Contribution of the GP Zones to the Hardening and to the Electrical Resistivity in Al10at.%Ag Alloy

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Abstract Using microhardness and electrical resistivity measurements, the contributions of the matrix and that of the Guinier-Preston zones to the hardening and to the electrical resistivity of the Al10at.%Ag alloy are determined separately during the Guinier-Preston zones precipitation. A linear correlation between the hardness and the electrical resistivity of the as quenched alloys exists. There is also a linear relationship between the contribution of the matrix to the hardening and that to the electrical resistivity of the isothermal aged alloy. However, no linear relation exists between the hardness and the electrical resistivity of the isothermal aged alloy.

Keywords: precipitation, transformed fraction, hardness, electrical resistivity

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1. Introduction

An Al-Ag supersaturated solid solution evolves towards the equilibrium state following the sequence [1,2,3,4]:

Supersaturated solid solution → Guinier-Preston (GP) zones → metastable γ'-phase → equilibrium γ -phase

The precipitate formation, which results from the diffusion of the solute atoms from the matrix to the precipitate particles, is responsible of a variation of the hardening and the electrical resistivity of the alloy [5]. The alloy hardening results from the interaction between the moving dislocations and the lattice defects. The alloy electrical resistivity results from the interaction between the free electrons and the lattice defects in the alloy. In a non deformed supersaturated solid solution, during an isothermal aging treatment, we can assume that the contribution of the dislocations and that of the grain boundaries to the hardening and to the electrical resistivity remain constant. Thus, the hardness and the electrical resistivity variations are essentially attributed to the interactions of the moving dislocations and the free electrons with the solute atoms and the precipitate particles [6,7]. During an isothermal aging treatment, due to the migration of the solute atoms to the precipitate particles, the contributions of the matrix to the hardening and to the electrical resistivity of the solid solution decrease whereas those of the precipitate phase increase. Our purpose is to determine the contributions of the matrix and the GP zones to the hardening and to the electrical resistivity in the Al-10at.%Ag alloy.

2. Experimental Methods

The Al10%Ag alloy was prepared by melting 99.99% and 99.99% pure aluminum and silver respectively, under an argon protection. After an homogenization at 540 °C and quenching, the alloys are cut into platelets specimen which are mechanically polished, homogenized at 540°C, quenched in water and treated at 125°C. A P1710 Phillips X-ray powder diffractometer, utilizing the monochromatic $CuK_{\alpha1}$ radiation, is used for the characterization of our alloys. The microhardness measurements were carried out under a load of 100 gr. Electrical resistivity measurements were carried out using the four points method at room temperature.

3. Results and Discussion

3.1. Characterization of the Solid Solution

Table 1. Integrated intensities ratios

hkl	Al (I_{hkl}/I_{111})	Al-Ag(I_{hkl}/I_{111})
111	100	100
200	50	51
220	21	30
311	20	21
222	6	6

The as quenched solid solution, Al10at.%Ag is characterized by X-ray diffraction. It is well known that an as quenched substitutional solid solution is in a disordered state. In the case of aluminum based solid solutions, the X-ray powder diffraction spectra gives peaks diffraction at the analogous positions of those given by the aluminum. The Al and Al-Ag powder diffraction spectra show that the successive peaks are at analogous positions (Figure 1a,b)

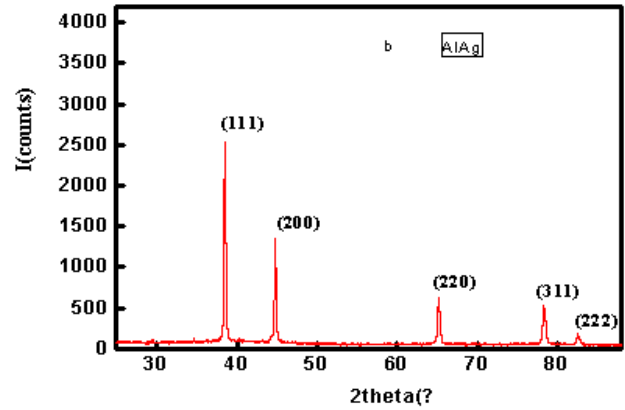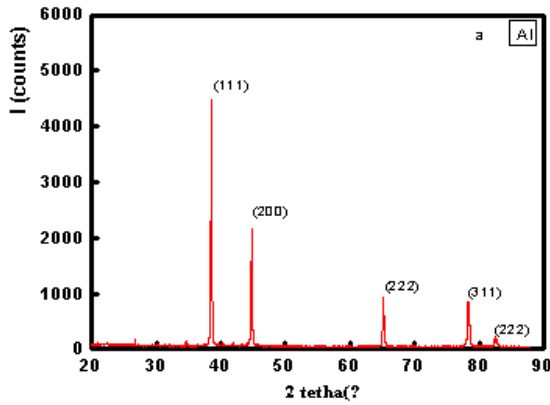and their integrated intensities vary in the same ratio (Table 1). The lattice parameters of Al and Al-Ag, determined using the Nelson-Riley [8] extrapolation function, are respectively 4,0462 Å and 4,0478 Å.

Figure 1. X-ray powder diffraction spectra of Al(a) and Al-Ag (b) as quenched solid solution

3.2. Hardening Contributions

The hardness isotherm curve, established at 125°C (Figure 2) shows a first step of hardening due to the GP zones precipitation and a second step due to the precipitation of the metastable γ' phase. The intermediate bearing corresponds to the metastable equilibrium state of the GP zones precipitation during which their volume fraction is maximum. The softening is due to the coarsening of the particles of the metastable γ'phase and to the precipitation of the particles of the equilibrium γ phase.
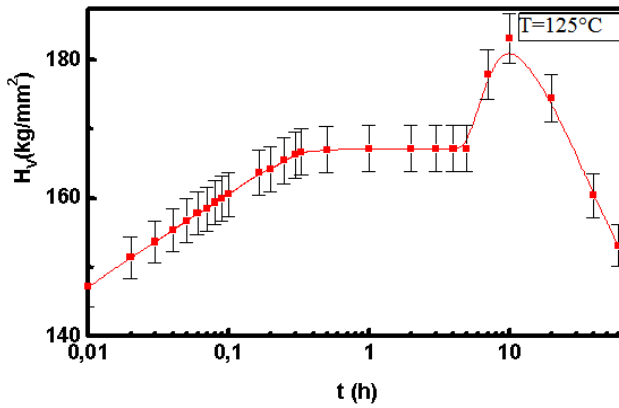

Figure 2. Isotherm hardness curve at 125°C

During the GP zones formation, the hardness, H_v, results from the matrix contribution, H_{vm}, and the GP zones contribution, H_{vGP} :

$$H_v = H_{vm} + H_{vGP} \qquad (1)$$

The matrix contribution to the hardening, H_{vm}, depends on its solute atom concentration, x_m. The matrix solute atom concentration during the GP zones formation is determined from the transformed fraction, F. The transformed fraction (Figure 3), is established from the Merle relation [9]:

$$H_v(t) = F . H_{v(\text{metastable equilibrium})} + (1 - F).H_v(0) \quad (2)$$

where $H_v(0)$ is the as quenched hardness, $H_v(t)$, the hardness of the alloy at the time t during the GP zones precipitation, and $H_{v(\text{metastable equilibrium})}$, the hardness of the alloy at the metastable equilibrium state of the GP zones

precipitation. The matrix solute atom concentration is obtained using the relation [10]:

$$F = (x_0 - x_m)/(x_0 - x_e) \qquad (3)$$

where x_0 is the solute atom concentration of the alloy and x_e, the solute atom concentration of the matrix at the metastable equilibrium state. At 125°C, the value of x_e, determined from the metastable equilibrium diagram [11] is 0,53 at.%.

The matrix contribution to the hardening, H_{vm}, is deduced from the hardness variation curve of homogenized alloys containing different solute atom concentrations (Figure 4) and the variation curve of the matrix solute atom concentration during the GP zones formation (Figure 5).
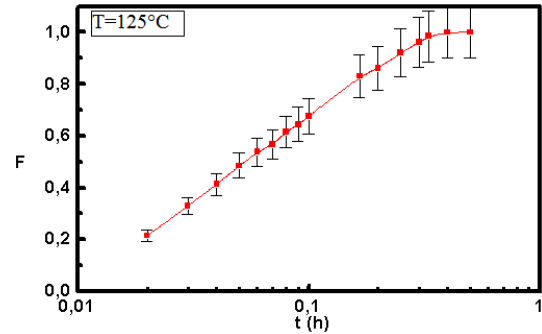

Figure 3. Transformed fraction during the GP zones precipitation at 125°C
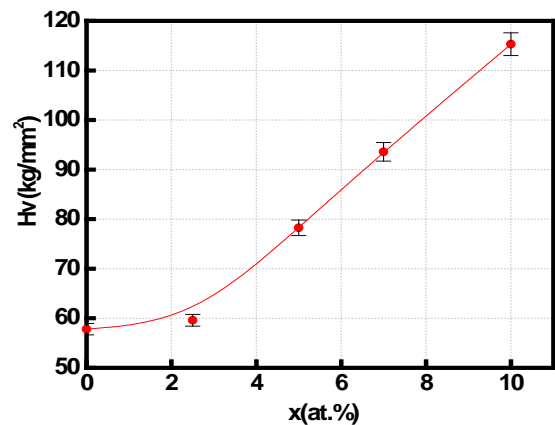

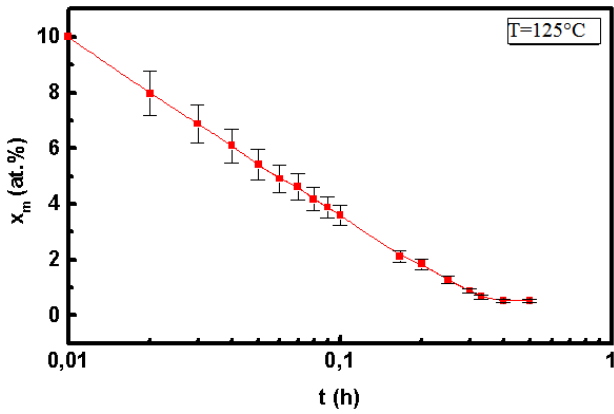**Figure 4.** Hardness curve variation of homogenized Alxat.%Ag alloys

Figure 5. Matrix solute atom concentration during the GP zones precipitation at 125°C

Thus, the GP zones contribution to the hardness, H_{vGP}, is given by the difference $H_v - H_{vm}$ (Figure 6).
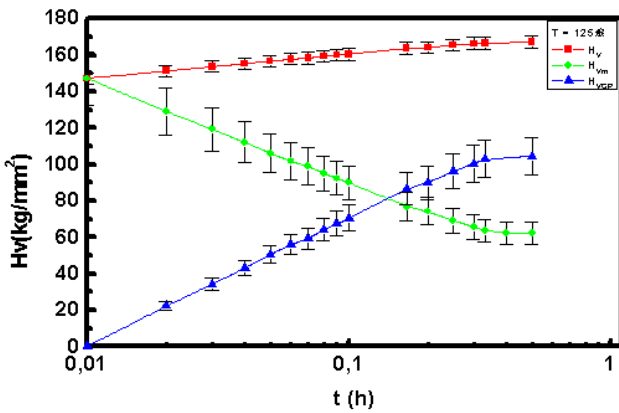

Figure 6. Contribution to the alloy hardening of the matrix, H_{Vm}, and that of the GP zones, H_{VGP}, during the GP zones precipitation at 125°C.

3.3. Electrical Resistivity Contributions

During the GP zones formation, the electrical resistivity of the alloy decreases and reaches a constant value at the metastable equilibrium state (Figure 7) during which the volume fraction of the GP zones is maximum.
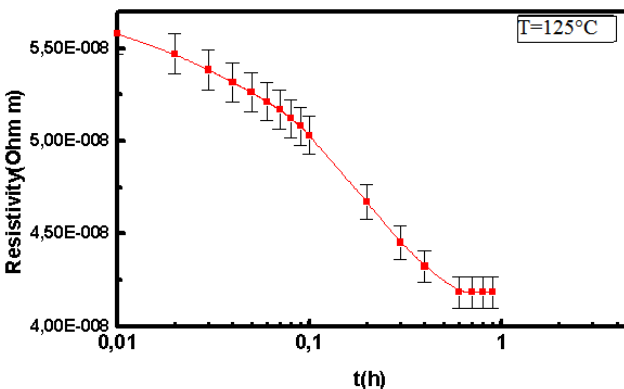

Figure 7. Electrical resistivity variation of the alloy during the GP zones precipitation at 125°C

According to the Matthiessen rule, the electrical resistivity results from the contribution of the phonons and that of all defects in the alloy such the dislocations, the grain boundaries, the solute atoms and the precipitate particles. During an isothermal aging treatment, the contribution of the phonons remains constant. Also, in a non deformed alloy, during an isothermal aging treatment, the contributions of the defects such the dislocations and the grain boundaries remain constant while those of the solute atoms and the precipitate particles vary.

In an as quenched and non deformed solid solution, during an isothermal aging treatment, the electrical resistivity, ρ, results from the contributions of the matrix, ρ_m, and that of the GP zones, ρ_{GP}:

$$\rho = \rho_m + \rho_{GP} \qquad (4)$$

The electrical resistivity contribution of the matrix is determined from the variation curve of the electrical resistivity of homogenized alloys containing different concentrations of solute atoms (Figure 8) and the variation curve of the matrix solute atom concentration during the GP zones formation (Figure 5). The variation curve of electrical resistivity of homogenized alloys shows an increase of the electrical resistivity with the solute atom concentration [12],
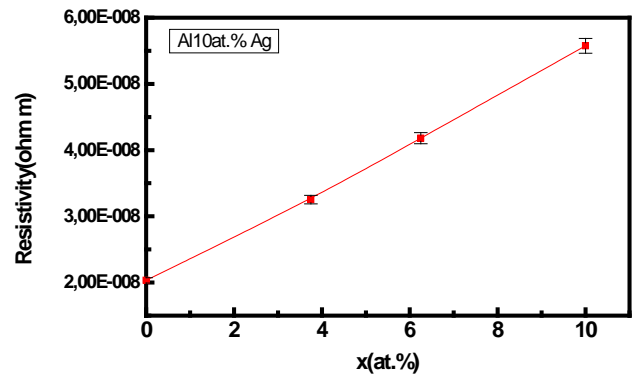

Figure 8. Electrical resistivity of homogenized Alxat.%Ag alloys.

The GP zones contribution to the electrical resistivity, ρ_{GP}, is given by the difference $\rho - \rho_m$ (Figure 9).
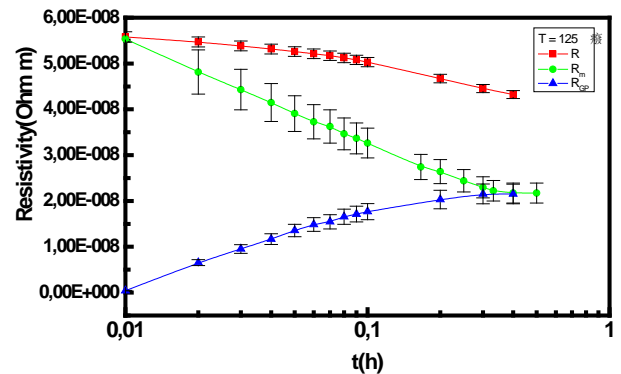

Figure 9. Contributions to the alloy electrical resistivity of the matrix, ρ_m, and of the GP zones, ρ_{GP}, during the GP zones precipitation at 125°C

4. Correlation between Hardness and Electrical Resistivity

A linear relationship is observed between the hardness and the electrical resistivity of the as quenched alloys (Figure 10). In the as quenched alloys, the hardness and the electrical resistivity variations are due only to the presence of the solute atoms. In the isothermal aged alloy, there is, also, a linear relationship between the contributions of the matrix to the hardness and to the

electrical resistivity of the alloy (Figure 11). However, no linear relation exists between the hardness and the electrical resistivity of the isothermal aged alloy (Figure 12). In the as quenched alloys, the hardness and the electrical resistivity variations are due only to the presence of solute atoms while in the isothermal aged alloy, there are due to the presence of the solute atoms and the GP zones. In such a case, the solute atom concentration of the matrix and the volume fraction of the GP zones vary simultaneously and no linear relation is observed in accordance with the results reported by Koch and Colijn [13].
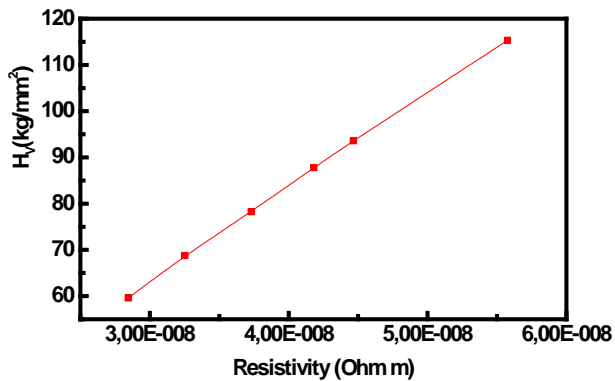

Figure 10. Variation of the hardness versus the electrical resistivity of the as quenched alloys

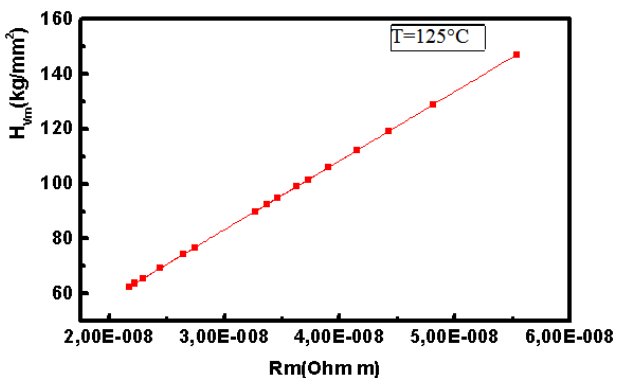**Figure 11.** Variation of the hardness contribution versus the electrical resistivity contribution of the matrix during the GP zones precipitation
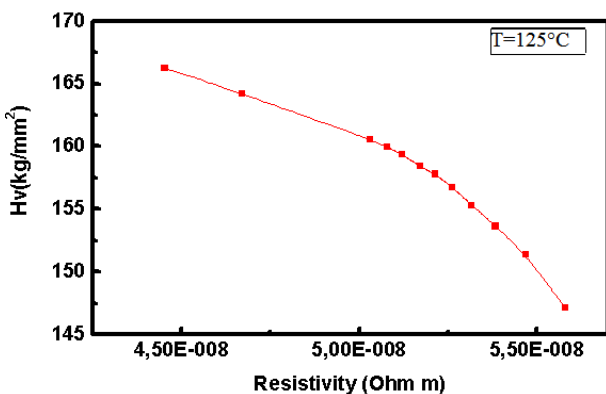

Figure 12. Variation of the hardness versus the electrical resistivity of the isothermal aged alloy

5. Conclusion

The contributions of the matrix and those of the GP zones to the hardening and to the electrical resistivity of the Al10at.%Ag alloy were determined separately. A linear relationship exists between the hardness and the electrical resistivity of the as quenched alloy while no linear relation exists between the hardness and the electrical resistivity of the isothermal aged alloy during the GP zones precipitation.

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