Effect of Some Additions on the Structure and Mechanical Properties of A356 - Al Si Alloy

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Abstract: The modified eutectic silicon or refinement of primary silicon particles with uniform distribution are desired in real casting practice. In order to modify the microstructure of Al-Si alloys, many techniques are available. However the deliberate additions of several elements during melting are still the most easy and efficient way than other different techniques. Trace addition of Na or Sr is commonly used to modify the eutectic structure of Al-Si alloys from coarse plate-like structure in unmodified alloys to fine fibrous morphology in modified ones. Such a fine structure can potentially increase the ductility and tensile properties of these alloys. It was concluded that, 7% Si – 0.3% Mg alloys appeared to be a good refiner when treated by the additions of 0.2-0.4% AlTiB master alloy. In the same time, this alloy reaches good modification by the addition of 0.2-0.4 wt % of Al-10% Sr. The obtained results were compared with those obtained by using the traditional well known AlSr master alloy, AlTiB and a mixture of both AlTiB and AlSr.

Keywords: Alloy, Mechanical Properties, Structure Properties

1. Introduction

Aluminum Silicon Alloys constitute the major part of significant application among aluminum foundry alloys. They exhibit a highly desirable combination of characteristics such as castability, weldability, corrosion resistance and machinability. Mechanical properties are also controlled by the cast structure [1].

The modification process of aluminum, silicon alloys causes dramatic morphological change of silicon phase from coarse flake-like to fine fibrous or spherical shapes [2-3]. The modification of AlSi alloys is usually achieved by the addition of small amount of about 0.01% by wt. of metallic sodium to the melt just before casting, where the actual amount of sodium needed may be as little as 0.001%. The mechanism by which the microstructure, size and the form of silicon phase are modified have been clearly studied [4, 5].

Also, Na or Sr are commonly used to refine the eutectic structure of Al-Si alloys, from a coarse plate-like structure in unmodified alloys; to fine fibrous morphology which is usually obtained by only trace additions of these elements. Such a fine structure can potentially increase the ductility and tensile properties of these alloys.

From another point of view, titanium and boron additions to Al-Si alloys in the form of master alloys (such as AlTi, AlB and AlTiB alloys) were found to be effective as grain refiner [6]. Al-5Ti-1B grain refiner was reported to be the best for the grain refinement of Al-Si alloys [7]. But they suffer from agglomeration of borides and defects during subsequent forming operation and poisoning by certain elements like Zn and Cr.

On the other hand, the grain refinement of aluminum and its alloys is normally achieved by melt inoculation with Ti and B in the form of aluminum master alloys. Experimental results have shown that, Ti can significantly refine aluminum grains, whilst the presence of B will further enhance grain refining performance. It has been reported that, Ti/B ratio of master alloy is an important factor and the best grain refining
effects can be obtained using master alloy with a Ti:B ratio of 5:1 by wt. %. The AlTiB master alloys contain TiB$_2$ particles, which tend to form clusters having effective particle sizes. Also, aluminide crystals can exhibit several morphologies and show a marked variation in size.

It was found also that, grain refinement has several benefits in cast alloys like improving the mechanical properties of the casting, the distribution of the second phase and microporosity on a fine scale, better feeding to eliminate shrinkage porosity, improved ability to achieve a uniform anodized surface as well as better strength and fatigue life [8].

However, this work aims to study the effect of some additions, like AlB, AlTiB and AlSr as refiner/modifier in separate or combined mixtures, on the macro- and microstructure as well as the mechanical properties of AlSi alloys.

2. Experimental Work

Experiments for grain refining and modification were performed in a muffle furnace provided with a temperature regulator. Al-Si alloys were melted firstly and Si content was analyses and cast iron for the mechanical testing). Revealing the microstructure, copper for the chemical analysis is done using a simultaneous quantometer, model 3460, ARL, Switzerland.

A series of experiments were carried out using the chosen grain refiners/modifiers as shown in Table 1. Chemical analysis was carried out for the macrostructure, copper for the chemical analyses and cast iron for the mechanical testing).

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<table>
<thead>
<tr>
<th>Addition</th>
<th>Si %</th>
<th>Mg %</th>
<th>Ti %</th>
<th>Sr %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without</td>
<td>6.89</td>
<td>0.28</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.2 AlTiB</td>
<td>7.02</td>
<td>0.31</td>
<td>0.019</td>
<td>-</td>
</tr>
<tr>
<td>0.3 AlTiB</td>
<td>6.97</td>
<td>0.29</td>
<td>0.025</td>
<td>-</td>
</tr>
<tr>
<td>0.4 AlTiB</td>
<td>7.01</td>
<td>0.29</td>
<td>0.14</td>
<td>-</td>
</tr>
<tr>
<td>0.2 AlB</td>
<td>7.02</td>
<td>0.31</td>
<td>0.007</td>
<td>-</td>
</tr>
<tr>
<td>0.3 AlB</td>
<td>7.09</td>
<td>0.32</td>
<td>0.006</td>
<td>-</td>
</tr>
<tr>
<td>0.4 AlB</td>
<td>7.08</td>
<td>0.28</td>
<td>0.006</td>
<td>-</td>
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<tr>
<td>0.2 AlSr</td>
<td>6.95</td>
<td>0.28</td>
<td>0.006</td>
<td>0.020</td>
</tr>
<tr>
<td>0.3 AlSr</td>
<td>6.93</td>
<td>0.30</td>
<td>0.006</td>
<td>0.039</td>
</tr>
<tr>
<td>0.4 AlSr</td>
<td>7.06</td>
<td>0.31</td>
<td>0.007</td>
<td>0.130</td>
</tr>
<tr>
<td>0.2 AlTiB + AlSr</td>
<td>6.98</td>
<td>0.28</td>
<td>0.014</td>
<td>0.020</td>
</tr>
<tr>
<td>0.3 AlTiB + AlSr</td>
<td>6.98</td>
<td>0.29</td>
<td>0.014</td>
<td>0.021</td>
</tr>
<tr>
<td>0.4 AlTiB + AlSr</td>
<td>6.97</td>
<td>0.31</td>
<td>0.022</td>
<td>0.038</td>
</tr>
</tbody>
</table>

Samples from each alloy are prepared metallographically according to ASTM E13 [9, 10]. Then they were inspected to reveal and characterize their microstructure by using optical microscope to identify the existing phases (their shapes, forms and distribution). Metallographic investigation was carried out using Metallurgical optical microscope, Olympus, Japan.

3. Results and Discussion

3.1. Structure

3.1.1. Unmodified Al- 7% Si Alloy

The structure of the 7% silicon hypoeutectic aluminum alloy in the as cast condition (without additions) for either refining or modification; can be shown in Figure 1. The obtained alloy is consisting of primary aluminum grains and an eutectic of aluminum and silicon. The shape of the eutectic structure is found to be needle like, as coarse grains with some other precipitates along with the grain boundaries.

Aluminum grains represent the global of the volume fraction of the structure while the eutectic represents small amount. The structure is in general of coarse grains according to (ASTM A-E 112) standard.

3.1.2. Alloys Treated With Al-Ti-B

The macrostructure and microstructure of Al-Si 7% after the addition of Al-5%Ti-1%B can be shown in Figures (2, 3). The refining alloy can be used to enhance the grain refining activity through the power of both titanium aluminide (TiAl$_3$) and titanium borides (TiB$_2$). The results didn’t show large differences than those obtained with the of Al-3%B.

3.1.3. Alloys Treated With Al-B

The modified macro- and micro structures obtained by the addition of % Al-B between 0.2- 0.4 can be shown in Figures 4 and 5. Such additions lead to: Refining the microstructure and more uniform distribution of eutectic along the grain boundaries of the primary aluminum and dendritic grain boundaries are observed. The silicon constitution in the structure of the eutectic 0.2 AlB is finer than the untreated alloy.

Subsequent additions of 0.3% and 0.4% of Al-3%B lead to more refining of the structure. Silicon constituent of the eutectic precipitates is finer than that without additions.

3.1.4. Alloys Treated with Al-Sr

The effect of adding Al-10% Sr on the macro- and microstructure is shown in Figures (6, 7). It revealed that, silicon constituent in the eutectic alloy is successfully refined.

It was found that, the addition of low Al-10% Sr as 0.2% was clearly effective in the refining (modification) of silicon precipitates, while 0.3% Al-10% Sr showed good effect on the grain refining of the structure. Increasing Al-10% Sr additions up to 0.4% showed a remarkable grain refining effect on the structure [7].

3.1.5. Alloys Treated with a Mixture of Al-Ti-B and Al-Sr

In this group, aluminum boards (AlB$_3$) worked as a grain refiner which successfully forms nuclei for solidification. Extra additions of AlTiB mains extra nuclei for solidification and then more grain refining occur.

The effect of adding Al-5% Ti-1% B, can be shown in Figure 3. It can be seen that, it is used to enhance the grain refining activity through the power of both titanium aluminide (TiAl$_3$) and Titanium borides (TiB$_2$). The results didn’t show any larger differences than those obtained by adding Al-3%B.

The effect of adding a mixture of Al-5% Ti-1% B + Al-10% Sr is exhibited in Figures 8 and 9, where they show remarkable effect on the structure. Silicon is generally modified even at low concentration of such mixture.
more modification of silicon is noticed by increasing the addition of the mixture from 0.3% to 0.4%. The mixture shows also a noticeable effect on the primary aluminum dendritic structure.

At both 0.2% and 0.3% additions of the mixture, the coarse grains enhanced the structure, while at 0.4% addition of the mixture, the structure is somewhat well refined. On the other hand silicon is modified even at a low percentage of the $(\text{AlTiB} + \text{AlSr})$ mixture. More spheroidization of silicon was noticed by increasing the percentage of the mixture up to 0.4%.

![Figure 1. 7% Si without additions, (X500).](image)

![Figure 2. Macrostructure of Al-7% Si without and with different AlTiB additions.](image)

![Figure 3. Microstructure of Al-7% Si with different AlTiB content, (X500).](image)

![Figure 4. Macrostructure of Al-7% Si without and with different AlB additions.](image)
Figure 5. Microstructure of Al-7% Si with different AlB content, (X500).

Figure 6. Macrostructure of Al-7% Si without and with 0.4 AlSr.

Figure 7. Microstructure of Al-7% Si with different AlSr content, (X500).
3.2. Mechanical Properties

The untreated and treated alloys were tested using tensile, hardness and elongation with different refining and modifier additions. Figure (10) shows the relation between the percentage of each individual additive and the mechanical properties. Also, all the obtained data are summarized in Table (2).

It can be noticed that, the ultimate tensile strength (UTS) increased linearly and sharply with increasing AlSr content. Most alloys show a remarkable increase in the hardness. The high hardness value (139 HB) was observed for the \((\text{AlTiB} + \text{AlSr})\) mixture On the other hand the elongation % values appeared clearly to depend on the type of addition. The addition of \((\text{AlTiB} + \text{AlSr})\) mixture also shows the highest tensile strength values that reached (256 MPa) which is about 300% of the value exhibited by the untreated Al 7% Si alloy.

The elongation decreased with increasing UTS and HB. The maximum value shown with AlB addition is 3.9%. It is clear from these results that \((\text{AlTiB} + \text{AlSr})\) refine/modified mixture act to produce cast alloy with relatively high ductility.

Table 2. Results of mechanical testing.

<table>
<thead>
<tr>
<th>Addition</th>
<th>UTS, MPa</th>
<th>Elongation, %</th>
<th>Hardness, HB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without</td>
<td>90.9</td>
<td>2.331</td>
<td>83</td>
</tr>
<tr>
<td>0.2 AlTiB</td>
<td>170.1</td>
<td>3.48</td>
<td>108</td>
</tr>
<tr>
<td>0.3 AlTiB</td>
<td>172.2</td>
<td>3.30</td>
<td>115</td>
</tr>
<tr>
<td>0.4 AlTiB</td>
<td>175</td>
<td>3.28</td>
<td>119</td>
</tr>
<tr>
<td>0.2 AlB</td>
<td>195.3</td>
<td>3.90</td>
<td>115</td>
</tr>
<tr>
<td>0.3 AlB</td>
<td>205</td>
<td>3.70</td>
<td>120</td>
</tr>
<tr>
<td>0.4 AlB</td>
<td>210.7</td>
<td>3.65</td>
<td>122</td>
</tr>
<tr>
<td>0.2 AlSr</td>
<td>227.3</td>
<td>3.633</td>
<td>121</td>
</tr>
<tr>
<td>0.3 AlSr</td>
<td>228.8</td>
<td>3.543</td>
<td>124</td>
</tr>
<tr>
<td>0.4 AlSr</td>
<td>234.6</td>
<td>3.43</td>
<td>128</td>
</tr>
<tr>
<td>0.2 AlTiB +AlSr</td>
<td>238.1</td>
<td>3.41</td>
<td>130</td>
</tr>
<tr>
<td>0.3 AlTiB +AlSr</td>
<td>248.4</td>
<td>3.33</td>
<td>134</td>
</tr>
<tr>
<td>0.4 AlTiB +AlSr</td>
<td>256</td>
<td>3.25</td>
<td>139</td>
</tr>
</tbody>
</table>
4. Conclusion

(a) The macrostructural evolution of eutectic in hypoeutectic AlSi alloys using grain refiner of different levels (of AlTiB, AlB, AlSr) or combined additions was characterized by a well-modified eutectic silicon structure. Increasing Al-10% Sr addition up to 0.4% showed a remarkable refining effect on the structure.

(b) Silicon is modified even at a low percentage of the AlTiB + AlSr mixture. More spheroidization of silicon was noticed by increasing the percentage of the mixture up to 0.4%

(c) AlTiB + AlSr mixture act to increase the ultimate tensile strength of the Al-7% Si sharply by about 300% compared to that exhibited by the untreated alloy.

(d) The best results of modification and refinement was observed when using a combined addition of Al Sr and Al-5Ti-1B.

References


