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The isothermal section of the phase diagram of the ternary system Al–Sn–Y at room temperature

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Abstract

The isothermal section of the phase diagram of the ternary system Al–Sn–Y (65 at.% Y or less) at room temperature was investigated by X-ray powder diffraction, differential thermal analysis, optical microscopy, electron microscopy, electron spectrum and electron probe microanalysis techniques. The section at room temperature consists of ten single-phase regions, 18 two-phase regions and nine three-phase regions. The single-phase region π ($Al_3Sn_9Y_8$) in this section at room temperature is a new ternary intermetallic compound. It was found that no single phase Al_4Y exists in the binary Al–Y. The other eight single-phase regions in the section correspond to binary intermetallic compounds in the systems Al–Sn, Al–Y and Sn–Y. The range of all homogeneous phase fields of terminal solid solution is too small to be observed at room temperature.

Keywords: Isothermal sections; Phase diagrams; Ternary systems

1. Introduction

Refs. [1–4] reported the phase diagram of the Al–Sn system. There exists no intermetallic compound in the system of Al–Sn. Refs. [2,3,5] reported the phase diagram of the Al–Y system. There exist five intermetallic compounds in this system. Of these, the Al_3Y, AlY and AlY_2 compounds are of the isomeride transition. Ref. [6] reported the diagram of the Sn–Y system. There exist five intermetallic compounds in this system too. In order to discover further characteristics and regularities concerning phase formation in the ternary Re–Al–Sn system (where Re denotes a rare earth), we have studied the isothermal section of the ternary system Al–Sn–Y (65 at.% Y or less) at room temperature.

2. Experimental details

The aluminium, tin and yttrium used for the experiments were of 99.99%, 99.95% and 99.90% purity respectively. Alloy buttons were prepared in an argon atmosphere in a high frequency induction furnace. The melting of all samples was done in alumina crucibles. 135 samples were prepared, each weighing 3 g.

The samples were sealed in silica tubes or glass tubes in vacuum during homogenization. The homogenization temperatures of the alloys were chosen on the basis of the binary phase diagram of the Al–Sn, Al–Y and Sn–Y systems and the solidus of some representative ternary alloys determined by differential thermal microanalysis. The alloys which contained more than 75 at.% Sn were homogenized at 180 °C for 60 days and then cooled at a rate of 10 °C h^{-1} to room temperature. The alloys which contained more than 20 at.% Sn and less than 75 at.% Sn were homogenized at 450 °C for 50 days and then cooled at a rate of 10 °C h^{-1} to room temperature. The alloys which contained less than 20 at.% Sn were kept at 600 °C for 40 days and then cooled at a rate of 10 °C h^{-1} to room temperature. The alloy powder used for X-ray diffraction was made from homogenized alloy buttons. The alloy powder was sealed in glass tubes in vacuum. The alloy powder was treated for 1 week at the above temperatures respectively and then cooled at a rate of 10 °C h^{-1} to room temperature.

X-ray diffraction analysis was performed with powder samples using a Rigaku 3015 diffractomer. A copper target voltage of 35 kV, current of 20 mA and a nickel filter were used. The boundaries of the various phase fields were not only determined by X-ray diffraction (disappearing-phase method) but also checked by electron probe microanalysis (EPMA) and optical microscopy.

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3. Results and discussion

3.1. Isothermal section at room temperature

By comparing and analysing the X-ray diffraction patterns of 135 samples, and by identifying the phases in each sample, the isothermal section of the phase diagram of the ternary system Al–Sn–Y (65 at.% Y or less) at room temperature was determined. It is shown in Fig. 1 that this section consists of ten single-phase regions: α (Al), β (Sn), η (Al_3Y), ξ (Al_2Y), ϕ (Sn_3Y), ϵ (Sn_2Y), θ (Sn_3Y_5), σ ($Sn_{10}Y_{11}$), δ (Sn_4Y_5) and π ($Al_3Sn_9Y_8$); 18 two-phase regions: $\alpha+\beta$, $\alpha+\phi$, $\alpha+\epsilon$, $\alpha+\pi$, $\alpha+\eta$, $\beta+\phi$, $\phi+\epsilon$, $\eta+\pi$, $\eta+\theta$, $\eta+\xi$, $\pi+\epsilon$, $\pi+\sigma$, $\pi+\delta$, $\pi+\theta$, $\epsilon+\sigma$, $\sigma+\delta$, $\delta+\theta$ and $\xi+\theta$; and nine three-phase regions; $\alpha+\beta+\phi$, $\alpha+\phi+\epsilon$, $\alpha+\pi+\epsilon$, $\alpha+\eta+\pi$, $\eta+\pi+\theta$, $\eta+\xi+\theta$, $\pi+\epsilon+\sigma$, $\pi+\sigma+\delta$ and $\pi+\delta+\theta$.

3.2. Phase analysis

The indexing and lattice parameter calculation from high angle diffraction lines of the intermetallic compounds Al_3Y, Al_2Y, Sn_3Y, Sn_2Y and $Sn_{10}Y_{11}$ show that these data are in agreement with the data reported in Refs. [2,3].

The indexing of the new phase π ($Al_3Sn_9Y_8$) has not been done yet. Further work on the structure will be carried out. There exists no intermetallic compound Al_4Y in the system of Al–Y.

3.3. Optical microscopy observations

The atomic numbers of Al, Sn and Y are 13, 50 and 39 respectively. The atomic scattering factor differences of Al, Sn and Y were too great to observe the X-ray diffraction patterns of Al, until the alloys contained 30 at.% Al. In order to determine the various phase fields in the ternary Al–Sn–Y system accurately, we used optical microscopy observation techniques except when we used the X-ray diffraction method. The microstructure of samples of the two-phase region $\alpha+\pi$ (sample 48, Al–21at.%Sn–19at.%Y) is shown in Fig. 2(a). The microstructures of samples of the three-phase regions $\alpha+\pi+\epsilon$ (sample 67, Al–30at.%Sn–20at.%Y), $\alpha+\beta+\phi$ (sample 55, Al–35at.%Sn–5at.%Y) and $\alpha+\pi+\eta$ (sample 80, Al–30at.%Sn–30at.%Y) are shown in Fig. 2(b), Fig. 2(c) and Fig. 2(d) respectively.

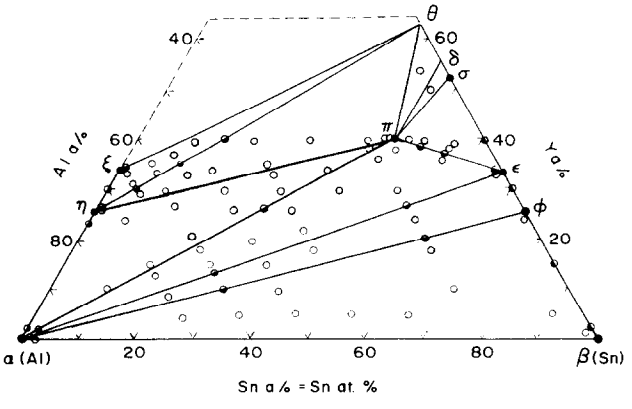

Fig. 1. Partial ternary section of the Al–Sn–Y system at 180 °C (Sn-rich part) and 450 °C (Al-rich part).

3.4. Solid solubility

Al, Sn and Y cannot form an interstitial solid solution at room temperature, because their atomic diameters are about the same. They cannot form a substitutional solid solution at room temperature, because their structures are different. When they substitute for each other, the system energy will increase, so that the system becomes unstable at room temperature. Neither Sn and Y in Al nor Al and Y in Sn show any detectable solid solubility.

3.5. The denaturation of Y

We find that the hardness of alloys increases when Y is added to Al. The test results are shown in Table 1. We observed that the η phase disperses homogeneously in Al on the metallograph. We think the increase in hardness of the alloys is the result of dispersion hardening.

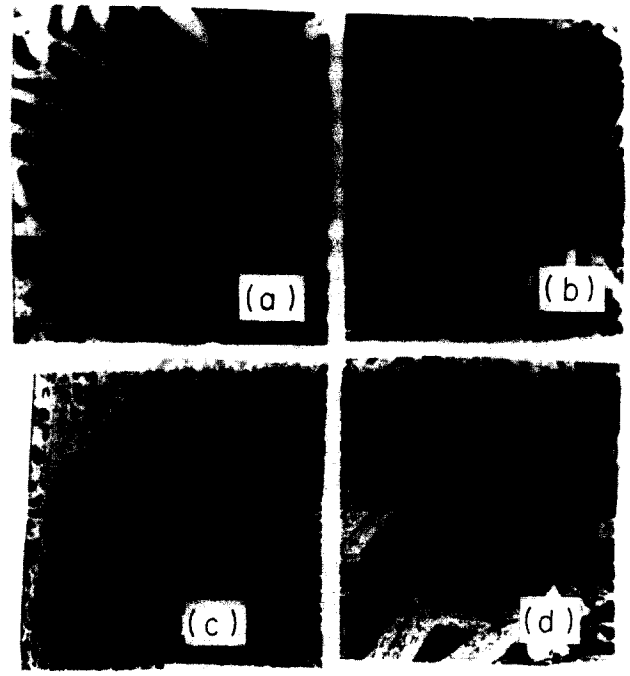

Fig. 2. Metallographs: (a) sample 48 (Al–21at.%Sn–19at.%Y), $\alpha+\pi$ (magnification, ×100); (b) sample 67 (Al–30at.%Sn–20at.%Y), $\alpha+\pi+\epsilon$ (magnification, ×150); (c) sample 55 (Al–35at.%Sn–5at.%Y), $\alpha+\beta+\phi$ (magnification, ×150); (d) sample 80 (Al–30at.%Sn–30at.%Y), $\alpha+\pi+\eta$ (magnification, ×150).

Table 1
Change in the hardness of alloys with Y content

Y content (at.%)	HB5/250/30
0	14.50
0.5	16.84
1.0	19.74
1.5	22.76
2.0	24.63
2.5	26.50
3.0	28.93

We discovered that the corrosion resistance of alloys to 20% nitric acid increases, but the corrosion resistance of the alloys to 10% sodium hydroxide decreases, when yttrium is added to aluminium.

Acknowledgment

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