Abstract

AlSi7Mg0.3 alloy which is used in the manufacture of cast aluminium wheels contains a substantial volume fraction of eutectic silicon phase owing to its chemical composition. It is a common practice in aluminium foundries worldwide to add to Al-Si foundry alloys as much as 200-300 ppm of strontium in order to counteract the detrimental effects of the inherently brittle eutectic silicon. This study focuses on the modification practice of AlSi7Mg0.3 alloy in the manufacture of aluminium wheels. Strontium additions were made in a wide range from 100 ppm to 2000 ppm under industrial conditions. The microstructural features and the mechanical properties of the aluminium wheels thus produced were investigated and compared at various Sr addition levels. The experimental results were analyzed to identify the level of strontium addition for optimum microstructural features and mechanical properties.

1. Introduction

AlSi7Mg0.3 is the most popular aluminium foundry alloy for cast wheels as they offer low density, light weight and excellent castability [1]. The inherently brittle eutectic silicon phase has a great impact on the mechanical properties of aluminium wheels [2]. Therefore, it is very important to control the microstructure. Modification practice plays a vital role in Al-Si alloys. Refinement of the eutectic silicon phase improves mechanical properties [3]. Strontium is well known as a most commonly used modifier element which transforms the morphology of the eutectic silicon from coarse platelike to fibrous [4].

In addition to the refinement of the eutectic silicon, Sr addition also reduces the harmful effects of iron intermetallics [5,6,7,8]. For Al-Si alloys, the presence of high iron contents promotes formation of platelike iron-rich intermetallic compounds, such as $\beta$-Al$_5$FeSi intermetallics which can constitute high stress concentrations and thereby cause adverse effects on the mechanical properties [5]. Strontium can transform most of $\beta$-Al$_5$FeSi intermetallics from platelike to chinese script morphology [8,9].

Strontium modification is also accompanied by some unexpected changes such as porosity development [10,11]. Several studies have reported that strontium modification leads to an increase in the level of porosity [12,13]. Grain refinement and modification practices are applied together into Al-Si alloys and enhance the mechanical properties exceedingly [2]. Regrettably, there is an interaction between boron and strontium in Al-Si melts that form SrB$_6$ compounds [14] that can result in a decrease in the performance of strontium and resulted in a loss of modification [15].

The present work was undertaken to identify the effect of strontium contents from 100 to 2000 ppm on the microstructural features and mechanical properties of the AlSi7Mg0.3 alloy. Experiments were carried out to probe the changes in the morphology of eutectic silicon, iron-rich intermetallic compounds, the amount of porosity and the eutectic grain size.

2. Experimental Procedure

The primary AlSi7Mg0.3 ingots were melted in SiC crucibles of 4 kg capacity, using an electric resistance furnace. The chemical analysis of the alloy was obtained with a commercial optical emission spectrometer (Table 1). Five sets of castings were produced by adding to molten AlSi7Mg0.3 alloy different levels of strontium ranging between 100 ppm to 2000 ppm using commercial AlSr15...
master alloy rods. The melting and casting practices were exactly the same as those employed in serial production with routine melt treatment processes such as fluxing, grain refinement and modification. Following solidification, the five groups of castings were subsequently solution heat treated at 540°C for 4 hours and quenched in water, artificially aged at 155°C for 3 hours and paint-baked at 200°C for 3 hours.

**Table 1.** Chemical analysis of AlSi7Mg0.3 alloy used in present work/wt-%

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<thead>
<tr>
<th></th>
<th>Si</th>
<th>Mg</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Ti</th>
<th>Al</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>6.91</td>
<td>0.30</td>
<td>0.08</td>
<td>0.001</td>
<td>0.002</td>
<td>0.11</td>
<td>Bal.</td>
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Microstructural observations of eutectic silicon and iron intermetallic characteristics were carried out after etching with a 0.5% HF solution using optical microscopy. Macrostructures were examined using stereo microscope for porosity. The grain structures were checked after etching in a solution of % 32 HCl, % 32 HNO₃, %32 H₂O and % 4 HF.

Five tensile test samples were tested in tension (applied force is 100kN) on a Zwick Z100 model tensile testing machine at ambient temperature with a strain rate of 5 mm.min⁻¹. Impact test specimens for Charpy test were prepared in accordance with ASTM E23. Charpy impact tests were carried out on specimens by using the Pendulum model impact test device at room temperature.

### 3. Results and Discussion

The microstructures of the modified alloys are illustrated in Figure 1. Modified alloys all exhibit the fine fibrous eutectic silicon morphology. Modification of eutectic silicon is completely achieved at all Sr addition rates. There is hardly any difference in the Si morphologies at different Sr levels. It is thus fair to conclude that Sr addition of 100 ppm suffices to modify the morphology of eutectic Si from needle shaped to fibrous.

Fig. 2 shows the porosity distribution on sections of modified alloys. A marked increase in porosity level is noted with increasing Sr.

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**Fig 1.** Microstructures of the alloys modified with (a) 100, (b) 200, (c) 500, (d) 1000 and (e) 2000 ppm Sr.

**Fig 2.** Porosity distribution in alloys modified with (a) 100, (b) 200, (c) 500, (d) 1000 and (e) 2000 ppm Sr.
Fe-rich intermetallic phases in modified alloys are shown in Figure 3. The majority of the Fe-rich intermetallic particles were identified to be $\beta$-$\text{Al}_5\text{FeSi}$ needles. $\beta$-$\text{Al}_5\text{FeSi}$ needles were gradually replaced with Chinese script $\alpha$-$\text{AlFeSi}$ particles with increasing Sr, suggesting that Sr additions above 1000 ppm encourages the transformation of needle-like $\beta$-$\text{Al}_5\text{FeSi}$ phases to Chinese script $\alpha$-$\text{AlFeSi}$ phase. Furthermore, Sr-additions above 1000 ppm results in the fragmentation of $\beta$-$\text{Al}_5\text{FeSi}$ needles and thus reduces their length.

![Fig. 3. Microstructures consisting of the Fe-rich intermetallic phase of the alloy modified with (a) 100, (b) 200, (c) 500, (d) 1000 and (e) 2000 ppm Sr.](image)

Figure 4 shows the grain structures of the modified alloys. The smallest grain sizes are achieved in the alloy modified with 100 ppm Sr and the grain size increases with increasing Sr.

![Fig. 4. Grain structures of the alloy modified with (a) 100, (b) 200, (c) 500, (d) 1000 and (e) 2000 ppm Sr.](image)

Typical values of yield and tensile strength and elongation for the investigated alloys are illustrated in Figure 5. While the yield and tensile strength values appear to be rather insensitive to the Sr addition rate, a marked increase in elongation is noted with increasing Sr. Nevertheless, the Charpy impact energy values at 25°C imply lower impact properties with increasing Sr content (Fig. 5.(b)).

![Fig. 5. (a) Yield strength and UTS, (b) elongation and Charpy impact energy values of the modified alloys.](image)
4. Conclusions

The following conclusions may be drawn:

1. Modification of eutectic silicon can be achieved with as much as 100 ppm Sr.
2. Sr increases the porosity content starting at 500 ppm Sr.
3. Sr helps to transform ß-Al5FeSi needles to Chinese Script D-AlFeSi.
4. Sr interferes with the grain refinement process and leads to some grain coarsening owing to its affinity to Boron.
5. Sr provides a marginal increase on yield strength and ultimate tensile strength while improves the elongation values.
6. In spite of the increase of elongation values, the fracture energy falls increasing Sr.

References