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Positron Studies of Precipitation Phenomena in Rapidly Solidified Al Alloys

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The precipitation process in a rapidly solidified (melt spinning techniques) Al-Cu(4.9 wt. %)-Mn (0.98 wt. %) alloy was studied by the positron lifetime method. The results are discussed in comparision with the development of the microstructure in this alloy and in an Al-Cu(4 wt. %) alloy prepared by conventional casting and quenching from the solid phase. The positron lifetime results are related to microhardness testing and TEM experiments.

1. Introduction

Rapidly solidified metallic alloys (liquid quench techniques) have been intensively studied for more than two decades (FURRER and WARLIMONT). The most important advantage of Al based alloys produced by rapide solidification techniques is due to the significantly higher solubility of alloying elements such a transition metals in the liquid state in comparision with the solid state. A considerable part of the transition metalls tends to form, together with Al, intermetallic phases, which are very stable against dissolution at higher temperatures. Thus, the formation of these intermetallic phases results in most cases in good warm strength properties of rapidly solidified Al alloys containing transition metalls. Contrary to that, conventional Al alloys containing for example Zn, Mg and/or Cu lose their strength above 150 °C due to coarsening and dissolution of precipitated particles.

We have investigated rapidly solidified alloys of Al-Zn-Mg and Al-Cu with additions of Mn by utilizing positron annihilation, electron microscopy and microhardness tests. In this paper we report on positron lifetime studies of a rapidly solidified Al-Cu-Mn alloy. For comparison, the results of conventionally quenched Al-Cu-Mn and Al-Cu alloys are discussed even.

2. Experimental

The material under investigation was an alloy of Al-Cu (4.9 wt.%)-Mn(0.98 wt. %). From the alloy we have produced melt spun ribbons with a thickness of 100 μm,

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from which a solidification rate of 5 . 10^4 K/s was evaluated. The melt was heated to a temperature of 900 °C before rapide solidification was performed (for more details see HEYROTH). The same material and a binary Al-Cu(4 wt. %) alloy were conventionally treated by solution annealing at 540 °C for 12 hours and quenching into water of room temperature.

Positron lifetime measurements were performed at room temperature with a conventional fast-slow coincidence device having a resolution of 260 ps. If positrons are captured by a single type of traps the lifetime spectrum is the sum of two exponentional functions. The lifetime value of the second component is characteristic of the type of positron trap, $\tau_2 = \tau_t$, the intensity I_2 of the component is a function of the positron trapping rate K.

$$I_2 = \frac{K}{1/\tau_b - 1/\tau_t + K} \tag{1}$$

where τ_b is the bulk positron lifetime and τ_t is the trapped positron lifetime. The trapping rate is a linear function of the number of traps. In case of extended traps like precipitates the trapping rate my be approximated by

$$K = 4\pi D_+ rN \,, \tag{2}$$

where r and N are the radius and the number density of particles, respectively. D_+ denotes the positron diffusion coefficient, $D_+ = 0.6\ \mathrm{cm}^2\,\mathrm{s}^{-1}$ in Al. In pure metals positrons my be trapped by vacancies, vacancy clusters and dislocations. As discussed by DLUBEK coherent Guinier-Preston (GP) zones, semicoherent and incoherent particles may localize positrons in decomposed Al alloys. In case of precipitates, misfit dislocations and incoherent particle-matrix interfaces form sites of positron localization.

3. Results nad Discussion

In Fig. 1 the average positron lifetime $\bar{\tau}$ is shown for the rapidly solidified Al-Cu-Mn alloy as a function of the isochronal (200 min) annealing temperature together with results of the conventionally treated samples of Al-Cu-Mn and Al-Cu. In Fig. 2 the lifetime τ_2 and intensity I_2 of the second (trapped positron) lifetime component is shown. For clarity we did omit the results of the conventionally quenched Al-Cu-Mn sample in this Figure.

It is commonly accepted that in the Al-Cu system the decomposition sequence is Guinier-Preston zones of type I (GP(I) for short) → GP(II) or $\Theta'' \to \Theta' \to \Theta$ (Al_2Cu). GP(I) and GP(II) are coherent whereas the intermediate phase Θ' and the equilibrium phase Θ form semicoherent and incoherent particles, respectively. The GP(I) zones consist of a Cu platelet on a (100) plane of the Al matrix while GP(II) zones may consist of two or more Cu layers separated by a few (one two three) Al layers (for review, see LORIMER). The average positron lifetime $\bar{\tau}$ of the as-quenched Al-Cu specimen (Fig. 1) is situated distinctly above the bulk lifetimes.

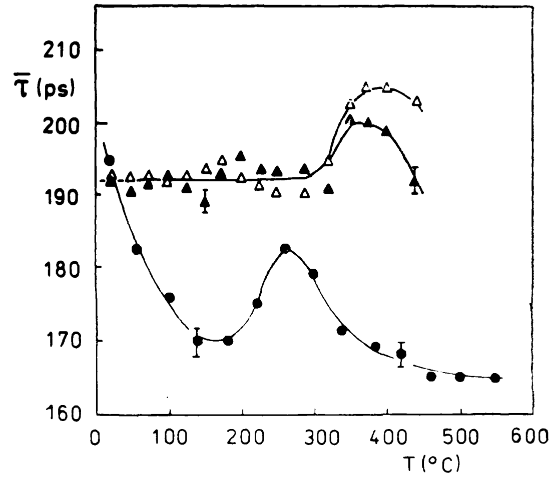

Fig. 1. Average positron lifetime $\bar{\tau}$ as a function of the isochronal (200 min) annealing temperature T in Al-Cu(4.9 wt. %)-Mn(0.98 wt. %) rapidly solidified (△) and in Al-Cu(4.9 wt. %)-Mn(0.98 wt.%) (▲) and Al-Cu(4 wt. %) (●) prepared by conventional casting and quenching from 540 °C into water of room temperature.

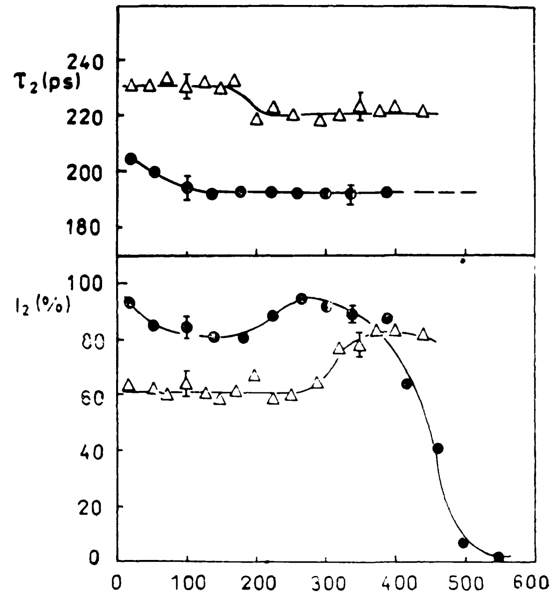

Fig. 2. Lifetime value τ_2 and intensity I_2 of the second (trapped positron) lifetime component. Notation as in Fig. 1.

in pure Al (165 ps) and pure Cu (110 ps). This indicates annihilation of positrons at a vacancy-type positron trap. The trapped positron lifetime, $\tau_2 = 204$ ps (Fig. 2), may be compared with the lifetime of positrons localized at vacancies in pure Al

(240 ps) and pure Cu (180 ps). This shows that in the as-quenched Al-Cu (4 wt. %) sample the majority of positrons annihilate from a localized state at a vacancy the next neighbour sphere of which contains both Al atoms and Cu atoms. The decrease in τ_2 between room temperature and 150 °C may be attributed to an increase of the Cu content in the vacancy surroundings. From the present results we may conclude that the vacancies are associated with well developed GP zones. But the vacancies may be also trapped by Cu clusters which are not GP zones (see DLUBEK).

Above a temperature of 150 °C $\bar{\tau}$ and I_2 exhibit a pronounced increase with a maximum at 260 °C. The trapped positron lifetime $\tau_2 = 192$ ps (Fig. 2) does not change above 150 °C. This shows that the type of positron trap does not change during annealing. The results may be well understood assuming positron trapping by misfit dislocations of the semicoherent particles of the Θ'-phase and, in a later annealing state, by the incoherent particle-matrix interface of Θ-particles. The behaviour of $\bar{\tau}$ and I_2 reflects then the formation of precipitates of the Θ' and Θ phase and above 260 °C their coarsening and dissolution. Near a temperature of 500 °C the average positron lifetime aproaches the Al bulk value of 165 ps indicating the disappearance of positron traps.

As can be seen in Fig. 1 $\bar{\tau}$ stays constant at a level of 192 ps between room temperature and 300 °C in both samples of the Al-Cu-Mn alloy which were treated either by rapide solidification or by conventional casting and quenching from the solid state. τ_2 has a value of 230 ps in the range between room temperature and 180 °C (Fig. 2). This value is distinctly above the τ_2-value in Al-Cu and approaches the positron lifetime of monovacancies in pure Al (240 ps). The results may be interpreted assuming positron trapping by quenchend-in vacancies which are stabilized by single Mn atoms or by small clusters of Mn atoms. Obviously, in the Al-Cu-Mn alloy positrons do not respond to the formation and development of the GP zones. Below 300 °C there are no differences in the lifetime spectra of the Al-Cu-Mn samples quenched from the liquid phase or from the solid state. This suprising observation may be related to the fact that in the solid state Al solves already 0.4 wt. % Mn at a temperature of 490 °C.

Above 300 °C $\bar{\tau}$ and I_2 increase in both samples of the Al-Cu-Mn alloy. This indicates an increase in the number of positron traps and may be attributed to the precipitation of Mn, which starts to migrate at these temperatures, from the supersaturated Al matrix. The higher $\bar{\tau}$ (and I_2) values in the rapidly solidified alloy may be easily understood as consequence of the higher supersaturation in this sample compared with the sample quenched from the solid state. From electron microscopical and diffraction investigation of an Al-Cu-Mn alloy LECONG DZUONG et al. concluded on the formation of particles of the $Cu_2Mn_3Al_{20}$-(T-) phase. Positrons may be trapped at the interface of these particles. The small decrease of τ_2 at about 180 °C indicates a change in the nature of the site of positron localization and may be due to the formation of nuclei of the $Cu_2Mn_3Al_{20}$-phase. During isothermal annealing of Al-Cu-Mn at 400 °C the microhardness shows an increase with a maximum after annealing for a period of 5 hours while the hardness of the Al-Cu sample decreases contiuously. The hardness testing experiments correlate well with the behaviour of the annihilation parameters. The precipitates of the $Cu_2Mn_3Al_{20}$-phase are much more stable than particles of the Al_2Cu-phase. In Al-Cu-Mn the maximum of the trapping effect appears at about 400 °C. The decrease of $\bar{\tau}$ and I_2 above 400 °C can be attributed to coarsening of the precipitates.

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