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RESEARCH ARTICLE

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Effect of heat treatment on gravity die-cast Sc-A356 aluminium alloy

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Abstract – The effects of scandium addition (0.00 wt.%, 0.2 wt.%, 0.4 wt.% and 0.6 wt.%) and T6 heat treatment on the microstructure and mechanical properties of A356 aluminium alloy have been investigated in the research reported in this paper. The Sc inoculated specimens were prepared by gravity die-casting, according to ASTM B557-06 standard. The cast samples were then subjected to heat treatment at solutionizing temperature of 540 °C for 8 h followed by water quenching and artificial aging at 160 °C for 6 h. The microstructure, microhardness and tensile strength of the heat-treated samples were examined with use of scanning electron microscope (SEM), optical microscope, Vicker's hardness tester, and Instron static machine respectively. Heat treatment was found to be able to effectively reduce grain size down to 16 μm (0.6 wt.% Sc), from 40 μm (original A356). The tensile strength was significantly improved, up to 338 MPa for heat treated 0.6 wt.% Sc-A356 having been achieved. The microhardness of 118 HV has been obtained for heat treated 0.6 wt.%Sc-A356.

Key words: A356, Scandium, Heat treatment, Mechanical properties, Gravity die-casting

1. Introduction

Aluminium is widely used in aviation, shipbuilding and automotive industries since World War II. Further industry development due to the urbanization and industrialization has made aluminium a substitute for heavier steel in automotive industry. Due to its cost, aluminium has been used in electrical engineering to replace copper. Aluminium and its alloys are widely used because they are lightweight, corrosion resistant, non-magnetic, of low melting point, moderately high coefficient of expansion, good thermal and electrical conductivity, malleable and ductile. Typical uses of aluminium are including stairs, elevators, grilles, decorative detailing, roofing, wall panels and many more [1].

Aluminium can be cast in any initial form by various casting processes and then subjected to downstream processes of rolling, extrusion, stamping, drawing and forging. For most applications, aluminium does not need protective coating however it needs anodizing for colour and strength improvement. In automotive, aerospace and structural applications, Al-Si alloys were used due to their high specific strength, specific stiffness, higher hardness, wear resistance and good elevated temperature resistance [2]. Al-Si alloys have microstructure that comprises a mixture of α-Al phase and eutectic Si, as well as various intermetallic phases that formed from other alloying elements. For example, A356 aluminium alloy is widely used in automotive due to its low density and excellent castability [3].

However, A356 aluminium alloy have coarse grains and large needle/platelike eutectic silicon which may contribute to low mechanical properties [4]. Previous researchers state that the mechanical properties of A356 can be improved by the addition of small amount of rare earth (RE) elements [5]. Furthermore, the cast structure of A356 aluminium alloy can be refined to improve its mechanical properties by applying heat treatment [6]. Scandium is a rare earth material that has gained popularity as alloying element in aluminium alloys for aerospace industry to achieve the requirements of high performance material either for strength or resistance to thermal shock. Scandium also helps reduce solidification cracking during welding of high strength aluminium alloys [7]. There are two typical heat treatment methods used for A356: T6 (solution heat treated up to 540 °C, water quenched then artificial aged up to 160 °C) and T5 (only artificial aged up to 160 °C) [8]. Comprehensive study on the effects of heat treatment on the mechanical properties of A356 inoculated with Sc at different weight percentages has been less reported in the literatures. Therefore, the current work aims to examine the microstructural characterization and to investigate the mechanical properties of heat treated A356 with different scandium weight percentages.

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Figure 1. Core and cavity of the die for die-casting.

2. Methodology and procedures

2.1. Sample preparation

In this work, four different compositions of scandium were produced through gravity die-casting, namely A356, A356 + 0.2 wt.% Sc, A356 + 0.4 wt.% Sc, and A356 + 0.6 wt.% Sc. The furnace crucible was set at 850 °C at the control panel for 90 min to fully melt A356 alloy. Then, the measured quantity of Al-2Sc was added to the molten aluminium alloy and the mixture was heated for 15 min for mixing purpose. Manual stirring of the melt was done for a few times to ensure the distribution of Sc to be even throughout the melt. Once the mixing process was done, the molten aluminium was poured into the cavity of the pre-heated gravity die-casting mould which has the design as shown in Figure 1.

2.2. Heat treatment

Four as-cast samples were machined into tension rods. The samples were heat treated in an electrical furnace at 540 °C for 8 h and quenched in cold water for 5 min. The samples were then naturally aged at room temperature for 20 h and then subjected to artificial aging at 160 °C for 6 h [9].

2.3. Testing

Surface morphology of the samples was examined by using optical microscope and Hitachi VP-SEM S-3400N. Energy dispersive spectroscopy (EDS) analysis was performed in conjunction with scanning electron microscope (SEM) examination. The uniaxial tensile test was performed at strain rate of 1 mm/min on the Instron 5582 universal testing machine until the specimen fractured. For Vicker's hardness test, the specimens were prepared according to ASTM E384.

3. Results and discussion

3.1. Microstructure evaluation

Figures 2–4 show the SEM results and average grain size of the samples before and after heat treatment process. The data shows that the grain size decreases as the wt.% of scandium increases. These outcomes verify that Sc can affect grain

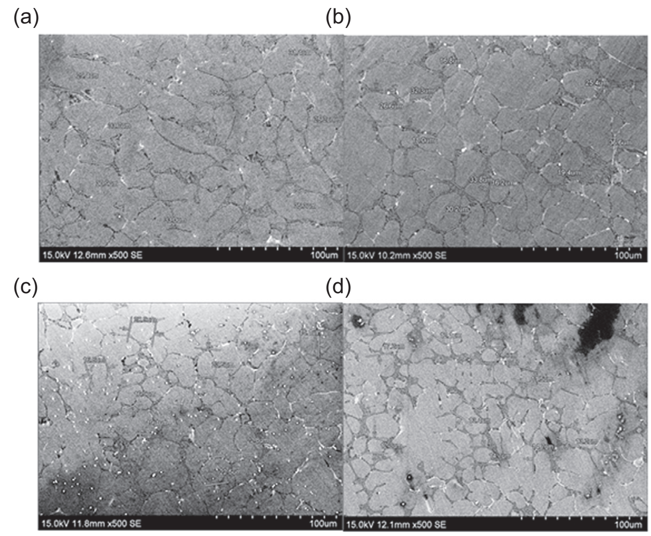

Figure 2. SEM micrographs of non-heat-treated samples (500×), (a) 0 wt.% Sc, (b) 0.2 wt.% Sc, (c) 0.4 wt.% Sc, and (d) 0.6 wt.% Sc.

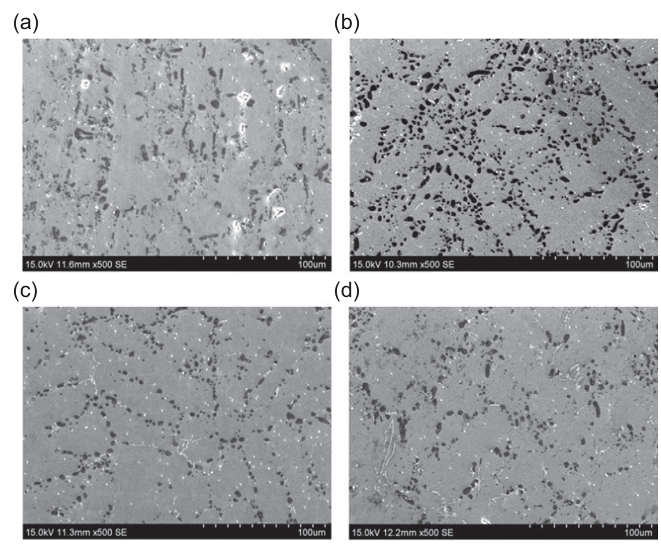

Figure 3. SEM micrographs of heat-treated samples (500×), (a) 0 wt.% Sc, (b) 0.2 wt.% Sc, (c) 0.4 wt.% Sc, and (d) 0.6 wt.% Sc.

refinement. Ma et al. [5] detected the addition of Sc could make the grain size of an alloy reduced and turned to non-dendritic form. However, when the percentage of Sc does exceed the needed amount, the grain size reduction is hardly seen. This is shown in Figure 4 which indicates only a slightly decrease from 0.4 to 0.6 wt.% of Sc; while from 0.2 to 0.4 wt.%, grain size reduction is significant. Costa et al. [10] stated that the formation of a perfect equiaxed structure is due to the precipitation of the Al_3Sc phase, which is the first forming phase from the melt in hypereutectic alloys. The columnar structure was replaced by a fine equiaxed structure throughout the sample. This is extremely important to the performance of a cast component. The fine and equiaxed grain microstructure

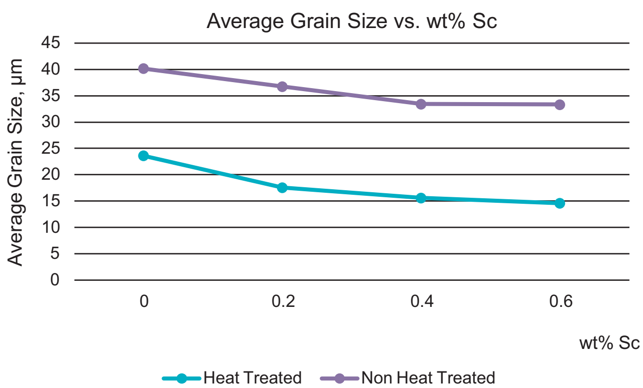

Figure 4. Graph of average grain-size vs. wt.% of scandium in A356.

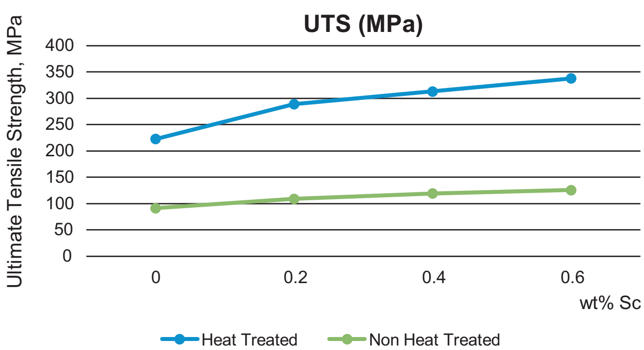

Figure 5. Graph of UTS (MPa) vs. wt.% of scandium in A356.

has numerous benefits in cast alloys: improving mechanical properties, distributing second-phase precipitates, reducing shrinkage porosity and improving the achievement of uniform anodized surfaces [9].

3.2. Tensile test evaluation

The result of tensile testing of heat treated samples is shown in Figure 5. The tensile strength increases when the scandium amount increases. Due to the modification and refining of the microstructure, tensile strength can be improved until 338 MPa by 0.6 wt.% of scandium which shows the highest tensile strength among the samples. The tensile strain developed during tensile test causes inhomogeneous deformation in the microstructure and so induces internal stresses between the intermetallic particles [11]. Higher value of tensile strength implies higher attraction between the particles.

3.3. Hardness test evaluation

Figure 6 shows the micro hardness of heat treated and non-heat treated samples. The result shows micro-hardness of the samples increase as the scandium percentage increase. Similar to tensile test result, 0.6 wt.% Sc sample has the highest value of microhardness. Both heat treated and non-heat treated samples shows almost consistent value when the scandium amount

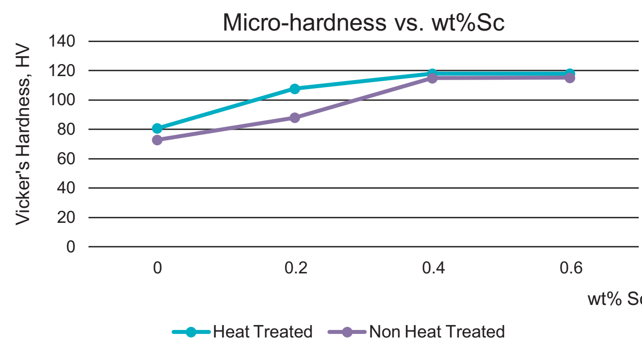

Figure 6. Vicker's hardness vs. wt.% of scandium in A356.

is 0.6 wt.%. Heat treated samples have lower grain size and improve the microhardness of A356. Non heat-treated samples show slightly lower reading of microhardness when compared to the heat-treated samples. The difference is only significant at 0.4 wt.% Sc.

4. Conclusions

In this research, A356 added with scandium were fabricated by using gravity die-casting and effects of the amount of scandium on microstructure and mechanical properties were investigated, referring to the heat treatment conditions. Based on this study, the following conclusions can be drawn:

1. The grain size of A356 could be refined by using Sc, reduced by 8% at 0.2 wt.% Sc but for further increase in Sc wt.%, the grain size does not reduce significantly. By applying heat treatment, the grain size of 0.2 wt.% Sc was reduced by 60% and does not reduce significantly after that.
2. By applying heat treatment, the ultimate tensile strength (UTS) of 0.6 wt.% Sc improves to 338.0 MPa, which is 52% improvement over the heat treated pure A356. For a practical purpose, using 0.4 wt.% of Sc should lead to achievement of a tensile strength of above 300.0 MPa, if heat treatment is applied.
3. It is shown that the microhardness has significant improvement: approximately 50% improvement, for 0.4 wt.% Sc, for both non-heat-treated and heat-treated samples. At 0.6 wt.% Sc, the microhardness is not improved further.

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