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# The 800 K isothermal section of the Y–Al–Sb phase diagram

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**Abstract**

The isothermal section of the Y–Al–Sb ternary system at 800 K has been investigated mainly by powder X-ray diffraction (XRD) with the aid of differential thermal analysis (DTA), optical microscopy and scanning electron microscopy (SEM). It consists of 12 single-phase regions, 23 two-phase regions and 10 three-phase regions. The maximum solid solubility of Al in $Y_5Sb_3$ is about 27 at.%. No ternary compounds were found.
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*Keywords:* Rare earth alloys; Crystal structure; Phase diagram; X-ray diffraction

## 1. Introduction

The Y–Al–Sb ternary system has not been studied over the full concentration region. Partial investigation of it was within the limits of 0–33.3 at.% Y and 0–50.0 at.% Sb at 773 K, and did not report ternary compounds [1]. Among the RE–Al–Sb related ternary systems (RE=rare earth elements), no phase diagrams were reported.

The binary systems Al–Sb, Al–Y and Sb–Y bounding the Y–Al–Sb system have been investigated in detail in the literature. There is only one intermediate phase AlSb in the Al–Sb system [2–6]. Schmidt and McMasters [7] presented the Sb–Y phase diagram and revealed four intermediate phases: $Y_3Sb$, $Y_5Sb_3$, $Y_4Sb_3$ and YSb. Seven intermediate phases occur in the Al–Y system: (α) $Al_3Y$, (β) $Al_3Y$, $Al_2Y$, AlY, $Al_2Y_3$, $AlY_2$, $AlY_3$ [8–12]. The binary compound $Al_3Y_5$ was reported in studies on the crystallization of Y–Al glasses [13].

## 2. Experimental details

The present investigation was carried out with 99 samples having weight of about 3 g. The purities of aluminium, antimony and yttrium used for preparation of samples in this work were 99.8, 99.9 and 99.7%, respectively. The alloy buttons were prepared in a vacuum arc furnace on the water-cooled copper crucible under an atmosphere of purified argon. Each button was melted three times in order to achieve homogeneity. Because the alloys contain antimony, the electric current was as low as possible so as to minimize the loss of weight by volatilization of antimony.

After melting the alloy buttons were sealed in evacuated quartz tubes for homogenization heat treatment. The homogenization temperatures were chosen on the basis of the binary alloy phase diagrams of the Al–Sb, Al–Y and Sb–Y systems and differential thermal analysis (DTA). The samples with more than 50 at.% Sb were homogenized at 873 K for 500 h. The rest of the alloys were homogenized at 1173 K for 500 h. Subsequently, they were cooled at a rate of about 10 K/h to 800 K and kept at this temperature for 200 h, then quenched in an ice-water mixture.

X-ray powder diffraction and scanning electron microscopy with energy dispersive analysis were used in the present investigation. Samples for X-ray diffraction analyses were powdered. The powder X-ray diffraction analyses were performed on a Rigaku D/Max 2500 V diffractometer with Cu Kα radiation and graphite monochromator operated at 40 kV, 250 mA. The Materials Data software Jade 5.0 [15] and Powder Diffraction File (PDF release 2000) were used for phase identification.

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Table 1
Analysis results of the X-ray diffraction pattern of sample $Y_{64}Al_{36}$ ($\lambda$=1.54056 Å)

| No. | 2$\theta$ | $d$ (Å) | $I$ (%) | Phase | No. | 2$\theta$ | $d$ (Å) | $I$ (%) | Phase |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 23.259 | 3.8211 | 2 | **$Y_3Al$** | 22 | 46.266 | 1.9607 | 1 | $Y_3Al_2$ |
| 2 | 24.12 | 3.6866 | 64 | $Y_3Al_2$ | 23 | 46.41 | 1.9525 | 2 | **$Y_3Al$** |
| 3 | 26.357 | 3.3784 | 1 | $Y_3Al_2$ | 24 | 46.719 | 1.9427 | 4 | $Y_3Al_2$ |
| 4 | 27.897 | 3.1955 | 35 | $Y_3Al_2$ | 25 | 46.954 | 1.9335 | 9 | $Y_3Al_2$ |
| 5 | 28.698 | 3.1081 | 4 | **$Y_2O_3$** | 26 | 47.539 | 1.9111 | 6 | $Y_3Al_2$ |
| 6 | 30.643 | 2.9151 | 56 | $Y_3Al_2$ | 27 | 48.313 | 1.8839 | 1 | $Y_3Al_2$ |
| 7 | 31.902 | 2.8029 | 100 | $Y_3Al_2$ | 28 | 48.723 | 1.8652 | 1 | $Y_3Al_2$ |
| 8 | 32.396 | 2.7622 | 14 | **$Y_3Al$** | 29 | 49.416 | 1.8428 | 7 | $Y_3Al_2$ |
| 9 | 32.862 | 2.7232 | 14 | $Y_3Al_2$ | 30 | 50.041 | 1.8213 | 2 | $Y_3Al_2$ |
| 10 | 33.758 | 2.6529 | 67 | $Y_3Al_2$ | 31 | 50.275 | 1.8133 | 4 | $Y_3Al_2$ |
| 11 | 34.38 | 2.6064 | 74 | $Y_3Al_2$ | 32 | 51.561 | 1.7711 | 29 | $Y_3Al_2$ |
| 12 | 36.397 | 2.4664 | 29 | $Y_3Al_2$ | 33 | 52.836 | 1.7313 | 19 | $Y_3Al_2$ |
| 13 | 36.899 | 2.434 | 3 | $Y_3Al_2$ | 34 | 54.042 | 1.6951 | 10 | $Y_3Al_2$ |
| 14 | 37.583 | 2.3892 | 7 | **$Y_3Al$** | 34 | 54.172 | 1.6919 | 4 | **$Y_3Al$** |
| 15 | 38.537 | 2.3342 | 2 | $Y_3Al_2$ | 36 | 55.296 | 1.6599 | 9 | $Y_3Al_2$ |
| 16 | 38.839 | 2.3192 | 2 | $Y_3Al_2$ | 37 | 56.948 | 1.6156 | 4 | $Y_3Al_2$ |
| 17 | 39.395 | 2.2853 | 6 | $Y_3Al_2$ | 38 | 57.136 | 1.6108 | 20 | $Y_3Al_2$ |
| 18 | 41.177 | 2.1905 | 5 | $Y_3Al_2$ | 39 | 57.661 | 1.5974 | 9 | $Y_3Al_2$ |
| 19 | 41.939 | 2.1524 | 5 | $Y_3Al_2$ | 40 | 57.761 | 1.5944 | 3 | **$Y_3Al$** |
| 20 | 42.233 | 2.1381 | 1 | **$Y_3Al$** | 41 | 58.286 | 1.5817 | 9 | $Y_3Al_2$ |
| 21 | 45.32 | 1.9994 | 18 | $Y_3Al_2$ | 42 | 59.992 | 1.5408 | 15 | $Y_3Al_2$ |

The sample consists of two phases (except minor $Y_2O_3$): $Y_3Al$ crystallizes in a cubic structure with $a$=4.7845(8) Å; $Y_3Al_2$ crystallizes in a tetragonal structure with $a$=8.2411(5) Å, $c$=7.6411(8) Å.

## 3. Results and discussion

### 3.1. Boundary binary systems

In present work we have studied the binary systems Al–Sb, Sb–Y and Al–Y at 800 K to identify the binary compounds. In the Al–Sb system we have obtained the binary compound AlSb. In the Sb–Y system, three binary compounds YSb, $Y_5Sb_3$ and $Y_3Sb$ have been confirmed. But in the present work we could not obtain binary compound $Y_4Sb_3$, because it is a high-pressure phase [14].

In the Al–Y system, the existence of five binary compounds (β)$Al_3Y$, $Al_2Y$, AlY, $Al_2Y_3$ and $AlY_3$ have been confirmed. Bailey [19] revealed that (α)$Al_3Y$ is a low-temperature phase stable below 917 K, (β)$Al_3Y$ is a high-temperature phase stable above 917 K. Under the present experimental conditions, we have obtained (β)$Al_3Y$ at 800 K, not (α)$Al_3Y$. The binary compound $AlY_2$ crystallizes in the orthorhombic with $Co_2Si$-type structure and $a$=6.642(2) Å, $b$=5.084(1) Å, $c$=9.469(2) Å [17]. The compound $Al_3Y_5$ is hexagonal with $a$=8.787 Å, $c$=6.435 Å and was produced by melt-spinning the buttons under helium at 15 kPa pressure [25]. In order to identify the existence of the binary phases $Al_3Y_5$ and $AlY_2$, we prepared several samples with the compositions from 62.5 at.% yttrium to 67.0 at.% yttrium which were annealed at 1173 K for 500 h in an evacuated quartz tube, cooled to 800 K at a rate of 10 K/h and then kept at 800 K

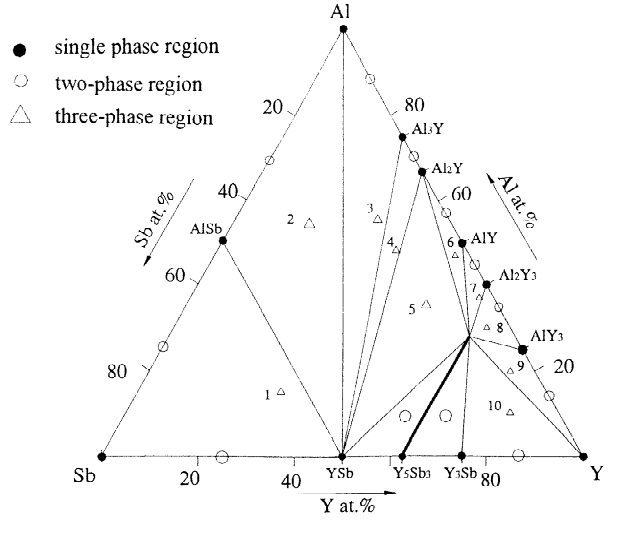


Fig. 1. The isothermal section Y–Al–Sb system phase diagram at 800 K.

Table 2
Details of the three-phase regions in the Y–Al–Sb

| Phase regions | Alloy composition (at.%) | | | Phase composition |
|---|---|---|---|---|
| | Y | Al | Sb | |
| 1 | 30 | 15 | 55 | Sb+AlSb+YSb |
| 2 | 16 | 54 | 30 | Al+AlSb+YSb |
| 3 | 30 | 55 | 15 | Al+$Al_3Y$+YSb |
| 4 | 37 | 48 | 15 | $Al_2Y$+$Al_3Y$+YSb |
| 5 | 50 | 35 | 15 | $Al_2Y$+$Al_xSb_{3-x}Y_5$+YSb |
| 6 | 50 | 47 | 3 | $Al_2Y$+AlY+$Al_xSb_{3-x}Y_5$ |
| 7 | 60 | 37 | 3 | AlY+$Al_2Y_3$+$Al_xSb_{3-x}Y_5$ |
| 8 | 65 | 30 | 5 | $Al_2Y_3$+$AlY_3$+$Al_xSb_{3-x}Y_5$ |
| 9 | 75 | 20 | 5 | $AlY_3$+Y+$Al_xSb_{3-x}Y_5$ |
| 10 | 80 | 10 | 10 | Y+$Y_3Sb$+$Al_xSb_{3-x}Y_5$ |

Table 3
The lattice parameters of $Y_5Al_xSb_{3-x}$

| Samples | Lattice parameters (Å) | |
|---|---|---|
| | *a* | *c* |
| $Y_5Sb_3$ | 8.878(2) | 6.254(3) |
| $Y_5Al_{0.8}Sb_{2.2}$ | 8.842(1) | 6.383(1) |
| $Y_5Al_{1.6}Sb_{1.4}$ | 8.829(1) | 6.441(2) |
| $Y_5Al_{2.16}Sb_{0.84}$ | 8.814(2) | 6.493(1) |
| $Y_5Al_{2.4}Sb_{0.6}$ | 8.8162(6) | 6.4711(4) |
| $Y_5Al_{2.8}Sb_{0.2}$ | 8.8079(7) | 6.4906(6) |

for 200 h. Subsequently the samples were quenched into ice-water mixture. The X-ray diffraction patterns of these samples only contain the X-ray diffraction patterns of $Al_2Y_3$ and $AlY_3$ except the pattern of a minor $Y_2O_3$ phase (at 28.698° $2\theta$). The X-ray diffraction data and phase analysis results of the sample $Al_{36}Y_{64}$ are listed in Table 1. We also observed the existence of the binary compound $AlY_3$, but not $AlY_2$ and $Al_3Y_5$ in the three phase regions. This means that binary compounds $Al_3Y_5$ and $AlY_2$ do not exist at 800 K.

### *3.2. The phase diagram of the Y–Al–Sb system at 800 K*

The isothermal section of the Y–Al–Sb system phase diagram at 800 K has been constructed by using the analysis results obtained in the present work (Fig. 1). This isothermal section consists of 10 three-phase regions, 23 two-phase regions, and 12 single regions. Details of the three-phase regions are given in Table 2. To obtain the maximum solid solubility of Al in $Y_5Sb_3$, several samples $Y_5Al_xSb_{3-x}$ ($x$=0, 0.8, 1.6, 2.16, 2.4, 2.8) were prepared. X-ray powder diffraction data were collected at room temperature using Cu Kα radiation. Highly pure silicon was used as an internal standard. The lattice parameters were refined by the Materials Data software Jade 5.0 and are listed in Table 3. The variation of the lattice parameters of $Y_5Al_xSb_{3-x}$ with Al content were shown in Fig. 2.

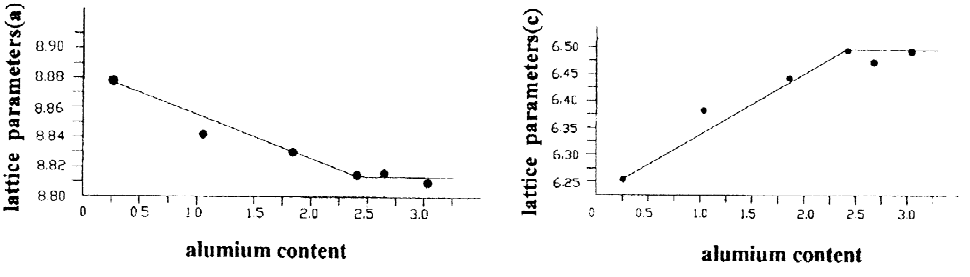


Fig. 2. Determination of the maximum solid solubility of Al in $Y_5Sb_3$ by means of lattice parameters of quenched powders.

Table 4
Crystallographic data of the initial components and the binary compounds for the Y–Al–Sb system

| Phase | Space group | Structure type | Lattice parameters (Å) | | | Reference |
|---|---|---|---|---|---|---|
| | | | *a* | *b* | *c* | |
| (α)Y | $P6_3/mmc$ | Mg | 3.663(1) | | 5.777(2) | This work |
| | $P6_3/mmc$ | Mg | 3.6474(7) | | 5.7306(8) | [16] |
| $AlY_3$ | $Pm\bar{3}m$ | $AuCu_3$ | 4.7845(8) | | | This work |
| | $Pm\bar{3}m$ | $AuCu_3$ | 4.818(2) | | | [17] |
| $Al_2Y_3$ | $P4_2/mnm$ | $Al_2Zr_3$ | 8.2411(5) | | 7.6411(8) | This work |
| | $P4_2/mnm$ | $Al_2Zr_3$ | 8.239(3) | | 7.648(4) | [17] |
| AlY | $Cmcm$ | BCr | 3.884(2) | 11.522(4) | 4.385(2) | [17] |
| $Al_2Y$ | $Fd\bar{3}m$ | $Cu_2Mg$ | 7.8611(8) | | | [18] |
| | $Fd\bar{3}m$ | $Cu_2Mg$ | 7.850(3) | | | This work |
| (α)$Al_3Y$ | $P6_3/mmc$ | $Ni_3Sn$ | 6.276(2) | | 4.582(1) | [19] |
| (β)$Al_3Y$ | $R\bar{3}m$ | $BaPb_3$ | 6.1884(9) | | 21.094(4) | This work |
| | $R\bar{3}m$ | $BaPb_3$ | 6.204(2) | | 21.184(7) | [19] |
| Al | $Fm\bar{3}m$ | Cu | 4.050(2) | | | [20] |
| AlSb | $F\bar{4}3m$ | SZn | 6.1350 | | | [21] |
| Sb | $R\bar{3}m$ | As | 4.3084 | | 11.274 | [22] |
| YSb | $Fm\bar{3}m$ | ClNa | 6.165 | | | [23] |
| $Y_3Sb$ | $P4_2/n$ | $PTi_3$ | 12.361(1) | | 6.180(1) | [24] |
| $Y_5Sb_3$ | $P6_3/mcm$ | $Mn_5Si_3$ | 8.9114(5) | | 6.2960(6) | [24] |

From Fig. 2 we can derive that the maximum solid solubility of Al in $Y_5Sb_3$ is about 27 at.%. Any solid solubility in other phases has not been observed. The crystallographic data of the initial components and the binary compounds for the Y–Al–Sb system are given in Table 4. No ternary compounds were discovered in this work.

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## References

[1] A.A. Mypabbeba, O.C. Bapeyhok, E.È. Lnalbpebcknm, J. CCCP 7 (1971) 38–40.
[2] G. Tamman, Z. Anorg. Chem. 48 (1906) 53–60.
[3] G.G. Urasow, Zh. Fiz. Khim. 51 (1919) 461–471.
[4] G.G. Urasow, Inst. Fiz. Khim. Anal. 1 (1921) 416–417.
[5] W. Guertler, A. Bergmann, Z. Metallkd. 25 (1933) 81–84.
[6] B.D. Lichter, P. Sommelet, Trans. Metall. Soc. AIME 245 (1969) 99–105.
[7] F.A. Schmidt, O.D. McMasters, J. Less-Common Met. 21 (1970) 415–425.
[8] R.L. Snyder, Ph.D. dissertation, Iowa State University, Ames, IA, 1960.
[9] C.E. Lun Jr., D.T. Klodt, Trans. Quart. 54 (1961) 168.
[10] M.E. Drits, E.S. Kadaner, N.D. Shoa, Izv. Akad. Nauk SSSR Met. 6 (1969) 150.
[11] M.E. Drits, E.S. Kadaner, N.D. Shoa, Russ. Metall. 6 (1969) 92.
[12] K.A. Gschneidner Jr., F.W. Calderwood, Bull. Alloy Phase Diagrams 10 (1989) 44–46.
[13] R. Richter, Z. Altounian, J.O. Strom-Olsen, U. Köster, M. Blank Bewersdorff, J. Mater. Sci. (London) 22 (1987) 2983–2986.
[14] R.J. Gambino, J. Less-Common Metals 12 (1967) 344–352.
[15] Jade 5, XRD pattern processing, Materials Data Inc., 1999.
[16] F.H. Spedding, A.H. Daane, K.W. Herrmann, Acta Crystallogr. 9 (1956) 559–563.
[17] T. Dagerhamn, Arkiv Kemi (Stockholm) 27 (1967) 363–380.
[18] B. Appa Rao, C. Vishnuvardhan Reddy, K. Satyanarayana Murthy, P. Kistaiah, J. Less-Common Metals 134 (1987) 91–97.
[19] D.M. Bailey, Acta Crystallogr. 23 (1967) 729–733.
[20] J. Bandyopadhyay, K.P. Gupta, Cryogenics (London) 18 (1978) 54–55.
[21] H. Sonomura, T. Nishimura, T. Miyauchi, Physica Status Solidi, Sect. A, Appl. Res. 61A (1980) K51–K53.
[22] C.S. Barrett, P. Cucka, K. Haefner, Acta Crystallogr. 16 (1963) 451–453.
[23] B. Frick, J. Schoenes, F. Hulliger, O. Vogt, Solid State Commun. 49 (1984) 1133–1137.
[24] F.A. Schmidt, O.D. McMasters, J. Less-Common Metals 21 (1970) 415–425.
[25] R. Richter, Z. Altounian, J.O. Strom-Olsen, U. Köster, M. Blank-Bewersdorff, J. Mater. Sci. (London) 22 (1987) 2983–2986.