

The Role of Ag and Vacancies in Al-Zn-Mg-Ag Alloys

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Motivation & Background

The introduction of Ag to Al-Zn-Mg alloys is seen to further increase hardness under both natural and artificial ageing conditions, with reports to **harden** under natural ageing conditions through several months (Fig.1) [1]. Vietz and Polmeat[2] attributed an increased peak hardness to the reduction in precipitate free zone (PFZ) observed when silver is present (Fig.2). This was further supported by Ogura via nano-hardness testing of PFZ's[3].

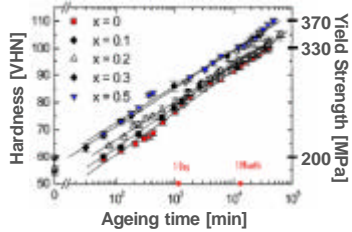


Figure 1: Hardness of Al-4Zn-3Mg-xAg (wt%) with natural ageing time[1].

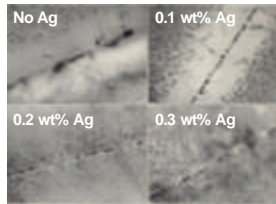


Figure 2: Electron micrographs of Al-4Zn-3Mg-xAg (wt%) after ageing at 150°C for 1 day. 35,000x[2]

Recent three-dimension atom probe (3DAP) studies have indicated that Ag has a strong tendency to cluster with Mg and Zn, with Ag providing enhanced cluster densities[4]. This phenomenon may contribute to the prolonged natural age hardening and the reduction in PFZ in the artificially aged alloys.

Ogura[5] noted that the size of grain boundary precipitates decreased as the concentration of silver was increased. The presence of silver promoted clustering, slowing the diffusion of solute to grain boundaries, hence a reduced PFZ.

Previous positron annihilation lifetime spectroscopy (PALS) analysis was used in the study of Al-Cu-Ag alloys, it was shown that the addition of Ag increased the mean positron lifetime[6] indicating an increase in vacancy concentration (Fig.4).

This project aims to determine the role of Ag and the interaction with vacancies in the mechanism for this hardening behaviour.

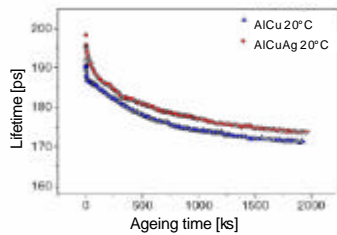


Figure 3: Positron lifetime Al-Cu and Al-Cu-Ag[6].

PALS

PALS can be used to investigate vacancy behaviour within alloys and therefore provide useful information about the clustering and hardening characteristics.

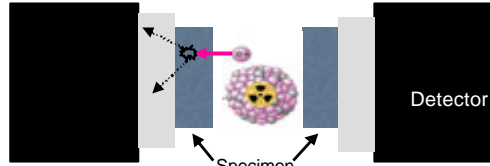


Figure 4: schematic representation of PALS

PALS involves the emission of a positron from a radioactive source, where the positron travels into a sample and annihilates either within the bulk of the material or a defect. At the points of positron emission and annihilation gamma rays are emitted, which allows the determination of an annihilation lifetime.

Annihilation measurements taken over a period of time warrant the calculation of a mean positron lifetime (t_{mean}). The mean positron lifetime reflects the concentration of trapping sites, in the case of alloys these trapping sites are typically mono-vacancies. The collection of mean lifetime values over time enables the monitoring of vacancy annihilation with ageing time.

Method

Each sample was solution heat treated at 460°C for 1 hour then rapidly quenched into ice water. PALS measurements were initiated immediately after the quench. The results of these spectra are summarised on Fig.5.

$$t_{mean} = \frac{t_1 \cdot I_1 + t_2 \cdot I_2}{I_1 + I_2}$$

$$m C_v = I_2 \left(\frac{1}{t_1} - \frac{1}{t_2} \right)$$

$\mu = 2.5 \times 10^{14} s^{-1} at$ (positron trapping coefficient for pure Al)

Table I: Typical bulk/vacancy annihilation lifetimes

	Al	Zn	Mg	Ag
t_{bulk}	162	161	175	164
$t_{vacancy}$	237	233	250	227

Table II: Alloy composition Al-4Zn-3Mg-xAg

wt% Ag	at% Ag
0.01	0.003
0.05	0.013
0.15	0.038
0.20	0.051
0.30	0.077
1.00	0.257

t_{mean} is a function of t_{bulk} (t_1) and $t_{vacancy}$ (t_2) and their respective intensities, I_1 and I_2 . These values can be extracted and used to calculate C_v , an absolute vacancy concentration.

Results & Discussion

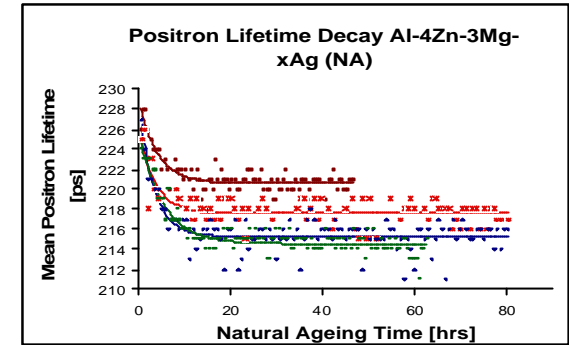


Figure 5: Mean positron lifetime with natural ageing time as a function of Ag content.

↑ Ag content ↑ Clustering ↓ t_{mean} Indicating ↓ Vacancy concentration

Quantitative calculation of vacancy concentration

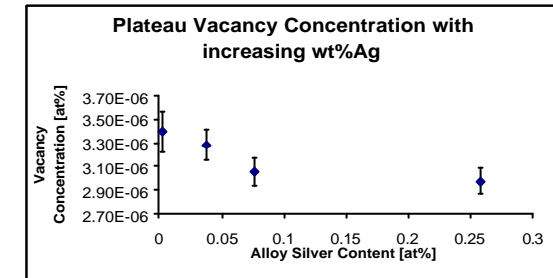


Figure 6: Absolute vacancy concentration as a function of Ag content.

Summary

It is believed that Ag stimulates early clustering, reducing the tendency for solute to diffuse to grain boundaries, putting vacancies to use earlier, resulting in the reduction of PFZ's.

The retained vacancy concentration does not increase with increasing silver, suggesting that the role of Ag is not to retain vacancies however its strong affinity to other solute atoms promotes clustering and therefore hardening.

References

- [1] C. E. Macchi, Acta Materialia, 2003
- [2] J. T. Vietz, Journal of Institute of metals, 1963-64
- [3] T. Ogura Science and Technology of Advanced Materials, 2004
- [4] S.K. Maloney micron, 2001
- [5] A. Dupasquier, Acta materialia, 2004