Effect of Na impurity on the elastic constants of Al-5%Mg alloy
不純物NaがAl-5%Mg合金の弾性定数におよぼす影響

Kenichi Tanigaki†, Keitaro Horikawa†, Hidetoshi Kobayashi†, Kanta Adachi†, Nobutomo Nakamura†, and Hirotsugu Ogi†

1. Introduction

Al-Mg alloys are widely used because of their favorable properties at room temperature, for example, strength, ductility and corrosion resistance. However, it is known that coarse-grained Al-Mg alloys containing 5mass% Mg (Al-5%Mg alloys) show grain boundary fracture and low ductility at high temperatures (around 573K)1,2). It is considered to be caused by a segregation of Na below 1 mol ppm to grain boundaries3).

In recent years, it was revealed that 5083 alloy containing 237 ppm of Na shows low ductility at room temperature3). It is possible that an Al-5%Mg alloy containing several hundred ppm of Na shows the same embrittlement at room temperature. However, the ductility investigation of Al-5% Mg alloys has been only carried out up to 28 ppm of Na4). Furthermore, it was reported that Na segregation decreases the grain boundary energy of Al tilt grain boundaries using \textit{ab-initio} calculations within the framework of the Rice-Wang thermodynamic model5). Several hundred ppm of Na may decrease elastic constants of Al-5%Mg alloys if it induces the embrittlement at room temperature.

In this study, we prepared two kinds of Al-5% Mg alloys containing 0.1 and 200 ppm of Na. The effects of a trace amount of Na on tensile properties and elastic constants at room temperature were investigated using quasi-static tensile test and the resonance ultrasound spectroscopy (RUS).

2. Experimental procedure

Two kinds of Al-5% Mg alloys were melted and cast in Ar atmosphere of 0.1 MPa using Al of 99.999% purity and Mg of 99.98% purity. The Al-5%Mg alloy containing less than 0.1 ppm of Na (Al-5%Mg-0.1ppmNa) and that containing approximately 200 ppm of Na (Al-5%Mg-200ppmNa) were prepared. The alloy ingots were homogenized at 703 K for 18 h in Ar atmosphere. The chemical compositions are shown in \textbf{Table 1}.

![Fig. 1 Stress-strain relationships of the Al-5%Mg alloys at room temperature.](image1)

![Fig. 2 SEM micrographs of the fracture surfaces in the Al-5%Mg-0.1ppmNa alloy (a) and the Al-5%Mg-200ppmNa alloy (b).](image2)

\textbf{Table 1} Chemical compositions of Al-5% Mg alloys (mol ppm).

<table>
<thead>
<tr>
<th>Alloys</th>
<th>Mg</th>
<th>Na</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-5%Mg-0.1ppmNa</td>
<td>5.68</td>
<td>&lt;0.0001</td>
<td>Bal.</td>
</tr>
<tr>
<td>Al-5%Mg-200ppmNa</td>
<td>5.48</td>
<td>0.0193</td>
<td>Bal.</td>
</tr>
</tbody>
</table>

\*tanigaki@me.es.osaka-u.ac.jp
Elastic constants of the Al-5%Mg alloys were determined using the tripod-type RUS method. The resonance frequencies of ideal free vibration can be measured by this method because no external force was applied to the specimen, except for the specimen weight, and no coupling agent was used. The resonance frequencies were computed using the Ritz method.

The rectangular-parallelepiped specimens are not perfectly isotropic because the average grain sizes are large. Therefore, we determined nine independent elastic constants $C_{ij}$ of the specimens and then estimated the isotropic elastic constants using the Hill approximation.

### 3. Results and discussion

The quasi-static test was carried out at room temperature with a strain rate of $8.3 \times 10^{-4} \text{s}^{-1}$. Figure 1 shows the effects of a trace amount of Na on the tensile mechanical properties of the Al-5%Mg alloys. The Al-5%Mg alloy was clearly embrittled at room temperature due to 200 ppm of Na. The SEM micrographs of fracture surfaces are shown in Figure 2. Al-5%Mg-200ppmNa showed an intergranular fracture and its reduction of area was low in contrast of Al-5%Mg-0.1ppmNa.

Table 2 shows the elastic constants $C_{ij}$ of Al-5%Mg alloys determined from measured resonant spectra (Fig. 3), the dimensions and the mass densities of the specimens. The isotropic Young modulus $E$, the shear modulus $G$, the bulk modulus $B$, and Poisson’s ratio $\nu$ estimated by the Hill approximation are shown in Table 3. The bulk modulus $B$ is nearly identical between the two materials. However, Al-5%Mg200ppmNa shows lower Young’s modulus and the shear modulus of Al-5%Mg alloys by 2.44% and 2.47%, respectively. The results support that Na segregation in Al-5%Mg alloys promotes grain boundary sliding.

### 4. Conclusion

The effect of a trace amount of Na on tensile properties and elastic constants of Al-5%Mg alloys at room temperature were investigated. The Al-5%Mg alloy containing 200 ppm of Na clearly embrittled at room temperature. It was also revealed that Young’s modulus and the shear modulus decrease with the addition of Na, while the bulk modulus remains unchanged.

### Reference


**Table 2** Elastic constants $C_{ij}$ of Al-5%Mg alloys determined by the RUS method.

<table>
<thead>
<tr>
<th>Elastic constants (GPa)</th>
<th>$C_{11}$</th>
<th>$C_{22}$</th>
<th>$C_{33}$</th>
<th>$C_{12}$</th>
<th>$C_{13}$</th>
<th>$C_{23}$</th>
<th>$C_{44}$</th>
<th>$C_{55}$</th>
<th>$C_{66}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-5%Mg-0.1ppmNa</td>
<td>111</td>
<td>118</td>
<td>110</td>
<td>61.9</td>
<td>60.0</td>
<td>60.9</td>
<td>27.7</td>
<td>26.2</td>
<td>26.0</td>
</tr>
<tr>
<td>Al-5%Mg-200ppmNa</td>
<td>108</td>
<td>109</td>
<td>115</td>
<td>59.7</td>
<td>62.8</td>
<td>63.4</td>
<td>25.4</td>
<td>27.5</td>
<td>27.3</td>
</tr>
</tbody>
</table>

**Table 3** Isotropic elastic constants of Al-5%Mg alloys estimated by the Hill approximation.

<table>
<thead>
<tr>
<th>Elastic constants</th>
<th>$E$ (GPa)</th>
<th>$G$ (GPa)</th>
<th>$B$ (GPa)</th>
<th>$\nu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-5%Mg-0.1ppmNa</td>
<td>71.1</td>
<td>26.4</td>
<td>78.2</td>
<td>0.348</td>
</tr>
<tr>
<td>Al-5%Mg-200ppmNa</td>
<td>69.5</td>
<td>25.7</td>
<td>78.1</td>
<td>0.352</td>
</tr>
<tr>
<td>difference (%)</td>
<td>-2.44</td>
<td>-2.47</td>
<td>-0.17</td>
<td>1.15</td>
</tr>
</tbody>
</table>

**Fig. 3** Resonant spectra of the Al-5% alloys measured by the RUS method at room temperature.