Bull. Mater. Sci., Vol. 25, No. 4, August 2002, pp. 315–317. © Indian Academy of Sciences.

Effect of alloying with zinc on SFE of aluminium by study of lattice imperfections in cold worked Al–Zn alloys

G KARMAKAR, R SEN†, S K CHATTOPADHYAY, A K MEIKAP and S K CHATTERJEE*

Regional Engineering College, Durgapur 713 209, India
†Bidhan Chandra Institution, Durgapur 713 205, India

MS received 4 April 2002; revised 24 May 2002

Abstract. A detailed X-ray Fourier line shape analysis has been performed on three compositions of Al–Zn alloys viz. Al–3·55 wt% Zn, Al–14·7 wt% Zn and Al–19·3 wt% Zn in *fcc* phase. It has been found that deformation stacking faults, both intrinsic α' and extrinsic α'' are absent in the cold worked state and twin fault β is found to be slightly present in the deformed lattice of the two initial compositions of the alloys. Similar to the effect of solute germanium and copper, respectively in Al–Ge and Al–Cu systems, hexagonal zinc also fails to impart faulting in *fcc* Al–Zn system. This corroborates the fact that aluminium has high stacking fault energy.

Keywords. Cold working; XRD; aluminium alloys; dislocations.

1. Introduction

X-ray diffraction is an established technique for the evaluation of microstructural defect parameters such as domain sizes, micro-strain within domain, and deformation stacking faults (De and SenGupta 1984; Van Berkum *et al* 1994). It is known that the normal ABC ABC . . . stacking sequence of close packed (111) planes in *fcc* structure assumes in the faulted region AB AB . . . stacking sequence which is the characteristic stacking sequence of basal planes of hexagonal close packed structure. It is also known that aluminium has high stacking fault energy and many alloying elements have failed to change this tendency of aluminium (Chattopadhyay *et al* 1990, 1992; Sen *et al* 1996). So it was decided to investigate the effect of hexagonal zinc as solute in aluminium lattice to form an alloy to determine the microstructural parameters of Al–Zn alloy systems in deformed state and to observe whether zinc as solute can change this characteristic property of aluminium. Moreover, the present X-ray diffraction analysis of the lattice imperfection in Al–Zn alloys is a continuation of a programme of study of lattice imperfections in Al-base alloys (Chattopadhyay *et al* 1990, 1992; Sen *et al* 1996). Detailed X-ray diffraction analysis based on line shift, line profile and line asymmetry of the X-ray diffraction profiles (Adler and Wagner 1962; Cohen and Wagner 1962; Chattopadhyay *et al* 1990, 1992; Sen *et al* 1996) has been performed on three compositions of Al–Zn alloys in α phase.

*Author for correspondence

2. Experimental and methods of analysis

Al–Zn alloys in α phase having three different compositions viz. Al–3·55, 14·7 and 19·3 wt% Zn were prepared from spectroscopically pure metals supplied by Johnson-Matthey and Co. Ltd, London by melting the ingredients in graphite crucibles sealed under vacuum in quartz ampoules as was done earlier for other Al base alloys (Chattopadhyay *et al* 1990, 1992). The alloys were homogenized at 400°C for 15 days. The cold working was performed by usual hand filling and flat diffractometer samples representing cold worked and standard annealed states were prepared from each alloy composition as before (Cohen and Wagner 1962; Chattopadhyay *et al* 1990, 1992). X-ray diffraction profiles were recorded in a Siemens Kristalloflex-4, X-ray diffractometer with CuK_α radiation. The detailed analysis (Chatterjee *et al* 1977; Sen *et al* 1996) was performed considering 111, 200, 220, 311, 222 and 400 reflections and Fourier coefficients, A_L, after Stoke's corrections were obtained by following the usual procedure. The size coefficients, A_L^S and distortion coefficients A_L^D, which are related with A_L as in (1) were separated from the log plot of A_L vs $l_0^2\,(h^2 + k^2 + l^2)$ for 111–222 and 200–400 pair of reflections (Warren 1969) (2). The microstructural parameters like coherent domain size, D_{eff}, related to the initial slope of A_L^S vs L (3) and microstrain $\langle \varepsilon_L^2 \rangle$ related to slope of log A_L vs l_0^2 were determined. The stacking fault probabilities like intrinsic α', extrinsic α'' and deformation twin fault probability β were evaluated from the initial slope of A_L^S vs L and using (4a) and (4b).

Table 1. The values of effective domain size, D_{eff}, r.m.s. strain $\langle \varepsilon_L^2 \rangle^{1/2}$ and stacking fault densities $(\alpha'-\alpha'')$ and $(4{\cdot}5\alpha'' + \beta)$.

Alloy composition	$(\alpha'-\alpha'') \times 10^3$ Line shift analysis Error limits $\pm 2{\cdot}0$ to $\pm 4{\cdot}0$	$(4{\cdot}5\alpha'' + \beta) \times 10^3$ Line asymmetry analysis, Error limit $= \pm 0{\cdot}003$	D_{eff} (Å) Error ± 5 Å to 10 Å		$\langle \varepsilon_L^2 \rangle^{1/2}$ at L = 50 Å	
			(111)	(100)	(111)	(100)
Al–3·55 wt% Zn	3·93	1·75	178	105	2·9	2·2
Al–14·7 wt% Zn	– 3·74	6·15	260	124	1·8	2·9
Al–19·3 wt% Zn	6·77	1·85	400	315	1·9	3·1

$$A_L = A_L^S A_L^D, \tag{1}$$

$$A_L^D = \exp(-2\pi^2 L^2 \langle \varepsilon_L^2 \rangle l_0^2 / a^2), \tag{2}$$

$$-(\mathrm{d}A_L^S/\mathrm{d}L)_{L\to 0} = 1/D_{\text{eff}}, \tag{3}$$

$$1/(D_{\text{eff}})_{111} = 1/D + (1/\sqrt{2}T)(3/4a_0)\{1{\cdot}5(\alpha' + \alpha'') + \beta\}, \tag{4a}$$

$$1/(D_{\text{eff}})_{200} = 1/D + (1/\sqrt{1{\cdot}5}T)(1/a_0)\{1{\cdot}5(\alpha' + \alpha'') + \beta\}. \tag{4b}$$

Using line shift analysis comprising the neighbouring peaks (Wagner 1966), the lattice parameter change, $\Delta a/a_0$ and stacking faults $(\alpha'-\alpha'')$ were calculated neglecting the effect of long range residual stress σ in powder samples.

3. Results and discussion

The values of $\Delta a/a_0$ and $(\alpha'-\alpha'')$ were calculated from line shift analysis. The values of $\Delta a/a_0$, which are due to dislocation networks (Wagner 1966), were observed to be very small and of the order of -2×10^{-3}. $(\alpha'-\alpha'')$ values (table 1) were also found to be small and within the error limit. The observation is similar to other Al-base alloy systems investigated in the series, i.e. Al–Cu and Al–Ge (Chattopadhyay *et al* 1990, 1992).

The peak asymmetry analysis similar to earlier work (Chattopadhyay *et al* 1990, 1992) was performed to determine the compound fault probability $(4{\cdot}5\alpha'' + \beta)$ which is shown in table 1. This was found to be higher than those obtained for other aluminium alloys (Chattopadhyay *et al* 1990, 1992). Detailed Fourier line shape analysis was performed by expressing the profiles as Fourier series. The Fourier coefficients, A_L, were plotted against L (Å) and are shown in figures 1 and 2 for Al–3·55 wt% Zn (alloy I) and Al–19·3 wt% Zn (alloy III), respectively. A similar variation of Fourier coefficients, A_L vs L has also been found in alloy II. The size and distortion coefficients, A_L^S and A_L^D, were separated from the log plot of A_L vs $l_0^2(h^2 + k^2 + l^2)$ (figure 3). From these coefficients, A_L^S and A_L^D, the effective domain size, D_{eff}, micro strain $\langle \varepsilon_L^2 \rangle$ and compound fault probability $[1{\cdot}5(\alpha' + \alpha'') + \beta]$ were determined (Chattopadhyay *et al* 1990, 1992) and are shown in table 2 along with respective error limits. The effective domain size, D_{eff} values are found to be smaller than Al–Cu or Al–Ge, and root mean square strain $\langle \varepsilon_L^2 \rangle^{1/2}$ values are found to be as small as those for these Al-base alloys.

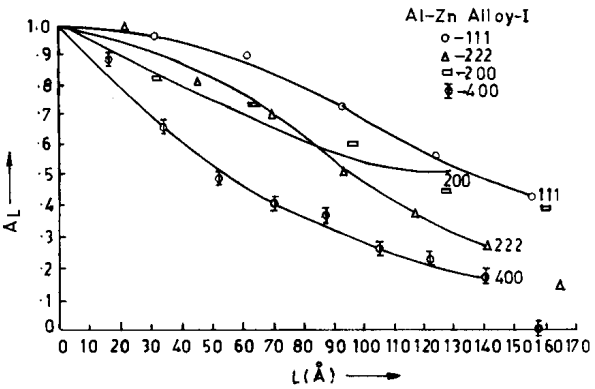

Figure 1. Fourier coefficient, A_L vs L (Å) for Al–Zn (alloy-I).

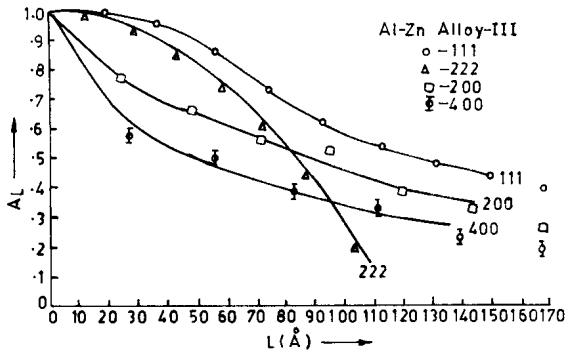

Figure 2. Fourier coefficient, A_L vs L (Å) for Al–Zn (alloy-III).

Combining the analyses of line shift, line asymmetry and line shape, the stacking fault densities, like intrinsic α', extrinsic α'' and deformation twin β were calculated and are shown in table 2. The values of α' and α'' are

Table 2. The values of stacking fault density $[1{\cdot}5\,(\alpha' + \alpha'') + \beta]$ and individual values of α', α'' and β.

Alloy composition	$[1{\cdot}5(\alpha'+\alpha'') + \beta] \times 10^3$ Line shape analysis Error limit ± 3·0 to ± 5·0	$\alpha' \times 10^3$ Error limit ± 3·0 to ± 10·0	$\alpha'' \times 10^3$ Error limit ± 1·0 to ± 7·0	$\beta \times 10^3$ Error limit ± 3·0 to ± 20·0
Al–3·55 wt% Zn	27·9	– 9·5	– 13·5	62·4
Al–14·7 wt% Zn	30·0	– 23·4	– 19·6	94·6
Al–19·3 wt% Zn	4·8	11·6	4·8	– 19·7

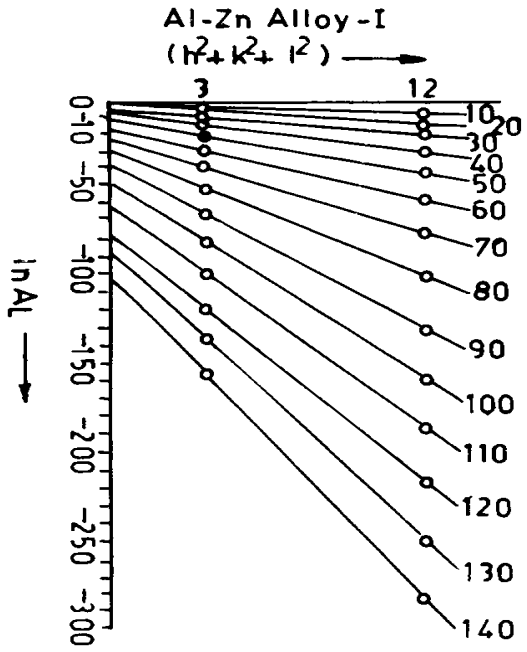

Figure 3. $\ln A_L$ vs $l_0^2(h^2 + k^2 + l^2)$ for Al–Zn alloy-I.

found to be either negative or small enough to be within the error limit. This indicates that in the present Al–Zn alloy system, the deformation faults, both intrinsic and extrinsic, are negligible and the system is thus not prone to such deformation faulting. This observation is comparable to other two Al-base alloys (Chattopadhyay *et al* 1990, 1992) studied earlier. The deformation twin β is, however, found to be above the error limit for alloys Al–3·55 wt% Zn and Al–14·7 wt% Zn whereas it is negative for Al–19·3 wt% Zn. This observation is, therefore, similar to the earlier observation on Al–Cu system (Chattopadhyay *et al* 1992), where β was found to be positive and slightly above error limit. Based on the observations obtained on Al–Zn system, it can be concluded that like other Al-base alloy, this alloy system is also not prone to deformation faulting like α' and α'' though there is a tendency for the formation of deformation twin at least at lower compositions. So, aluminium retains its characteristic of having high stacking fault energy even when, with an idea of introducing faulting tendency, it is alloyed with hexagonal zinc.

4. Conclusion

Aluminium retains its high stacking fault energy even when it is alloyed with hexagonal zinc and subjected to extensive cold work. This is similar to the observations made in a previous work (Chattopadhyay *et al* 1990, 1992).

References

Adler R P I and Wagner C N J 1962 *J. Appl. Phys*. **33** 3451

Chatterjee S K, Halder S K and Sengupta S P 1977 *J. Appl. Phys*. **48** 1442

Chattopadhyay S K, Chatterjee S K and Sengupta S P 1990 *Metall. Trans*. **A21** 2597

Chattopadhyay S K, Chatterjee S K and Sengupta S P 1992 *Metall. Trans*. **A23** 1371

Cohen J B and Wagner C N J 1962 *J. Appl. Phys*. **33** 2073

De M and SenGupta S P 1984 *Pramana – J. Phys.* **23** 721

Sen R, Chattopadhyay S K and Chatterjee S K 1996 *Metall. Trans*. **A27** 503

Van Berkum G M, Vermeulen A C, Delhez R, De Keijser T H and Mittemeijer E J 1994 *J. Appl. Cryst.* **27** 345

Wagner C N J 1966 *Local atomic arrangements studied by X-ray diffraction* (New York: AIME) Vol. **36**, Ch. 7

Warren B R 1969 *X-ray diffraction* (Reading: Addison-Wesley)