CHAPTER 8

Effect of varying Si content on the microstructure, hardness and tensile properties of Al-Si-0.4Mg-2Ni alloy

8.1 Introduction

In the previous chapter 7, the effect of varying Ni content and the effect of varying test temperature on the hot tensile properties of Al-8Si-0.4Mg alloy were studied. In this chapter, the effect of varying Si (4, 8, 12 and 16wt%) content on the microstructure, hardness and mechanical properties of Al-Si-0.4Mg-2Ni alloy will be investigated.

8.2 Results and discussion

8.2.1 Microstructural observation

Fig. 8.1 shows the microstructure of as-cast Al-0.4Mg-2Ni-4Si alloy. The particle shaped eutectic Si morphology is clearly visible in the Fig.8.1. Figs. 8.2, 8.3 and 8.4 shows the microstructures of as-cast Al-0.4Mg-2Ni-8Si, Al-0.4Mg-2Ni-12Si and Al-0.4Mg-2Ni-16Si alloys. The eutectic Si morphology is found to be particle shaped in all these alloys.

![Particle shaped Si](image)

Fig.8.1 Microstructure of as-cast Al-0.4Mg-2Ni-4Si alloy
Fig. 8.2 Microstructure of as-cast Al-0.4Mg-2Ni-8Si alloy

Fig. 8.3 Microstructure of as-cast Al-0.4Mg-2Ni-12Si alloy
The Co addition to Al-Fe-Si alloy reduces the size of the eutectic Si phase as studied by Kilicaslan et al.[1]. An addition of Cr to Al-Fe-Si alloy is found to have no significant influence on the elongated morphology of eutectic Si as reported by Hong et al. [20]. From the microstructural observation of Al-8Si-0.4Mg alloy (refer Fig.4.1), it is observed that the eutectic Si morphology is elongated. After 2wt% Ni addition (refer Fig.4.2), the eutectic Si morphology changes to particle shaped. Hence it can be observed that the eutectic Si morphology changes from elongated to particle shaped by the Ni addition and for all Al-0.4Mg-2Ni-xSi (x= 4, 8, 12 and 16) alloys, eutectic Si morphology remained to be particle shaped.

8.2.2 Intermediate phase formation

The SEM image of Al-0.4Mg-2Ni-xSi (x=4, 8, 12 and 16) alloys are shown in Figs.8.5, 8.7, 8.9 & 8.11 respectively. The white particles distributed in the images show the presence of an intermediate phase in the modified alloy. The EDS spectrum of the white particle and base metal in Fig.8.5 is shown in Fig.8.6. It is observed from the EDS spectrum that Al and Ni are present in the white particle and in the base metal Al, Ni, Si and Mg are present. The composition analysis showed that the intermediate phase is Al₃Ni. Similarly for the Al-0.4Mg-2Ni-xSi(x=8, 12 and 16) alloys also, the composition analysis of the corresponding EDS spectrums showed that Al₃Ni was the intermediate phase formed during solidification.
Fig. 8.5 SEM image of Al-0.4Mg-2Ni-4Si alloy

Fig. 8.6 EDS result of Al-0.4Mg-2Ni-4Si alloy (a) white particle and (b) base metal
Fig. 8.7 SEM image of Al-0.4Mg-2Ni-8Si alloy

Fig. 8.8 EDS result of Al-0.4Mg-2Ni-8Si alloy (a) white particle and (b) base metal
Fig. 8.9 SEM image of Al-0.4Mg-2Ni-12Si alloy

Fig. 8.10 EDS result of Al-0.4Mg-2Ni-12Si alloy (a) white particle and (b) base metal
Fig. 8.11 SEM image of Al-0.4Mg-2Ni-16Si alloy

Fig. 8.12 EDS result of Al-0.4Mg-2Ni-16Si alloy (a) white particle and (b) base metal

Fig. 8.13 shows the XRD pattern for the as-cast Al-8Si-0.4Mg-2Ni alloy. It is seen from the pattern that the peaks correspond to the Si, Al and Al$_3$Ni (JCPDF no. 800005, 652869 & 652418 respectively). Similarly for Al-0.4Mg-2Ni-xSi (x=8, 12 and 16) alloys (Figs 8.14 to 8.16) (all in the as-cast condition), the same XRD pattern was observed as in the Al-4Si-0.4Mg-2Ni alloy corresponding to the Si, Al and Al$_3$Ni (JCPDF no. 800005, 652869 & 652418 respectively).
Fig 8.13 XRD result of Al-0.4Mg-2Ni-4Si alloy

Fig 8.14 XRD result of Al-0.4Mg-2Ni-8Si alloy
Al-Si alloy added with Ti, leads to the formation of Al$_3$Ti intermediate phase as reported by Saheb et al.[7] and Al-Si-Fe alloy added with Co, leads to the formation of Al$_3$Co intermediate phase as reported by Kilicaslan et al.[1]. So it can be observed that the presence of intermediate phase can be confirmed through EDS analysis. Further it can be concluded that the intermediate phase Al$_3$Ni forms during solidification in all the Al-0.4Mg-2Ni-$x$Si ($x$= 4, 8, 12 and 16) alloys.

Figs. 8.17, 8.19, 8.21 and 8.23 shows the TEM image of Al-0.4Mg-2Ni-$x$Si ($x$= 4, 8, 12 and 16) alloys respectively. The SAED (selected area electron diffraction) patterns for Al-0.4Mg-2Ni-$x$Si ($x$= 4, 8, 12 and 16) alloys are shown in figs 8.18, 8.20, 8.22 and 8.24 respectively.
Fig 8.17 TEM image of Al-0.4Mg-2Ni-4Si alloy

Fig 8.18 SAED pattern of Al-0.4Mg-2Ni-4Si alloy
Fig 8.19 TEM image of Al-0.4Mg-2Ni-8Si alloy

Fig 8.20 SAED pattern of Al-0.4Mg-2Ni-8Si alloy
Fig 8.21 TEM image of Al-0.4Mg-2Ni-12Si alloy

Fig 8.22 SAED pattern of Al-0.4Mg-2Ni-12Si alloy
The diameter(f) of the rings were calculated and \((f/2)^{-1}\) was found for these rings and these d-spacing values were matched with JCPDF data cards. Al3Ni data card (JCPDF no. 652418) showed peaks at these d-spacing values. Thus it was concluded that Al3Ni is the intermediate phase forming in all these alloys. Al3Ni phase has been marked in all the figs (8.17, 8.19, 8.21 and 8.23) and was found to be similar to Al3Ni phases reported in ref[53] and ref[54].
8.2.3 Hardness data

Hardness values obtained for Al-0.4Mg-2Ni-xSi (x=4, 8, 12 and 16) alloys are shown in Table 8.1.

Table 8.1 Hardness data for varying Si content

<table>
<thead>
<tr>
<th>Sl.no.</th>
<th>Alloy</th>
<th>Hardness (Hv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Al-0.4Mg-2Ni-4Si</td>
<td>396</td>
</tr>
<tr>
<td>2</td>
<td>Al-0.4Mg-2Ni-8Si</td>
<td>430</td>
</tr>
<tr>
<td>3</td>
<td>Al-0.4Mg-2Ni-12Si</td>
<td>441</td>
</tr>
<tr>
<td>4</td>
<td>Al-0.4Mg-2Ni-16Si</td>
<td>455</td>
</tr>
</tbody>
</table>

Fig. 8.25 shows the hardness vs. wt% Si plot for Al-0.4Mg-2Ni-xSi (x=4, 8, 12 and 16) alloys in the aged condition (error bars included). It is observed from the plot that the formation of Al3Ni intermediate phase in Al-0.4Mg-2Ni-xSi (x=4, 8, 12 and 16) alloys, is the reason for increasing hardness.
Table 8.2 shows the %increment in Hardness for Al-0.4Mg-2Ni-xSi (x=4, 8, 12 and 16) alloys. It is observed from the table 8.2 that the % increment in hardness is an increasing function with increasing Si addition in the base alloy and is due to the formation of Al3Ni intermediate phase in Al-0.4Mg-2Ni-xSi (x=4, 8, 12 and 16) alloys studied. Thus it can be concluded that the hardness increases with increasing Si content in Al-Si-0.4Mg-2Ni alloy.

Table 8.2 %Increment in Hardness

<table>
<thead>
<tr>
<th>Sl no.</th>
<th>Hardness with 4 wt% Si addition(Hv)</th>
<th>Hardness with 8 wt% Si addition(Hv)</th>
<th>%Increment in Hardness(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>97</td>
<td>430</td>
<td>7.9</td>
</tr>
<tr>
<td>2</td>
<td>Hardness with 4 wt% Si addition(Hv)</td>
<td>Hardness with 12 wt% Si addition(Hv)</td>
<td>%Increment in Hardness(%)</td>
</tr>
<tr>
<td></td>
<td>97</td>
<td>462</td>
<td>10.2</td>
</tr>
<tr>
<td>3</td>
<td>Hardness with 4 wt% Si addition(Hv)</td>
<td>Hardness with 16 wt% Si addition(Hv)</td>
<td>%Increment in Hardness(%)</td>
</tr>
<tr>
<td></td>
<td>97</td>
<td>480</td>
<td>12.97</td>
</tr>
</tbody>
</table>

An increase in the hardness was observed after the Co addition while studying the influence of Co on the as cast Al-Fe-Si alloy in ref[1] by determining the hardness. The effect of Co addition on melt spun Al-5Fe-25Si alloy was studied by ref [2] by determining the micro hardness and an increase in the micro-hardness was observed after the Co addition up to 5wt%. An increase in the hardness was observed after Ni addition till 0.7 wt% into Al-Fe-Si alloy as reported in ref [14], 0.5 wt% Ni addition into Al-Cu alloy as reported in ref[15] and 0.5 wt% Ni addition into Al-Zn alloy as reported in ref [17] (all in the aged condition). Similarly, based on all these studies it can be observed that Si addition into Al-0.4Mg-Si-2Ni alloy can lead to increase in the hardness values.

8.2.4 Tensile test data

Table 8.3 shows the tensile properties obtained for Al-0.4Mg-2Ni-xSi (x= 4, 8, 12 and 16) alloys in the aged condition.
Table 8.3 Tensile properties for varying Si content

<table>
<thead>
<tr>
<th>Sl.no.</th>
<th>Alloy</th>
<th>UTS(MPa)</th>
<th>YS(MPa)</th>
<th>% El</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Al-0.4Mg-2Ni-4Si</td>
<td>68</td>
<td>60</td>
<td>5.0</td>
</tr>
<tr>
<td>2</td>
<td>Al-0.4Mg-2Ni-8Si</td>
<td>130</td>
<td>101</td>
<td>5.1</td>
</tr>
<tr>
<td>3</td>
<td>Al-0.4Mg-2Ni-12Si</td>
<td>154</td>
<td>112</td>
<td>5.0</td>
</tr>
<tr>
<td>4</td>
<td>Al-0.4Mg-2Ni-16Si</td>
<td>165</td>
<td>120</td>
<td>5.2</td>
</tr>
</tbody>
</table>

Fig. 8.26 shows the ultimate tensile strength results of Al-0.4Mg-2Ni-xSi (x=4, 8, 12 and 16) alloys. It is observed that the UTS increases linearly with the increasing Si content. The increasing UTS with the increasing Si content is due to the presence of an intermediate phase Al₃Ni formed during solidification.

![Ultimate tensile strength vs. wt% Si](image)

**Fig.8.26 Ultimate tensile strength vs. wt% Si**

Fig.8.27 shows the yield strength results of Al-0.4Mg-2Ni-xSi (x=4, 8, 12 and 16) alloys in the aged condition. It is observed from fig 8.27 that the YS increases linearly with the increasing Si content. The increasing YS with the increasing Si content is due to the formation of intermediate phase Al₃Ni.
The elongation does not vary significantly with the increasing Si content as observed from the table 8.2. Thus it can be observed that the Si addition has no detrimental effect on the elongation. It can be observed from the table 8.2 that the UTS is an increasing function of the hardness.

Fig. 8.28 shows the YS vs. hardness plot for Al-0.4Mg-2Ni-xSi (x = 4, 8, 12 and 16) alloy combination. It can be observed from the plot 8.28 that the YS is also an increasing function of the hardness. Further it can be observed from the table 8.2 that the %E1 is not a function of the hardness.

An increase in the UTS and YS after the Ni addition in Al-Cu alloy was reported by Naeem et.al[15] and this improvement in the tensile properties was attributed to the refinement of grains.
An increase in the UTS and YS was reported after the Ni addition in Al-Zn alloy by Naeem et al [17]. Ref [4] has studied about the Ti addition into Al-5Mg alloy and reported that the tensile properties of the base alloy increases with increasing Ti addition. Ref [9] has also reported an increase in tensile properties of Al-5Mg-0.6Mn alloy with increasing Ti addition, and this increase was attributed to the Al3Ti intermediate phase formation. From all these findings, it can be similarly observed that the tensile properties of cast Al-0.4Mg-2Ni-Si alloys can also be remarkably improved with the Si addition because of the transitional stage Al3Ni formation. This phase offers resistance to the dislocation motion in the alloy there by increasing the strength of the alloy.

8.3 Conclusions

The following conclusions are drawn based on the results of this study.

- As seen from SEM, EDS examination, XRD, TEM and SAED pattern investigation, Al3Ni is the transitional stage framed in Al-0.4Mg-2Ni-xSi (x= 4, 8, 12 and 16) compounds.
- Increasing Si expansion prompts to an expansion in the hardness of the Al-0.4Mg-2Ni-Si combination and is expected to be because of the Al3Ni transitional stage occurring.
- %Increment in hardness increments with expanding Si expansion into the base combination.
- UTS of the Al-0.4Mg-2Ni-Si combination increments, with expanding Si content and this is because of the formation of an intermediate phase Al3Ni.
- With expanding Si content, YS of the Al-0.4Mg-2Ni-Si combination increments.
- The increment in YS is also a direct result of the development of a transitional stage Al3Ni.
- %El remains consistent with expanding Si content, in the Al-0.4Mg-2Ni-Si combination.
- Si expansion has no impeding impact on the %El of the Al-0.4Mg-2Ni-Si combination.
- UTS and YS are found to be increasing functions of hardness.
- %El was not found to be a function of hardness.
- Increasing Si expansion, prompts to an expansion in the hardness and mechanical properties of the Al-0.4Mg-2Ni-Si combinations.