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Pre-precipitation in Al–0.1 wt % Cr alloy

Tracer diffusion measurements in aluminium show that the 3d transition metals, particularly chromium, iron and manganese, diffuse with high activation energies [1–3]. Kinetic studies on supersaturated Al–Cr solid solutions lead to an activation energy of 3.14 eV for the decomposition process [4]. It would be interesting to check whether these large values of the activation energy have any bearing on the interaction between chromium atoms and vacancies in Al–Cr alloys. The pre-precipitation phenomenon in a quenched Al–0.1 wt % Cr alloy is studied in this investigation by electrical resistivity measurements and transmission electron microscopy. The isothermal annealing data are analysed to evaluate the magnitude of the chromium–vacancy binding energy.

The Al–0.1% Cr alloy was prepared from 99.999% pure aluminium and a master alloy containing 5% chromium. The ingot, after homogenization at 600° C for 120 h, was reduced in a number of stages to a 0.1 cm diameter wire. Electrical resistivity measurements were carried out at liquid nitrogen temperature on samples with a length to area ratio of 7.47×10^3 cm^{-1}, using a precision Kelvin bridge. Samples for isochronal and isothermal annealing treatments were quenched from 500° C into iced brine at 0° C and the as-quenched resistivity ρ_q measured immediately. Isochronal treatments were carried out at intervals of 10° C in the temperature range 0 to 100° C for a fixed time of 5 min at each temperature; the resistivity ρ_T was measured after every step. Isothermal studies were made in the temperature range 0 to 30° C by measuring the resistivity ρ_t of the sample as a function of time. A final anneal at 70° C for 30 min was used to measure the resistivity ρ_∞, corresponding to the resistivity after completion of the recovery stage. The samples for electron microscopic examination were obtained by electro-polishing strips 3.0 cm × 1.5 cm × 0.02 cm quenched from temperatures in the range 500 to 600° C into brine at 0° C and aged for 24 h at 20° C.

The results of the isochronal annealing experiments are shown in Fig. 1 where the difference in resistivities, $\rho_q - \rho_T$, is plotted against temperature. There is a prominent recovery stage in the temperature range 0 to 40° C which is similar to that observed in a number of aluminium-base alloys [5]. The experimental data for the kinetics of this recovery stage are shown in Fig. 2 as plots of $\Delta\rho/\Delta\rho_0$ against time where $\Delta\rho = \rho_t - \rho_\infty$ and $\Delta\rho_0 = \rho_q - \rho_\infty$. The errors in the experimental points are small (< 5%) in the early stage of annealing, becoming significant (~15%) in the later stages. The kinetics are of the first order for long annealing times, as deduced from the linearity of the ln $(\Delta\rho/\Delta\rho_0)$ against time plots, with transients present in the early stages.

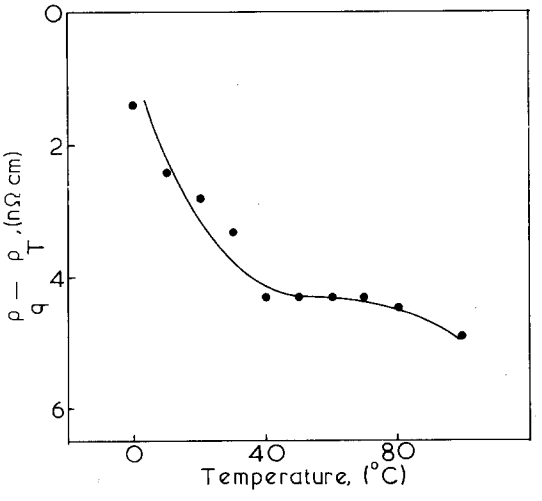

Figure 1 Isochronal annealing of Al–0.1% Cr alloy quenched from 500° C.

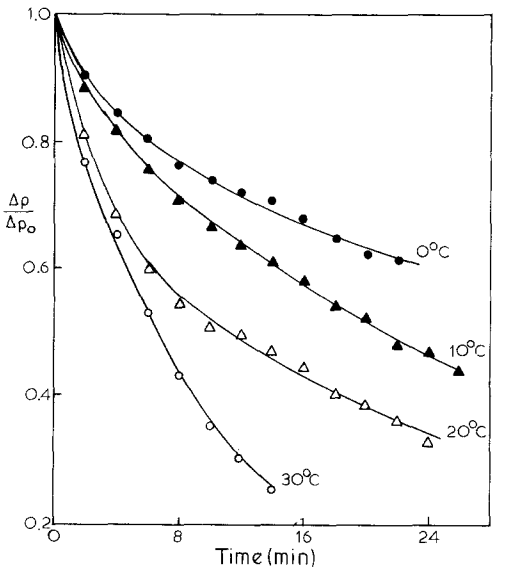

Figure 2 Isothermal annealing of Al–0.1%Cr alloy quenched from 500° C.

Electron microscopic examination of the alloy reveals the presence of Frank faulted loops when the quenching temperature exceeds 530° C. A typical micrograph is shown in Fig. 3. Diamond shaped prismatic loops (A in Fig. 3) are occasionally observed. The nature of the vacancy clusters in this alloy is similar to that observed in aluminium-base alloys containing zinc, magnesium, silver and manganese [6].

The absence of dislocation loops in samples quenched from 500° C indicates that the annealing process is characterized by the migration of simple defects such as single vacancies and divacancies to permanent sinks. The deviation from linearity of the $\ln(\Delta\rho/\Delta\rho_0)$ against time plots in the early stage of annealing indicates that the migration of single vacancies does not contribute to the recovery process exclusively [7]. Consequently the kinetic data are analysed on the basis of the simultaneous diffusion of single vacancies and divacancies to permanent sinks. In this case the variations in the concentrations of single vacancies (C_v), divacancies (C_{2v}) and solute–vacancy complexes (C_{vi}) with time can be expressed by a set of non-linear differential equations [7]. The total concentration of the defects, N ($= C_v + 2C_{2v} + C_{vi}$), present at any time can be obtained by integrating the differential equations. Details of this procedure have been explained in an earlier investigation on Al–0.1 wt% Mn alloy [8]. The results pertinent to isothermal annealing in the Al–Cr alloy are shown in Fig. 4, which is a plot of N/N_0 against time for the annealing temperature of 30° C, and for solute–vacancy binding energies of 0.15, 0.16 and 0.17 eV.

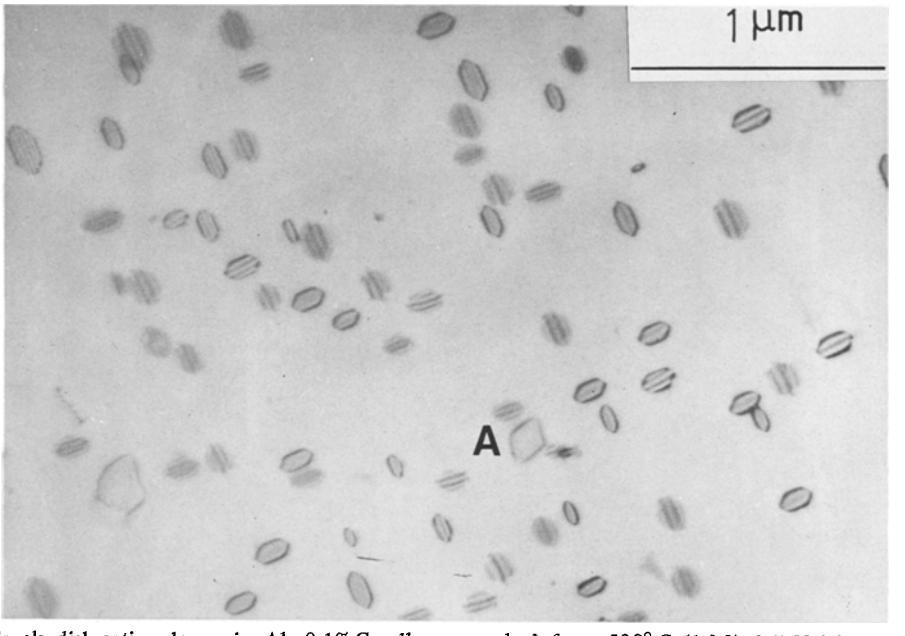

Figure 3 Frank dislocation loops in Al–0.1%Cr alloy quenched from 590° C (1 0 0) foil [0 0 2] operating reflection.

N_0 is the total vacancy concentration at the beginning of the annealing process and can be calculated from a knowledge of the quenching temperature, divacancy binding energy and solute–vacancy binding energy [7]. The experimental data for annealing at 30° C are also shown in Fig. 4 assuming that the contributions of the defects to resistivity are the same. It is clear that the chromium–vacancy binding energy lies between 0.16 and 0.17 eV. The isothermal data for other temperatures lead to binding energy values in the range 0.13 to 0.17 eV with a mean of 0.15 eV. This is to be compared with the value of 0.10 eV obtained for the manganese–vacancy complex in Al–0.1% Mn alloy [8]. The higher value for chromium is in agreement with theoretical estimates of binding energy based on maximum solid solubility in aluminium [9] and the melting points of chromium and manganese [10].

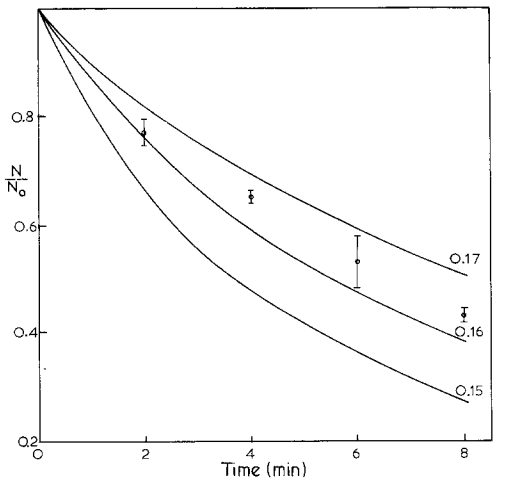

Figure 4 Variation in the total vacancy concentration with time for annealing at 30° C. Quenching temperature 500° C.

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Ion–ion interaction and superconductivity of metals and intermetallic compounds

The application of superconductors to produce very strong magnetic fields, has stimulated investigations with the objective of as high a critical temperature for the superconducting phase transition as possible. Several authors [1–4] have analysed the influence of different physical factors on the critical point of phase transition in superconductors. The influence of phonon spectra, electron–electron indirect interaction as well as the density of states have been taken into account. These efforts brought some important results, for example the explanation of Matthias'rules and raising of the critical temperatures of commercial superconductors.

In this work we wish to analyse the connection between the ion–ion potential and critical temperature. The contribution of ion–ion interaction to the phenomenon of superconductivity is rather important, but in spite of this, it has not been examined up to now.

Ion–ion interaction in metal is described by the