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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

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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 boundaries[2].

In recent years, it was revealed that 5083 alloy containing 237 ppm of Na shows low ductility at room temperature[3]. 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 Na[4]. Furthermore, it was reported that Na segregation decreases the grain boundary energy of Al tilt grain boundaries using *ab-initio* calculations within the framework of the Rice-Wang thermodynamic model[5]. 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 approximatly 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 **Table 1**.

Round-bar tensile specimens with a gage length of 10.0 mm, a diameter of 4.0 mm, and a fillet radius of 3.0 mm were machined from the ingots. Rectangular-parallelepiped specimens for RUS with dimensions of 4.514 x 5.019 x 10.164 mm^3 (Al-5%Mg-0.1ppmNa) and 5.086 x 5.859 x 10.084 mm^3 (Al-5%Mg-200ppmNa) were machined from each ingots. Their mass densities were 2600 and 2594 kg/m^3, respectively. All the specimens were then annealed at 783 K for 0.5 h in air atmosphere. Average grain sizes obtained from optical micrographs were 1122 and 1061 µm, respectively.

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

Alloys	Mg	Na	Al
Al-5%Mg-0.1ppmNa	5.68	<0.0001	Bal.
Al-5%Mg-200ppmNa	5.48	0.0193	Bal.

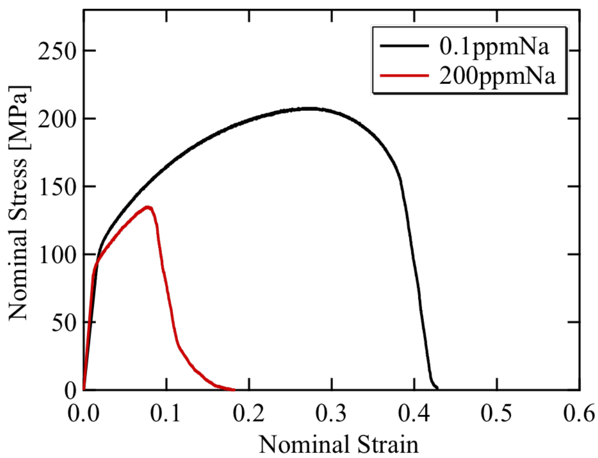

Fig. 1 Stress-strain relationships of the Al-5%Mg alloys at room temperature.

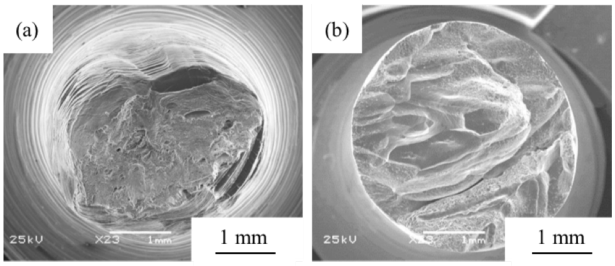

Fig. 2 SEM micrographs of the fracture surfaces in the Al-5%Mg-0.1ppmNa alloy (a) and the Al-5%Mg-200ppmNa alloy (b).

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Elastic constants of the Al-5%Mg alloys were determined using the tripod-type RUS[6]. 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* 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 x 10^{-4} s^{-1}. **Fig. 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 **Fig. 2**. Al-5%Mg-200ppmNa showed an intergranular fracture and its reduction of area was low in contrast of Al-5%Mg-0.1ppmNa.

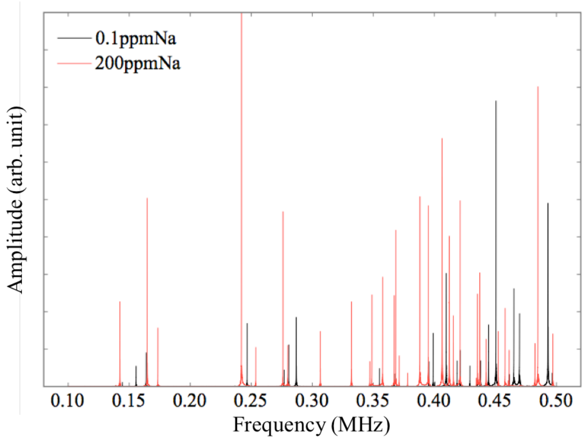

Fig. 3 Resonant spectra of the Al-5% alloys measured by the RUS method at room temperature.

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 *v* 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[7].

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

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

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

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

	Elastic constants			
	E (GPa)	*G* (GPa)	*B* (GPa)	*v*
Al-5%Mg-0.1ppmNa	71.1	26.4	78.2	0.348
Al-5%Mg-200ppmNa	69.5	25.7	78.1	0.352
difference (%)	-2.44	-2.47	-0.17	1.15