Modification of Al-Si Alloy (LM 28) By MnO₂ Addition

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Abstract— Modification of primary silicon was studied in Al-Si hypereutectic alloys with 17 Wt % silicon content. The alloys modified through non-conventional method using oxide addition. The effect of oxide on the morphology and size of Si phases in the hypereutectic Al-Si alloys investigated. The results show that the addition of MnO₂ to the hypereutectic Al-Si alloys can modify the primary Si phases. In this, the primary Si phase is refine and the shape of the eutectic Si changed from long needle-like to short rod-like. The modified Al-17Si alloys have microstructures consisting of uniformly distributed α-Al phase, eutectic Al-silicon and fine primary Si - particles in the inter-dendrite region. The evaluation of microstructure showed that the fraction of primary silicon decreased with increasing the oxide content. The improved properties are dependent on uniform distribution of fine fibrous eutectic Al-silicon and fine primary Si- particles. The finest microstructure could be observed respectively when 2.5 wt % and 5 wt% MnO₂ were added. In this case, hardness, tensile strength and % elongation increased than without added casting.

Keywords—Hardness, Hypereutectic Al-Si alloy, Microstructural Refinement, Modification, Tensile strength.

I. INTRODUCTION

With the development of automobile industry, the need of hypereutectic Al-Si alloys is increasing greatly [1,4]. The hypereutectic Al-Si alloys are widely used in cylinder block, air compressor and pump due to their high fluidity, good wear resistance and low thermal expansion [1,2,3,4,7]. The normal microstructures of hypereutectic Al-Si alloys usually consist of coarse primary Si phase and needle like eutectic Si, which greatly aggravate the mechanical properties of these alloys, and limit the application of them. Therefore, the control of the morphology and size of Si phase has become the most important processing for these alloys [4]. Having a combination of low coefficient of thermal expansion, high specific strength and high wear resistance, hypereutectic Al–Si alloys are attractive for a range of applications such as in military, liner-less engine blocks, cylinder liners, heavy duty engines, aeronautic components, pistons and pumps [1,2,3,7]. The high wear resistance of these alloys, due to the hard primary Si particles that form during solidification, comes at the expense of extremely short machine tool life [3].

To minimize this problem the primary Si particles must be controlled to a uniform small size and spatial distribution [2]. It is known that an equi-axed grain structure ensures uniform mechanical properties, reduced hot tearing, improved feeding to eliminate shrinkage porosity, distribution of second phases and microporosity on a fine scale as well as improved machinability in castings. Researchers may use P [4, 5], Sr [6-12] and Na [12-13] for modification. The cost of Sr is quite high compare to sodium and phosphorus. We used low cost MnO₂ for modification.

II. EXPERIMENTAL METHOD

Started with Al-17%Si (Wt %) alloy as a base alloy, MnO₂ was added to the base alloy to observe the modification of it. The mother alloy was melted at 700°C in an electrical resistance furnace .When the alloy was completely melted, at the suitable temperature then 2.5 and 5wt%MnO₂ was added into the alloy melt respectively. To ensure homogeneity, the melt was gently stirred, held for about 5 min, then degassed it with N₂, cleared off dross and adjusted temperature. Lastly, the melt poured into a metal mould at 700°C in the forms of cylindrical bars.

For microstructural analysis the sample were sectioned transversally and prepared by standard polishing procedures. The microstructure of the specimen was observed using Neophot 02 Optical microscope and Scanning Electron Microscope (JEOL-56 LV). Size of the primary silicon was measured by using SEM (BSE mode). Under mechanical test, hardness and tensile tests carried out. Tensile properties of modified and unmodified sample were determined from Monsanto 20 tensile testing machine with a strain rate of 0.05 mm per minutes. The average of three readings was taken as tensile strength value. The size of the tensile test specimen with a 5 mm gauge diameter,25 mm gauge length and total length of the specimen 47mm diameter. Hardness test was carried out on 20mmx 10mm long cylindrical test bar using Brinell Hardness Tester. It was performed with a load 31.625 kg for 10 seconds by a steel ball indenter of 2.5 mm diameter. The average of six readings was taken as the hardness value.
III. RESULT AND DISCUSSION

The chemical analysis of raw LM 28 and MnO₂ added alloys were analyzed using Spectrometer and SEM-EDS results. Table 1, 2 and 3 indicate the results of same.

**TABLE 1**
CHEMICAL COMPOSITION OF RAW LM 28 ALLOYS

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Si (wt. %)</th>
<th>Ni (wt. %)</th>
<th>Cu (wt. %)</th>
<th>Mg (wt. %)</th>
<th>Mn (wt. %)</th>
<th>Al (wt. %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw(LM28)</td>
<td>17.8-18.0</td>
<td>0.71</td>
<td>0.80-0.95</td>
<td>0.99</td>
<td>-1.03</td>
<td>0.13-0.15</td>
</tr>
</tbody>
</table>

**TABLE 2**
CHEMICAL COMPOSITION OF 2.5% MnO₂ ADDED ALLOYS

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Si (wt. %)</th>
<th>Ni (wt. %)</th>
<th>Cu (wt. %)</th>
<th>Mg (wt. %)</th>
<th>Mn (wt. %)</th>
<th>Al (wt. %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MnO₂ added</td>
<td>18.05</td>
<td>5.02</td>
<td>1.08</td>
<td>0.42</td>
<td>0.45</td>
<td>Balance</td>
</tr>
</tbody>
</table>

**TABLE 3**
CHEMICAL COMPOSITION OF 5% MnO₂ ADDED ALLOYS

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Si (wt. %)</th>
<th>Ni (wt. %)</th>
<th>Cu (wt. %)</th>
<th>Mg (wt. %)</th>
<th>Mn (wt. %)</th>
<th>Al (wt. %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MnO₂ added</td>
<td>20.28</td>
<td>9.29</td>
<td>1.21</td>
<td>0.66</td>
<td>0.76</td>
<td>Balance</td>
</tr>
</tbody>
</table>

A. Microstructure study

**Optical microstructure**

Optical micrographs of cast Al–17%Si piston alloy at 100X are shown in figure 1 (a). It indicates that the polyhedral-shaped primary silicon particles are present in the matrix of Aluminium–Silicon eutectic apart from eutectic silicon that is long, interconnected and needle in shape. Microstructures of modified Al–17%Si alloy with MnO₂ are shown in figure 1 (b) 1(c). The microphotograph indicates the absence of large size primary silicon phase. Only 5-10% of primary silicon is observed in its original state. Size difference of primary silicon indicated in fig. 2(a) 2(b) 2(c) at 250X magnification. Careful observation to micrographs at 250X figure 2(b,c) revealed that MnO₂ modifies the eutectic silicon and primary Si-particles.

**SEM (BSE mode) Microstructure:**

Below figure: 3 indicate the size analysis of primary silicon by SEM. BSE (Back Scattered Electron) mode is used to identify the size of primary silicon in modified and unmodified samples. The unmodified Al-17Si Fig. 3(a) contained coarse primary Si with average particle size of approximately 26 μm. Figure 3(b) & 3(c) shows the influence of modifier on the morphology of Si phase. The modified structure by 2.5% MnO₂ added sample (3(b)) reflex the size of primary silicon in the range of 19-20 μm. the modified structure by 5% MnO₂ added sample indicate the size of the primary silicon in the range of 12-13 μm.

**Figure 1.** Optical micrographs of conventionally cast Al-17Si alloy without Etchant at low magnification, 100X:
- a) Al-17Si without modification to show the size and distribution of primary Si and;
- b) Al-17Si with modification by 2.5%MnO₂
- c) Al-17Si with modification by 5%MnO₂

**Figure 2.** Optical micrographs of conventionally cast Al-17Si alloy without Etchant at low magnification, 250X:
- a) Al-17Si without modification to show the size and distribution of primary Si and;
- b) Al-17Si with modification by 2.5%MnO₂
- c) Al-17Si with modification by 5%MnO₂

**Figure 3.** Size analysis of primary silicon by SEM(BSE) Mode
- a) Al-17Si without modification
- b) Al-17Si with modification by 2.5%MnO₂
- c) Al-17Si with modification by 5%MnO₂
Below figure: 4 indicate the SEM analysis of an alloy. BSE (Back Scattered Electron) mode used to identify the location of the heavy metals (Fe, Cu, Si, Ni) and light metal (Al, Mg etc) into α-aluminium. The grey colour embossed type needles or network like structure indicate the presence of primary silicon enriches region (eutectic silicon), which further strengthen the final alloy. As the increase in MnO$_2$ content, the structure becomes more and more refined.

![SEM micrographs of conventionally cast Al-17Si alloy, at magnification, 100X:](image)

(a) Al-17Si without modification  
(b) Al-17Si with modification by 2.5% MnO$_2$  
(c) Al-17Si with modification by 5% MnO$_2$

![SEM micrographs of conventionally cast Al-17Si alloy, at magnification, 270X:](image)

(a) Al-17Si without modification  
(b) Al-17Si with modification by 2.5% MnO$_2$  
(c) Al-17Si with modification by 5% MnO$_2$

Figure 6 shows the EDS analysis indicates the chemistry of the overall alloy. The following figure 7 indicates the EDS spectrum at different locations and conforms the presence of heavy elements at different locations like fig 7(a) indicate Cu enrich phase with weight percentage of Al-63.75,Mn-0.98,Cu-10.37. Similarly, at other location the amount of heavy alloying element are at different concentration Ni enrich phase with weight percentage of Al-76.29,Mn-0.76,Cu-3.13,Ni-11.46 as presented in fig 7(b). The obvious location of Si is also identified and presented in fig 7(c) with Si enrich phase with weight percentage of Al-53.86,Si-15.54,Mn-1.98,Cu-2.94,Ni-6.21.

![Overall analysis of LM 28 alloy by EDS](image)

![EDS analysis of LM 28 alloy modified by 5% MnO$_2$ at various locations](image)

B. Hardness:

To understand the effect of MnO$_2$ content on hardness value of LM 28 and MnO$_2$ added LM 28 alloys were investigated. It was observed that the hardness of modified samples is increased as compared of unmodified. Such improvements in hardness can be attributed to two basic factors i.e. reduced average primary silicon particle size and marginal modification of eutectic silicon needle into fine fibrous form. Figure 8. Shows the graphical representation of hardness value of the alloy before and after modification respectively. All the given values are of an average of six measurements. It was found that by increasing the MnO$_2$ content, the hardness value of an alloy increases.

![Effect of modification level on the hardness of Al-17wt%Si alloy casting](image)
C. Tensile Properties Measurement:

To understand the effect of MnO₂ content on tensile strength value of LM 28 and MnO₂ added LM 28 alloys were investigated. It was observed that the tensile strength of modified samples is increased as compared of unmodified. Figure 9. shows the graphical representation of tensile strength value of the alloy before and after modification respectively. After modification the sharpness of the silicon needle reduces and it increases the tensile strength. All the given values are of an average of three measurements. It was found as the MnO₂ content increases tensile strength value also increases from 121 MPa for 2.5% MnO₂ addition to 130 MPa for 5% MnO₂ addition and its value increases from the raw material (75-76 Mpa).

Figure 9. Effect of modification level on the ultimate tensile strength of Al-17wt.% Si alloy casting

IV. CONCLUSION

From the experimental results, following conclusions can be drawn.
1. The MnO₂ plays a significant role in modification of primary silicon particles.
2. The modified hypereutectic cast Al–17%Si-2.5%MnO₂ and Al–17%Si-5%MnO₂ alloy results in finer and more uniformly distributed primary silicon particles compared to that of conventional Al-17Si cast alloy. Besides the refinement of primary silicon particles, modification of eutectic silicon particles was also observed.
3. There is increase in hardness value.
4. Tensile Strength obtained is higher than the raw material sample and also increases with the MnO₂ content.
5. Optical micrographs represent the modify structure due to the addition of MnO₂ content which is similar to the structure modify by addition of Sr, Na and P.

REFERENCES