. A series of melting and casting experiments was carried out to ensure that the intended weight percentage is achieved in the final casting. The composition of yttrium in the as-cast alloy was ensured to be mixed and dispersed equally by Energy-Dispersive X-Ray Spectroscopy (EDX). The master alloy Al-3Y was produced first and used to cast 0.3 and 0.6 wt% samples. The as-cast A356 alloy was then observed under the optical microscope to determine its microstructural characteristic. The specimens were also examined by Scanning Electrons Microscope (SEM). The inoculation of yttrium was found to be able to reduce the primary coarse α-Al and refine the eutectic silicon phase to finer and more fibrous structure. The grain size measured in μm^2/grain is 65.2 for pure A356, 51.1 for Al-0.3Y and 57.3 for Al-0.6Y. The addition of 0.3 wt% yttrium to A356 alloy was found to be the most optimal to achieve the finest grain and modify the coarse eutectic phase to be more fibrous. The grain refining efficiency of yttrium is attributed to its ability to reduce the growth of the coarse dendritic grains and smoothen the interface between α-Al and eutectic phase.

***Keywords*:** Yttrium, gravity die casting, grain refinement, eutectic phase.

1. Introduction

The A356 alloy belongs to a group of hypoeutectic Al-Si alloys. A conventional cast aluminium-silicon alloy, A356 has been increasingly used in the automotive industry due to its low cost, increased energy efficiency and the concomitant environmental benefits. In addition, aluminium-silicon alloys have castability and good corrosion resistance (Zhao et al., 2011). Besides, A356 also has some benefits in other mechanical properties like good ductility (Hu et al., 2012). The Si content in the alloy has low density and the latent heat is five times higher than Al. Silicone also reduces the weights of the alloy and improves its castability. It can be a very effective wear resistant material due to its high hardness (Kim et al., 2006). However, the formation of Al-Si alloys usually contains undesired acicular-like eutectic silicon and coarse primary silicon phase. The precipitated eutectic silicon has detrimental effects which may result in poor mechanical properties such as low strength and low ductility. Therefore, these precipitations must be modified and refined simultaneously so that the eutectic Si structure is transformed to a finer fibrous structure. Al-Ti-B master alloys are well established for use as grain refiners in aluminium-silicon alloys (Ghadimi et al., 2013). For example, mechanical properties can be improved, susceptibility to hot cracking is reduced and fluidity is improved. Other than Al-Ti-B alloy, the Al-Ti-C alloy is also a typical grain refiner. The quality of casting can be improved by grain refinement where the size of primary α-Al grains nucleated in the as-cast product is reduced. The efficiency of these refiners can be easily undermined by the presence of elements like Zr and V (Li P. et al., 2013).

The rare earth elements in conventional casting aluminium alloys have shown beneficial effects on melting and solidification. These elements reduce the content of impurities and the secondary dendritic arm spacing. Previous study shows that cerium, also plays a role similar to that of yttrium. It was reported that the mechanical properties of Al-Li-Mg alloys was improved and the negative effect of impurity Fe content was controlled by cerium addition (Zhang J. et al., 2011). The objective of current work is to obtain a verified weight percentage of yttrium addition in the A356 casting by using SEM-EDX so that the effect of yttrium on the grain refinement of A356 microstructure can be studied accurately. This will pave a path for further testing of its mechanical properties.

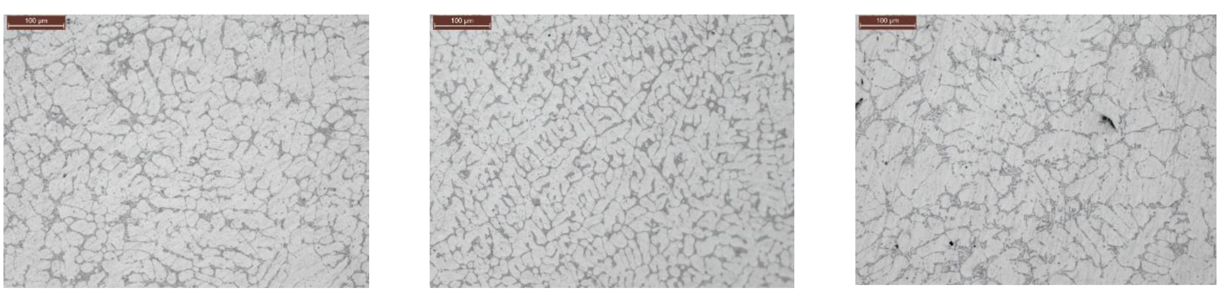
2. Experimental Method

The A356 was supplied in ingot form and it was cut into smaller pieces weighed about 1.3~1.6kg. The yttrium is in rock form with 99.9% purity. Initial casting was done by melting the predetermined A356 and yttrium in the electrical furnace to obtain a master alloy of Al-5Y. A gravity die casting mould was used to cast the Al-5Y master alloy. The desired composition of 5wt% yttrium was confirmed by using the EDX of a SEM machine. Subsequently, the Al-5Y master alloy was used to cast Al-0.3Y and Al-0.6Y respectively by adding different amount of pure A356 and Al-5Y in a smaller mould. The as cast sample was in cylindrical shape. Unmodified A356 was cast to benchmark the results. The top, middle and bottom sections of the cylinder were taken for cold mounting to prepare for grinding with 600, 800 and 1000 grit sizes. After that polishing was done with polycrystalline diamond paste of 15, 9, 6 and 3µm sequentially to obtain a very fine surface for optical microscopy and EDX-SEM examinations. Specimens on the SEM mounting plate is shown in Fig. 1. A total of five points on the surface will be measured for its yttrium composition and the results are averaged.

Fig. 1. Specimen on the Plate

3. Results and Discussion

The microstructures of optical microscope for 0, 0.3 and 0.6 wt%Y A356 casting are show in Fig. 2. The pure A356 which is originally unmodified contains acicular-like longish α-Al and coarse eutectic silicon phases. After addition of 0.3 wt%Y into A356 alloy, the microstructure shows the grains become finer and the eutectic phase is more fibrous. Addition of 0.6 wt%Y does not further reduce the grain size. Therefore, 0.3 wt% is the optimal level of yttrium to grain refine A356.



a) Pure A356 b) A356 + 0.3wt%Y c) A356 + 0.6wt%Y

Fig. 2. Optical microstructures

The EDX machine is working together with SEM to analyse the chemical elements contents in the sample. An example of EDX spectrum for 0.3wt%Y in A356 is shown in Fig. 3. The chemical elements data of all samples are given in Table 1. The results show that our addition of yttrium wt% is accurate as planned. The existence of manganese in 0.6wt%Y sample could be the cause of resistance to grain refinement of the α-Al due to the forming of Mn-Al precipitate that is not homogeneously distributed in the cast structure and impedes the recrystallization of α-Al. This results in elongated grain structure (Lloyd D. J., 1982).

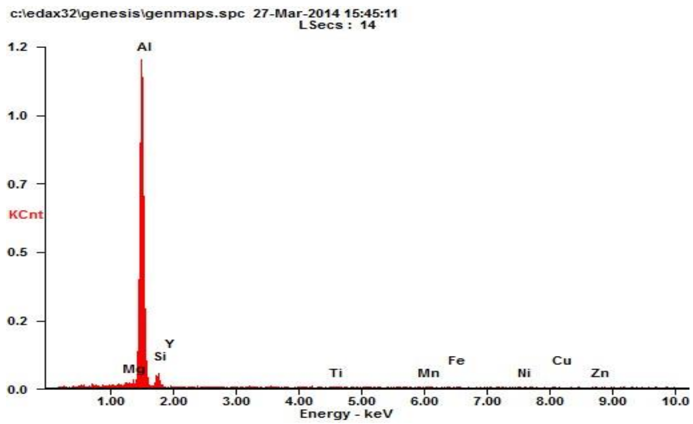
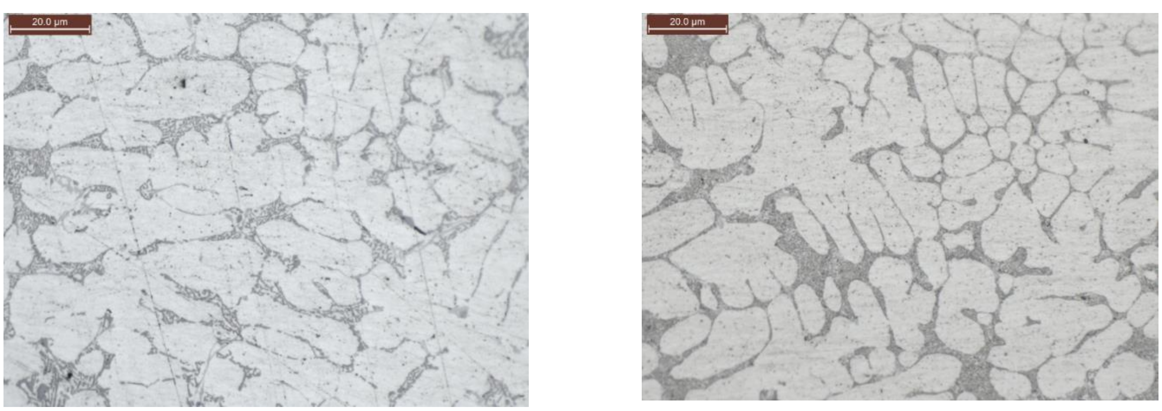


Fig. 3. EDX Analysis for A356 + 0.3 wt% Yttrium

Table. 1. EDX analysis (in wt%).

Elements	A356	A356 + 0.3wt%Y	A356 + 0.6 wt%Y
Mg	0.82	0.66	0.67
Al	92.31	92.23	92.05
Si	6.56	6.53	6.28
Y	0.00	0.33	0.61
Ti	0.18	0.14	0.13
Mn	0.00	0.00	0.11
Fe	0.13	0.11	0.15

Fig. 4 shows a closer look at the eutectic phase of the microstructure that compares the difference between unmodified A356 and 0.3 wt%Y. The unmodified A356 has a coarser eutectic phase while the 0.3 wt%Y modified alloy has a more fibrous, more globular and well dispersed eutectic phase in between the primary α-Al matrix. ASTM E112-10 is used as a guideline to measure grain size and the results are 62.93, 42.61 and 56.90 µm for 0 wt%, 0.3 wt% and 0.6 wt% of yttrium addition respectively.



a) Pure A356 b) A356 + 0.3wt%Y

Fig. 4. Eutectic phase of the die cast structure

4. Conclusion

Based on the microstructure observations done by optical microscope, the unmodified A356 aluminium alloy contains coarse eutectic silicon phase and α-Al grains. Addition of Yttrium was found to be effective to refine α-Al grains and the eutectic silicon phase was refined to be more fibrous. However, the dendritic structure of α-Al phase could not be transformed into globular structure. The optimal composition of 0.3 wt% yttrium in A356 was found to be able to achieve the finest grain size and produce the most fibrous eutectic phase by inhibiting the grain growth of α-Al and transforming the sharp eutectic silicon phase into a more fibrous form.

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