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LETTER

The correlation between solid solubility and its temperature dependence for solutes in aluminium

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In a classic paper, Fink and Freche [1] showed linear correlations between logarithms of eutectic concentration relative to solid solubility and reciprocal of temperature T and between logarithm of solid solubility x versus reciprocal of temperature T, all for a limited number of solutes (including, Mg, Cu, Si, Mn, Cr and Ni) in aluminium.

The present purpose is to re-test this latter correlation for the larger number of solutes in aluminium for which assessed data is now available. Table 1 lists the sources and range of this data [1–20] and Fig. 1a plots slope S of log x against $1/T$ versus log of solubility at $T = 800$ K (the temperature of reference chosen by Fink and Freche) while Fig. 1b plots the same slope versus the maximum solubility (at the eutectic or peritectic temperature). The open points and full line in Fig. 1 show the original data of Fink and Freche, while the filled points show the data from Table 1. The Table 1 data in Fig. 1a is in good accord with the earlier representation except for the results for Nd, Zr, Cr, Ti and Y which lie at somewhat lower values of S. Al–Zr, Al–Cr and Al–Ti are peritectic systems, while the results for Nd and Y (also Ni) are each based on just three experimental points from single references [19, 21]. The results for Fe are from the piece of work that gives the lowest values of solid solubility and the results for Al–Be show a lot of experimental scatter. With these provisos, the results show a reasonable fit with the correlation which gives

$$S = \frac{d(\log x_{800\,\mathrm{K}})}{d(1/T)} = a \log(x_{800\,\mathrm{K}}) \tag{1}$$

where $x_{800\,\mathrm{K}}$ is atom fraction and $a = -1180 \pm 30$ K (leaving out the results for Ti, Cr, Zr, Y and Ni).

Where x is known at 800 K, eq. (1) gives an indication of the associated temperature dependence of solid solubility x for eutectic systems based on Al. More commonly, it is the maximum solid solubility x at the eutectic temperature which is known and so Fig. 1b shows the equivalent correlation of S versus log x_{MAX}. Figure 1b shows a similar distribution of points to Fig. 1a, though now with the highly soluble Ag showing a relatively higher value of S than the trend line and, again, Nd, Zr, Cr, Y and Ti showing relatively lower values. Otherwise, the data show a reasonable fit with:

$$S = a \ \log x_{\mathrm{MAX}} \tag{2}$$

where, again, x_{MAX} is atom fraction and $a = -1430 \pm 40$ K (and again leaving out the results for Ti, Cr, Zr, Y and Ni).

Using the approximation (for sufficiently dilute solutions) [22–24]

$$x = x_0 \ \exp\left(-\frac{Q}{RT}\right) \tag{3}$$

where Q is the applicable heat of solution, and R is the gas constant
then

$$S = Q/2.303R$$

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Table 1 Sources and ranges of solid solubility (x) data for Figs. 1a and b, ranked in decreasing order of maximum solid solubility x_{MAX}

Solute	x_{MAX}, atom fraction	T_{EU}, °C	$x_{800\ K}$, atom fraction	T-range of x-data, °C	Slope S of log x versus $1/T$, K	Heat of solution Q, kJ/mol	Source of data
Zn	0.67	381	(0.748)	60–374	170	3.3	Murray [2]
Ag	0.235	567	0.050	200–567	1530	29.3	McAlister [3]
Mg	0.189	450	(0.268)	200–449	1090	20.9	Murray [4] Amano et al. [5]
Li	0.137	601	0.115	150–600	740	14.2	Elliott and Shunk [6]
Cu	0.025	548	0.021	200–548	2170	41.6	Murray [7]
Ge	0.020	420	0.0396	177–395	2020	38.7	McAlister and Murray [8]
Si	0.016	577	0.011	200–575	2440	46.7	Murray and McAlister [9]
Ti	0.0078	665*	0.00355	530–660	1940	37.1	Minamoto et al. [10]
Mn	0.0067	658	0.00185	500–654	3110	59.6	McAlister and Murray [11] Minamoto et al. [10]
Cr	0.0035	661.5*	0.0014	375–661	2240	53.8	Murray [12]
Sc	0.0023	660.0	0.00055	470–660	3480	66.6	Murray [13]
Be	(0.0015)	644	0.00375	300–645	4100	78.5	Murray and Kahan [14]
Zr	0.00083	660.8*	0.0002	500–661	3200	61.3	Murray et al. [15]
Au	0.0006	650	0.000088	470–650	4720	90.4	Murray et al. [16]
Y	0.0005	639	0.000275	500–620	(1530)	(29.3)	Gschneidner and Calderwood [17]
Fe	0.00025	655	0.000028	450–620	5520	105.7	Lendvai et al. [18]
Ni	0.00023	640	0.000035	500–640	5080	97.3	Fink and Willey [19]
Nd	0.00008	640	0.000014	500–600	(4420)	(84.6)	Gshneidner and Calderwood [20]

*Peritectic

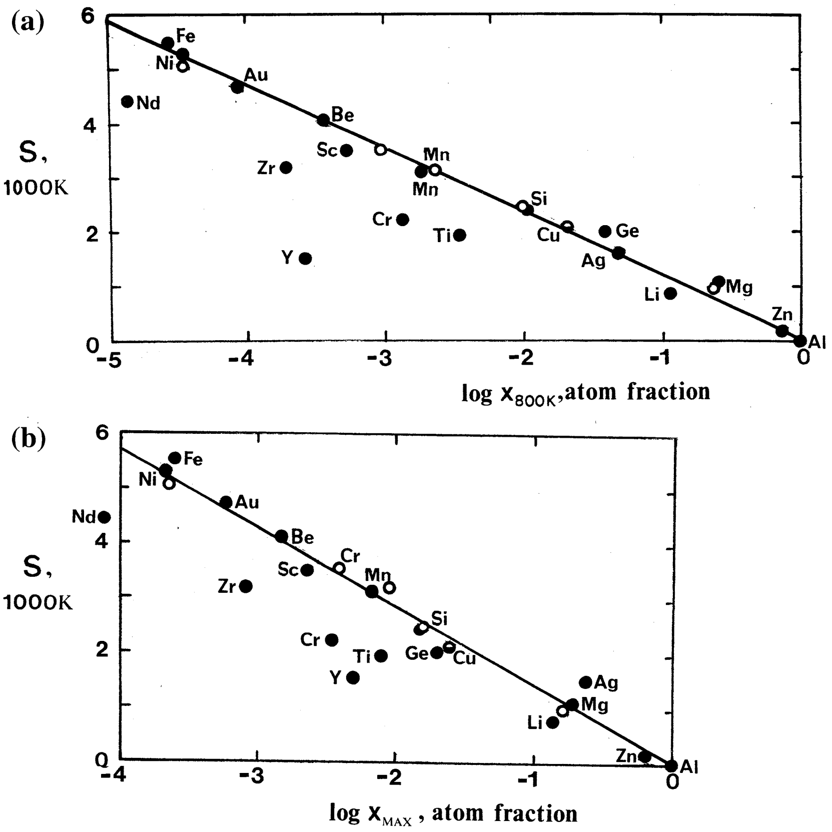

Fig. 1 Slope S of log x versus $1/T$ plotted against solid solubility (**a**) x_{800K} at 800 K and (**b**) x_{MAX} at the eutectic or peritectic temperature for solutes in aluminium. Open points are from Fink and Freche [1]. Closed points are from data given in Table 1

Table 2 Use of eq. (2) to determine the temperature dependence of solid solubility from its value at the eutectic temperature

System	x_{MAX}, atom fraction	T_{EU}, °C	S from eq. (2), K	Associated Q, kJ/mol	Associated x_o, atom fraction	Ref. to x_{MAX} data
Al–B	0.000045	659.7	6220 ± 390	119 ± 8	210	Duschanek and Rogl [25]
Al–Pb	0.00020	658	5290 ± 330	101 ± 6	97	Kondo et al. [26]
Al–Sn	0.00027	598	5100 ± 320	98 ± 6	195	McAlister and Kahan [27]

so

$$Q = 2.303RS$$

A knowledge of x at 800 K or the eutectic temperature then allows the pre-factor x_0 to be determined, and hence the dependence of x on temperature. For example, Table 2 tabulates outcomes for the pre-factor x_0 and heat of solution Q for three systems [25–27] for which x_{MAX} only is known, using eq. (2) to define the temperature dependence. Verification of the accuracy of these outcomes awaits experimental determination of the temperature dependence of solid solubility for these systems.

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