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Studying the recovery of as-received industrial Al alloys by positron annihilation spectroscopy

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Abstract

Positron annihilation lifetime (PAL) spectroscopy, Doppler broadening of annihilation radiation (DBAR) spectroscopy and Vickers microhardness (Hv) measurements were performed to study the micro- and macro-structure variations during isochronal annealing from room temperature (RT) to 500 °C of commercial pure Al (1 1 0 0), Al–Mn–Mg (3 0 0 4) and Al–Mg–Si (6 2 0 1) alloys. Three annealing stages of microstructures have been identified as recovery, partial recrystallization and complete recrystallization followed by grain growth. A positive correlation between the macroscopic mechanical properties (Hv) and positron annihilation parameters has been achieved for the three samples under investigation.

Keywords: Al alloys; Positron annihilation lifetime; Doppler broadening; Vickers microhardness

1. Introduction

It is well known that positron annihilation offers a unique way to characterize the electronic and defect structure of solids. Positrons, injected in a solid, lose their energy in a few picoseconds and, after a diffusion motion, annihilation mostly in two 511 keV γ quanta with an electron of the medium. Due to their positive charge, positrons are efficiently trapped by defects. The two most frequently used techniques to detect and to investigate the properties of defect volume and their interaction with the medium are the lifetime and the Doppler broadening techniques. Abd El Wahab and Arafa [1] have used the Doppler broadening measurements to study the isochronal annealing of cold worked commercially pure Al and Al–Mn alloys. They deduced the line shape central (*S*) and wing (*W*) parameters in the range from room temperature (RT) to 823 K and correlated with the corresponding microhardness measurements. The variation of microhardness and line shape parameter with temperature indicated the presence of three stages of microstructures in both Al and Al–Mn alloys, which are recovery, partial recrystallization and complete recrystallization. Mohsen et al. [2] applied positron annihilation lifetime (PAL) to study lattice defects during

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isochronal annealing of industrial Al samples after deformation and annealing. Their results showed that isochronal annealing of commercially pure Al, Al–Mn–Mg and Al–Mg up to 823 K reveals recovery in three stages after plastic deformation. Gomaa et al. [3] used PAL, scanning electron microscope (SEM) and Vickers microhardness (Hv) measurements to study the isochronal annealing of Al–Mn (3 0 0 4) alloy in the temperature range from RT to 823 K after cold rolling at RT with various deformations of 7% and 23%. A positive correlation was found between mean lifetime (τ_m) of positrons and Vickers microhardness. Three annealing stages of microstructures in Al–Mn (3 0 0 4) alloy were distinguished which were attributed to recovery, partial recrystallization and complete recrystallization followed by grain growth.

In the present work, the annealing stages during isochronal annealing of three industrial Al alloys in the temperature interval (room temperature to 500 °C) were studied using positron annihilation lifetime, Doppler broadening of annihilation radiation (DBAR) and Vickers microhardness. An attempt was made to establish a correlation between the positron annihilation parameters and the macroscopic mechanical properties through the measurements of Vickers microhardness for the samples under investigation.

2. Experimental details and data analysis

The samples under study are the Al (1 1 0 0), Al (3 0 0 4) and Al (6 2 0 1) alloys. Al (1 1 0 0) and Al (3 0 0 4) were obtained from the military factory 63-Egypt, while Al (6 2 0 1) was supplied by Egyptian Cables Company. The chemical composition of these samples is shown in Table 1. The samples were cut into a square of 1 cm side and 1.25 mm thickness. All the samples were isochronal annealed for 1 h in the temperature range from RT to 500 °C at an interval of 50 °C then quenched in water at RT. For lifetime and Doppler broadening measurements, a ^{22}Na positron source of activity 20 μCi was sandwiched between two identical samples. A conventional positron lifetime spectrometer with a resolution of 220 ps was used for PAL measurements [4]. The recorded lifetime spectra were analyzed using the PATFIT program [5] in terms of two lifetime components τ_1 and τ_2 with relative intensities I_1 and I_2. The variation in lifetime values is relevant to defect type, while changes in the intensities reflect defect concentration. Meanwhile, positron mean lifetime, τ_m, can be calculated using the formula $\tau_m = I_1\tau_1 + I_2\tau_2$.

DBAR measurements were performed simultaneously with the PAL measurements. The most essential part in DBAR spectrometer is the high purity germanium detector with an energy resolution of 1.2 keV (full width at half maximum, FWHM) for 622 keV ^{137}Cs γ-line. Each DBAR spectrum was analyzed using DOPPLERFIT program [6] from which the *S*-parameter is extracted. The *S*-parameter is defined as the ratio of the number of counts in a fixed central window with channels wide (511 ± 0.639 keV) to the number of counts in a spectrum with channels wide (511 ± 3.833 keV). The normalized line shape parameter S_{nor} can be determined from the ratio of S/S_{ref}, where S_{ref} was obtained by measuring the line shape parameter using well-annealed Al (1 1 0 0). The Vickers microhardness tester, ZEISS model mhp-160 was used for measuring the microhardness [7]. These measurements were performed at RT using a load 30 g for 30 s. More than 10 readings were taken for each sample and the standard deviations were estimated.

3. Results and discussion

Figs. 1–3 show S_{nor}, τ_m and Hv as a function of isochronal annealing temperature for Al (1 1 0 0), Al–Mn–Mg (3 0 0 4) and Al–Mg–Si (6 2 0 1) alloys,

Table 1
The chemical composition of the alloys (wt.%)

Material	Element									
	Al	Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	B	Others
Al (1 1 0 0)	98.6601	0.54	0.44	0.3	0.006	0.009	0.008	0.003	–	–	0.008
Al (3 0 0 4)	97.459	0.25	0.3	0.06	1.04	0.8	0.05	0.011	–	–	0.03
Al (6 2 0 1)	98.13	0.5	0.3	0.1	0.03	0.55	0.1	–	0.03	0.06	0.1