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Effect of Pressure on Precipitation in an Al-4·3% Cu Alloy

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ABSTRACT

The effect of hydrostatic pressures up to 12 kbar on the rates of formation of θ'' and θ' precipitates in an Al-4·3% Cu alloy has been studied. Pressure strongly inhibits the rates of formation of these precipitates. The θ'' precipitates were formed at 170°C and the θ' at 220°C. The activation volume for the θ'' formation was $12{\cdot}4 \pm 0{\cdot}4$ cm³ mole⁻¹ and that for θ' formation was $12{\cdot}3 \pm 0{\cdot}6$ cm³ mole⁻¹, i.e. effectively the same. Measurements of rates of formation of θ'' and θ' at various temperatures at atmospheric pressure also give the same activation energy of 27·45 kcal mole^{-1} (1·19 ev) for the formation of the two types of precipitate.

§ 1. INTRODUCTION

COMPARED with the amount of work done by varying the ageing temperature in the examination of the formation of the various types of precipitate in the Al–Cu alloys, very little has been done using pressure as the main variable. Goliber, McKee, Kasper, Tillyard, Cahn and Phillips (1959), using a solid as the pressure transmitting medium, measured the effect of a pressure of 30 kbar on the formation of the θ precipitate at 400°C. The rate of precipitation was 40 times less than when a specimen was aged at the same temperature at atmospheric pressure, and they obtained an activation volume of 6·8 cm^3 mole^{-1}. Both Goliber *et al.* and Hilliard and Cahn (1961) calculate that a pressure of 30 kbar would increase the solubility of copper in aluminium at a temperature of 400°C by only 9% compared with the solubility at atmospheric pressure and thus would have a negligible effect on the precipitation rate. The conclusion was therefore reached that the reduction in precipitation rate by pressure was due to the decrease in the diffusion rate of copper in aluminium. Work by Phillips (1961) on a Cu–Be alloy supports this conclusion. He found that the precipitation rate in this alloy was decreased by pressure although calculation had shown that pressure should markedly reduce the solubility of Be in Cu. In another investigation Harvey, Kaufman, Kulin, Leyenaar and Udin (1960) used alloys of nominal composition Al-4% Cu, 0·5% Mn, 0·5% Mg and Al-4·5% Cu, 0·6% Mn, 1·5% Mg. Specimens were aged at 100°C at atmospheric pressure and at 20 kbar. The ageing process was followed by hardness and resistivity measurements. Unfortunately, the scatter in the results was large and the only definite conclusion was that the ageing rate was reduced by pressure.

In the work reported in this paper the effect of hydrostatic pressures up to 12 kbar was determined on the rate of formation of θ'' precipitates at an ageing temperature of 170°C and also on the formation of θ' precipitates at 220°C. It was essential to use purely hydrostatic pressures, as the presence of shear stresses produced plastic deformation in the specimens and the results were not then reproducible. The activation energy and the activation volume were derived for the formation of both types of precipitate. Both the activation volume and the activation energy were found to be the same in both cases.

§ 2. Experimental

The specimens of the Al–Cu alloy had dimensions of about 0·4 cm × 0·125 cm × 0·006 cm and a copper content of 4·32% by weight. The impurities present in parts per million were: Fe 10, Mg 10, Ca 8, Ag 7, Pb 6, Na 5, Si 5, Mn < 1. The grain size was about 0·1 cm diameter, which meant that a specimen only contained a few grains. The specimens were homogenized at 540°C for 2 hr in a restricted air-flow vertical furnace. They were then quenched into water which contained a few drops of teepol at 0°C. Only specimens which sank immediately were used in the experiments. The time of fall from the furnace to the quenching bath was about 0·2 sec. After quenching, the specimens were aged in air at 20°C and atmospheric pressure for 24 hr. This treatment allowed the fast reaction (De Sorbo, Treaftis and Turnbull 1958) to be completed and brought the specimens into a reproducible standard starting condition in the slow reaction region for ageing treatments at higher temperatures. For the formation of θ'' and θ' precipitates at atmospheric pressure the specimens were aged in an oven at 170°C and 220°C respectively. These ageing treatments at 170° and 220° were also done under pressure and the high pressure cell will now be described.

The high pressure apparatus used was of the tetrahedral type. It was originally designed by Hall (1958) and lately modified by Lloyd, Hutton and Johnson (1959) and by King (1965). Briefly, the apparatus consists of four anvils, each of which presses onto a face of a pyrophyllite tetrahedral cell which contains the specimen. The cell, with a side length of 1·125 in., is shown in fig. 1 as it was used for the bismuth pressure calibration which will be mentioned later. The cell is similar to one described by Curtin, Decker and Vanfleet (1965). A hollow stainless-steel tube of diameter 0·19 in. was incorporated into the pyrophyllite tetrahedron and an electrical connection made from one end of the tube to a face of the cell by a copper tab. The other end of the tube emerged at another face of the tetrahedron. An electrical current could be passed through the tube via the anvils which touched the two faces, and the cell could thus be heated. The tube was filled with a silicone fluid with a viscosity of 20 cstoke at 25°C and sealed at both ends by teflon plugs. This silicone fluid was found to remain liquid at all experimental conditions provided the pressure and temperature were increased progressively to the operating conditions. A chromel–alumel thermocouple which was led out between the anvils measured the temperature of the silicone fluid, and the data of Hanneman and Strong (1965, 1966)