EFFECT OF SODIUM ON HOT DUCTILITY OF AN Al-5MASS%Mg ALLOY AND AN Al-5MASS%Mg-0.04MASS%Y ALLOY

Hiroshi Okada[1] and Motohiro Kanno[2]
1. Department of Materials Science, Division of Engineering, Graduate School, The University of Tokyo, Bunkyo-ku, Tokyo 113, JAPAN.
2. Department of Materials Science, Faculty of Engineering, The University of Tokyo, Bunkyo-ku, Tokyo 113, JAPAN.

Abstract

The previous work has shown that impurity hydrogen causes high temperature embrittlement of an Al-5mass%Mg alloy. The embrittlement disappears in an Al-5mass%Mg-0.04mass%Y alloy, since yttrium-bearing compounds trap impurity hydrogen not to enhance cavity formation at grain boundaries. In the present work, the ductility of Al-5mass%Mg-0.04mass%Y alloys to which trace amounts of sodium were added was examined at elevated temperatures. It was found that the embrittlement appeared in an Al-Mg-Y alloy containing 0.60massppm sodium and that did not in an Al-Mg-Y alloy containing 0.06massppm sodium. On the other hand, an Al-Mg alloy containing 0.06massppm sodium showed the embrittlement and hot ductility further decreased with a slight increase of sodium. It was concluded that the effect of both impurities had to be eliminated to suppress the embrittlement of the Al-Mg alloy.

Introduction

It is known that Al-Mg alloys containing magnesium of more than 5mass% show high temperature embrittlement based on intergranular fracture (1,2). The previous work has shown that the embrittlement of an Al-5mass%Mg alloy is caused by impurity hydrogen, and that the addition of 0.04mass%Y inhibits the embrittlement because of the hydrogen trapping caused by yttrium-bearing compounds (3).

However, it has been recently reported that the embrittlement does appear in Al-Mg-Y alloy (4), and a similar phenomenon was found also in the authors' laboratory. Figure 1 shows two kinds of fracture surfaces of Al-4.7%Mg-0.03%Y alloy specimens: one is transgranular and the other is intergranular. These two specimens were prepared from different ingots after the same homogenizing, cold-swaging and annealing. Exactly speaking, the sources of aluminum of 99.99% purity used in the melting of the ingots were different from each other. This fact implies that these two alloys contain different amounts of impurities and that the embrittlement in the Al-Mg-Y (Fig. 1c) is caused by a certain kind of impurity. The glow discharge mass spectrometry (GD-MS: VG MicroTrace, VG9000), which had the detection limit of 1massppb for the bulk analysis, was carried out to obtain further information on impurities, and revealed that sodium content was higher in the Al-Mg-Y alloy which showed the embrittlement, although the content was lower than 1massppm.

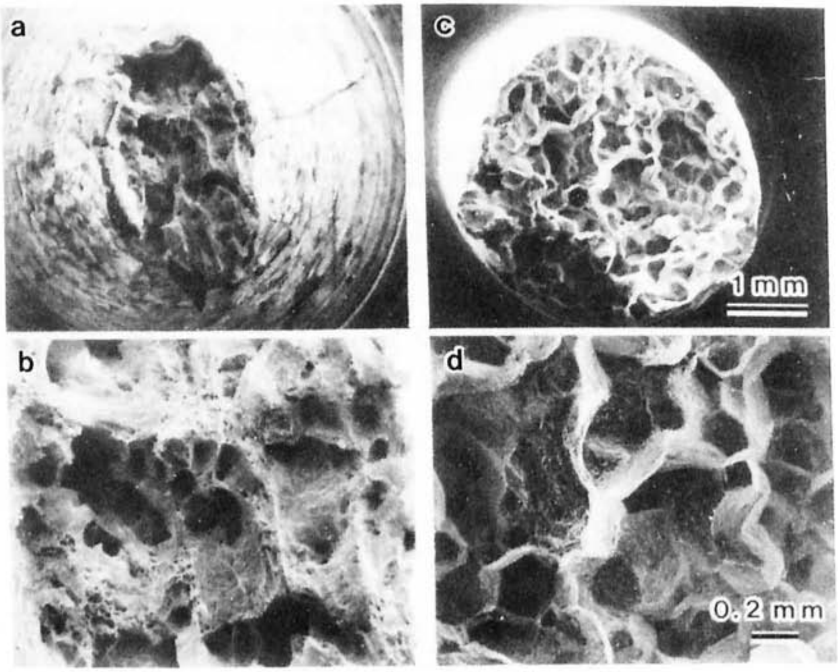

Figure 1. SEM fractographs of the Al-4.7%Mg-0.03%Y specimens tested at 300°C and at a strain rate of $8.3 \times 10^{-4} s^{-1}$. Gage length and diameter are 10 and 4mm, respectively. Grain size is 0.3mm. Reduction in area: 67%(a) and 33%(c). Sodium content: 0.14massppm(a) and 0.35massppm(c). (b, d): magnified images of (a, c), respectively.

As for the effect of sodium, Ransley and Talbot has reported that the hot-working properties of Al-Mg alloys are severely impaired by sodium of the order of 0.001mass% (1). However, no information on the effect of sodium of lower than 1massppm has been obtained. In the present work, ductility of Al-5mass%Mg and Al-5mass%Mg-0.04mass%Y alloys to which trace amounts of sodium were added was closely examined at temperatures ranging from 200°C to 400°C.

Experimental

Six kinds of Al-5.0mass%Mg ("mass%" will be simply represented as "%" below) and Al-5.0%Mg-0.04%Y alloys with and without trace amounts of sodium were melted and cast in air. Here, aluminum of 99.999% purity and magnesium of 99.9% purity were used. Yttrium and sodium were added using Al-3%Y and Al-0.01%Na master alloys, which were prepared in the authors' laboratory. All the molten metals were covered with $MgCl_2$ during melting and were degassed by C_2Cl_6 before casting. Table I shows contents of impurities analyzed by GD-MS (VG MicroTrace, VG9000), demonstrating that sodium of 0.06ppm is present even in the alloys to which sodium is not added. The six ingots were homogenized at 430°C for 18h in a vacuum of 10^{-2}Pa and cold-swaged by 70%. Round tensile test pieces of 10mm in gage length and 4mm in diameter were machined from the swaged rods and annealed at 510°C for 0.5-16h in a vacuum of 10^{-2}Pa so that

Table I. Contents of impurities analyzed by GD-MS (massppm)

element	Al-Mg			Al-Mg-Y		
	0.06Na	0.20Na	0.61Na	0.06Na	0.50Na	0.60Na
Li	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Be	0.015	<0.003	0.003	0.013	<0.003	<0.003
B	0.017	0.025	0.024	0.019	0.017	0.023
Na	**0.06**	**0.20**	**0.61**	**0.06**	0.50	**0.60**
Si	13.6	10.9	10.2	13.3	9.9	10.9
K	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Ca	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Ti	0.047	0.030	0.028	0.059	0.032	0.029
V	0.022	0.024	0.020	0.020	0.020	0.019
Cr	0.13	0.06	0.05	0.16	0.10	0.07
Mn	5.90	2.62	2.43	5.90	2.38	2.43
Fe	5.00	1.73	1.72	5.14	1.55	1.59
Co	0.013	0.080	0.043	0.021	0.018	0.014
Ni	0.28	0.03	0.03	0.28	0.05	0.04
Cu	0.87	0.86	0.78	1.03	0.69	0.74
Zn	5.6	5.7	5.3	5.9	5.1	5.7
Ga	0.10	0.07	0.06	0.09	0.07	0.07
Ge	0.37	<0.1	<0.1	0.39	0.46	0.51
As	0.026	0.017	0.014	0.027	0.060	0.028
Sr	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Zr	0.034	0.062	0.016	0.130	0.100	0.079
Nb	0.01	0.01	0.01	0.27	0.29	0.28
Mo	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ag	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cd	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
In	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Sn	0.065	0.19 0	<0.05	0.064	<0.05	<0.05
Sb	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ba	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ce	0.062	0.051	0.057	0.072	0.080	0.084
Pb	0.72	0.68	0.67	0.79	0.70	0.78
Bi	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Th	0.009	0.009	0.009	0.008	0.009	0.009
U	0.006	0.007	0.006	0.006	0.007	0.007

* Yttrium contents in Al-Mg alloys containing 0.06, 0.20 and 0.61massppm sodium are 0.025, 0.020 and 0.020massppm, respectively.

the grain size of the test pieces was about 0.3mm. Tensile tests were made at temperatures ranging from 200°C to 400°C and at a strain rate of $8.3\times10^{-4}s^{-1}$ in a vacuum of 10^{-2}Pa.

Results and Discussion

Figure 2 shows hot ductility of the Al-Mg and Al-Mg-Y alloys without sodium addition. High temperature embrittlement appears in the Al-Mg alloy at 275°C, and does not in the Al-Mg-Y one, as has been reported by Itoh et al. (5) and the present authors (3). From fractographs obtained at 275°C (Fig. 3), the embrittlement of the Al-Mg alloy is attributed to intergranular fracture with microdimples, resulting from formation, growth and coalescence of cavities at grain boundaries. In the previous work (3), it is concluded that impurity hydrogen causes the embrittlement of the Al-Mg alloy enhancing formation and growth of the cavities at grain boundaries, and that yttrium-bearing compounds trap hydrogen to inhibit the embrittlement in the Al-Mg-Y alloy.

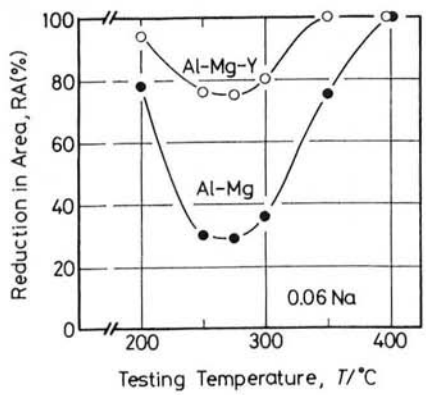

Figure 2. Reduction in area vs. testing temperature curves of Al-5%Mg and Al-5%Mg-0.04%Y alloys containing 0.06ppm sodium.

Effect of sodium on hot ductility of the Al-Mg-Y alloy is shown in Fig. 4. The result of the Al-Mg-Y alloy with low sodium of 0.06ppm is again presented in this figure. It is noted that ductility of the Al-Mg-Y alloy decreases as sodium content increases, and that high temperature embrittlement appears in the Al-Mg-Y alloy containing 0.60ppm sodium at 275°C. Since the effect of impurity hydrogen is eliminated in these

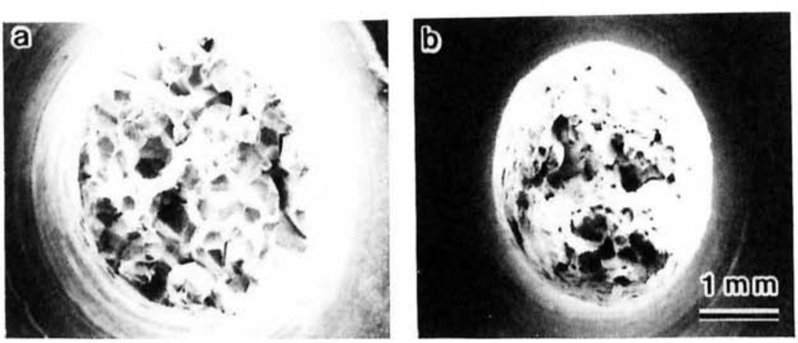

Figure 3. SEM fractographs of Al-Mg (a) and Al-Mg-Y (b) specimens tested at 275°C. Sodium content is 0.06ppm.

alloys due to yttrium addition, this embrittlement is caused by sodium alone. Moreover, the embrittlement caused by sodium is based on intergranular fracture (Fig. 5) as well as that caused by hydrogen (Fig. 3a).

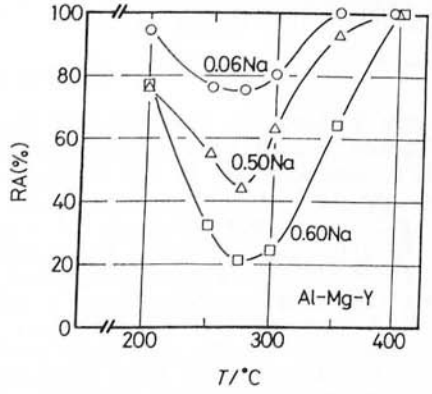

Figure 4. Effect of sodium on reduction in area of an Al-Mg-Y alloy.

Fracture surfaces of the low-sodium Al-Mg alloy and the high-sodium Al-Mg-Y are magnified to examine why the intergranular fracture occurs in the Al-Mg-Y alloy containing high sodium (Fig. 6). The previous work has shown that impurity hydrogen enhances formation and growth of cavities at grain boundaries, resulting in the intergranular fracture with microdimples (3). Figures 6a and 6b represent this type of fracture surface. In the high-sodium Al-Mg-Y alloy, facets with no microdimples are seen (Fig. 6d) as well as that with microdimples (Fig. 6c). Ransley and Talbot have suggested that sodium lower the surface energy of cavities so that cavities are easily to form (1). However, their idea does not explain the origin of the intergranular fracture without microdimples. It is, therefore, not clear how sodium is related to formation of the intergranular fracture with and without microdimples.

Although the solid solubility of sodium in aluminum is not clear around 300°C, there is a possibility that sodium segregates to grain boundaries. To confirm whether sodium segregates to grain boundaries or not, auger electron microscopy (AES, ULVAC·PHI-610), where specimens can be fractured in ultra high vacuum of 10^{-8}Pa, was carried out for the high-sodium Al-Mg-Y alloy prestretched about 25% at 275°C. However, sodium was not detected on the intergranular fracture surface. There may be two possibilities as the reason: the amounts of segregating sodium are not so high or the detection limit of sodi-

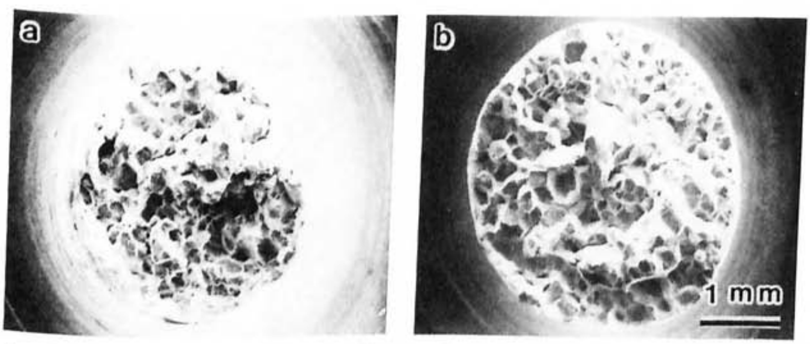

Figure 5. SEM fractographs of Al-Mg-Y specimens containing sodium of 0.50 (a) and 0.60ppm (b) tested at 275°C.

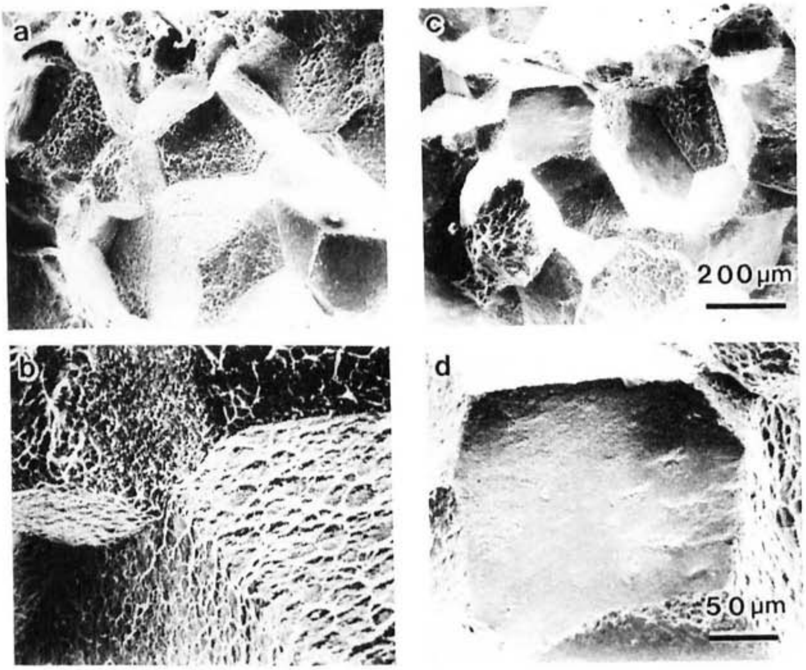

Figure 6. Magnified images of Fig. 3a (a, b) and Fig. 5b (c, d).

um by AES is not so low. At present, it is not certain which one is truly operative and therefore another analytical method should be applied. Although secondary ion mass spectrometry (SIMS) has higher sensitivity than AES, SIMS was not used for the following reasons: SIMS was not equipped with the device for fracture operated in ultra high vacuum and fracture surfaces obtained in air would be immediately contaminated with carbon, oxygen, sodium and so on existing in air.

Effect of trace amounts of sodium on hot ductility of an Al-Mg alloy was also investigated, and the result is shown in Fig. 7, where the hot-ductility of the Al-Mg alloy with low sodium of 0.06% is again presented. It is noted that ductility of the

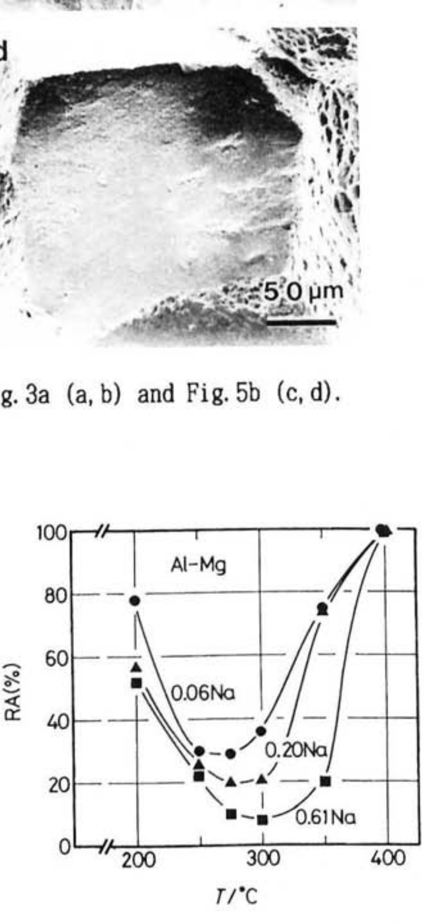

Figure 7. Effect of sodium on reduction in area of an Al-Mg alloy.

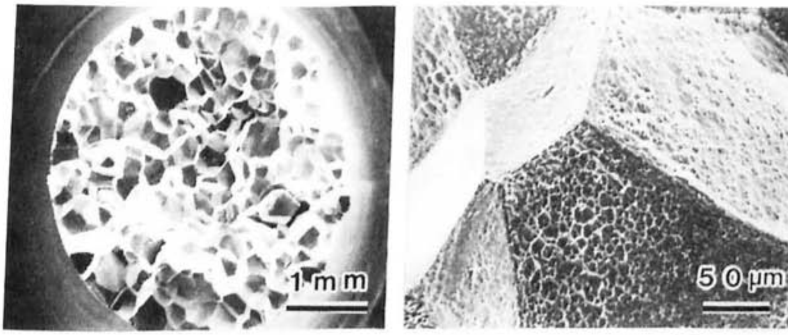

Figure 8. SEM fractographs of an Al-Mg specimen containing 0.61ppm sodium.

Al-Mg alloy decreases as sodium content increases as in the Al-Mg-Y alloy, and that high temperature embrittlement caused by both sodium and hydrogen is severer than that by sodium or hydrogen alone. Figure 8 indicates that the embrittlement of the Al-Mg alloy containing 0.61ppm sodium is based on intergranular fracture with shallow microdimples compared with that of the low-sodium Al-Mg alloy (compare with Fig.6b). It is concluded that impurity sodium causes high temperature embrittlement of Al-Mg alloys as well as impurity hydrogen, and that effect of both elements has to be eliminated to suppress the embrittlement.

Summary

Effect of trace amounts of impurity sodium on hot ductility of an Al-5%Mg alloy and an Al-5%Mg-0.04%Y alloy has been examined at temperatures ranging from 200°C to 400°C. High temperature embrittlement appears in the Al-Mg-Y alloy containing 0.60ppm sodium and does not in the Al-Mg-Y alloy containing 0.06ppm sodium. The embrittlement in the ternary alloy is caused only by sodium. On the other hand, the embrittlement appears in an Al-Mg alloy containing 0.61ppm sodium as well as in the Al-Mg alloy containing 0.06ppm sodium. The former embrittlement is caused by both sodium and hydrogen, and the latter one by hydrogen alone. It is concluded that effect of both impurity elements has to be eliminated to inhibit the embrittlement.

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