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GRAIN GROWTH IN ALPHA-BRASSES

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Grain growth in alpha-brasses containing 10, 15, 20 and 30 atomic percent zinc has been investigated in rods of 1 cm diameter at 973, 1023 and 1073 K. The dependence of the mean grain-diameter D on the time of isothermal anneal t correlates well with the relation:

$$D^2 - D_0^2 = K_0\, t \exp(-H_0/kT) \exp[cH^* \{1 - (T/T_s)\}/kT],$$

proposed by Feltham and Copley, where c is the solute concentration, H^* an activation energy equivalent to about 9 L, where L is the latent heat of melting, and T_s a constant (1200 K) of the order of the solidus temperature of the brasses. In agreement with the theoretical model, H_0 (0.87 eV) and K_0 (1.4×10^{-3} cm^{2}sec^{-1}) were found not to be significantly concentration dependent. Furthermore, grain growth was almost blocked when the ratio of the specimen diameter to the mean grain-diameter dropped during isothermal anneal to a limiting value of about twenty.

1. Introduction

Isothermal grain growth in pure metals and solid solutions is usually described by the equation[1-4]

$$D^2 - D_0^2 = K\, t \exp(-H/k\, T), \tag{1}$$

where D and D_0 are the initial and the instantaneous mean grain-diameters, respectively, t the time of isothermal grain growth at the temperature T, and H the activation energy for grain-boundary self-diffusion. K is a constant proportional to the volume per atom, the lattice spacing, and the specific surface energy at grain boundaries. Feltham and Copley[2] consider that as K and H depend on the elastic constants of the metal, and as these in turn depend on the concentration of the alloying element, both parameters should be functions of the composition of the alloy. In their study of grain growth they found the concentration dependence of K and H in α-brasses containing 10, 20, 30 and 35 at. % zinc at $T = 748$—973 K to be encompassed by the relation

$$D^2 - D_0^2 = K_0\, t \exp(-H_0/kT) \exp[cH^* \{1 - (T/T_s)\}/kT], \tag{2}$$

which differs from that for copper by the presence of an additional exponential term embodying the solute concentration c, an activation energy, H^*, equivalent to about 9 L, where L is the latent heat of melting, and the temperature T_s which is close to the solidus temperatures of the α-brasses studied. It should be noted that K_0 and H_0 refer to the pure metal i. e. copper as is apparent on putting $c = 0$ in equation (2). The concentration dependent term is considered to imply that atom transfer across grain-boundaries is facilitated by a relaxation of zinc-copper bonds which is energetically equivalent to melting of a group of nine atoms, nine being assumed to be the average coordination number prevalent at grain interfaces.

In the necessarily somewhat idealised theoretical treatment Feltham and Copley[2] found K_0 to be equal to about 10^{-2} cm^{2}sec^{-1}, while the values found experimentally were 1—2 orders of magnitude lower. (It should be noted that in their Fig. 4, the ordinate represents $K \times 10^5$ cm^{2}sec^{-1}, not $K \times 10^4$ cm^{2}sec^{-1} as shown.) Inclusions and specimen size could be expected to influence the growth rate and thus the value of K. In the present work specimens were of different diameter (1 cm rather than 0.2 cm) and the impurity spectrum was not entirely the same as in the specimens used by Feltham and Copley[2]. The temperature range used by them extended from 748 to 973 K. The main object of the present work was to examine the validity of equation (2) for α-brasses at higher temperatures of isothermal anneal, i. e. in the range 973—1073 K with the specimens of 1 cm diameter. A further objective was to explore the limiting value of the ratio of the specimen diameter to the mean grain-diameter for which the grain-growth rate has been visualised[1] to decline considerably.

2. *Experimental*

The zinc contents of the brasses used were nominally 10, 15, 20 and 30 atomic percent. The main metallic impurities, as in Ref. 2, were traces of iron (< 10 ppm), tin and bismuth. Specimens, 2 cm long, were cut from the rolled *as received* rods of 1 cm diameter by means of a fine saw. Specimens of a given composition were grouped into twelve batches, and each batch was sealed into a separate silica tube filled with oxygen-free argon at 13 kPa. To minimise dezincification, the silica tubes were part-lined with brass sheets. Grain growth was studied at 973, 1023 and 1073 K for various times of isothermal anneal in the range extending from 15 to 1200 min.

After the grain-growth treatment, each specimen was reduced in diameter by about 1 mm, by chemical polishing for about 10 minutes at 318—328 K in a solution containing 25% (Vol.) H_3PO_4, 25% acetic acid and 50% conc. HNO_3. This was done to ensure elimination of any grain-size or composition heterogeneity. Mean grain-diameters (Fig. 1) were obtained by the line intercept method.

3. *Results and discussions*

The linearity of the grain-growth isotherms in Fig. 1 confirms the applicability of equation (1) to α-brasses. However, grain growth at 1073 K was found to be almost blocked in the annealing time range of 300—1200 min due to the specimen size effects[1]; the ratio of the specimen diameter to the mean grain-diameter attained at $t = 300$ min was about twenty. The straight lines in Fig. 2, derived from the slope of the grain-growth isotherms (Fig. 1), yield the values of H shown in Fig. 3. From these and the data in Fig. 1, equation (1) enables one to evaluate K (Fig.4).

It is apparent from Figs. 3 and 4 that the dependence of H and K on the solute concentration c can be represented rather well by

$$H = H_0 - H^* c \tag{3}$$

and

$$K = K_0 \exp(-K^* c), \tag{4}$$

where H_0 and H^* are 0.87 and 1.11 eV, respectively, $K_0 = 1.4 \times 10^{-3}$ cm^{2}sec^{-1} and, with c expressed as fraction, $K^* = 10.7$. The value of H_0 compares quite well with that obtained by Feltham and Copley[2] (0.88 eV) but K_0 obtained here is close to their theoretical ($\approx 10^{-2}$ cm^{2}sec^{-1}) than to their experimentally determined value (3×10^{-4} cm^2 sec^{-1}), pointing to the influence of specimen characteristics, such as dimensions and inclusion content etc on the grain-growth rate.

Now equation (1) in conjunction with equation (3) and (4) yields equation (2), with $H^* = 1.11$ eV and $T_s = 1204$ K. Both, H^* and T_s are in excellent agreement with the corresponding values given by Feltham and Copley[2] for grain-growth data appertaining to α-brasses in the range 748—973 K (1.10 eV, 1200 K). It should be mentioned that they did not allow the ratio of the specimen diameter to the final mean grain-diameter attained during grain-growth to fall below 20; this value coincides with that at the onset of the abrupt slowing-down of grain--growth observed in the present work.

We therefore conclude from the foregoing evidence that equation (2) applies to α-brasses also over the range 973—1073 K. Equally, it can provide a suitable basis for studying isothermal grain-growth in other substitutional solid-solutions. Nevertheless, the minimum dimensions of the specimen should be preferably larger than twenty times the mean grain size.

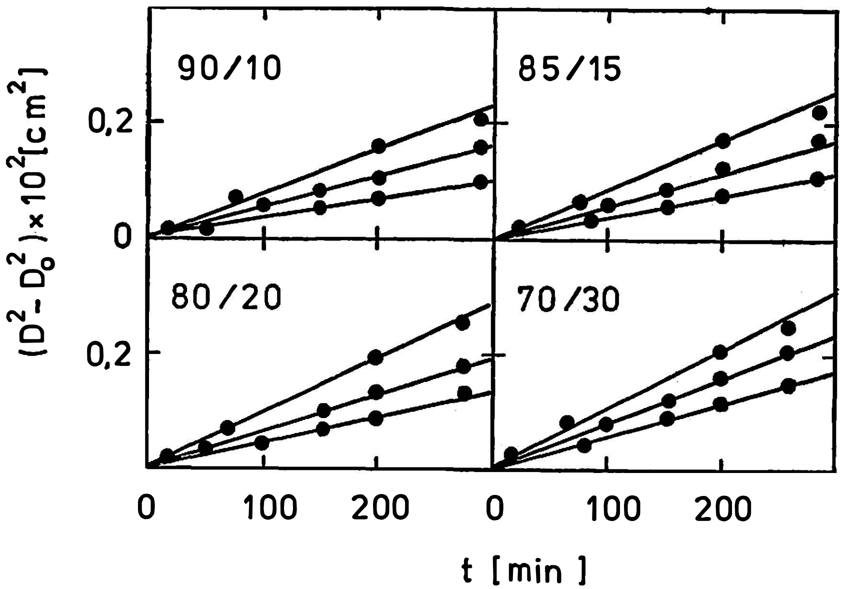

Fig. 1. Grain-growth isotherms of α-brasses. For a given composition, the annealing temperatures are, from top to bottom, 1073, 1023 and 973 K.

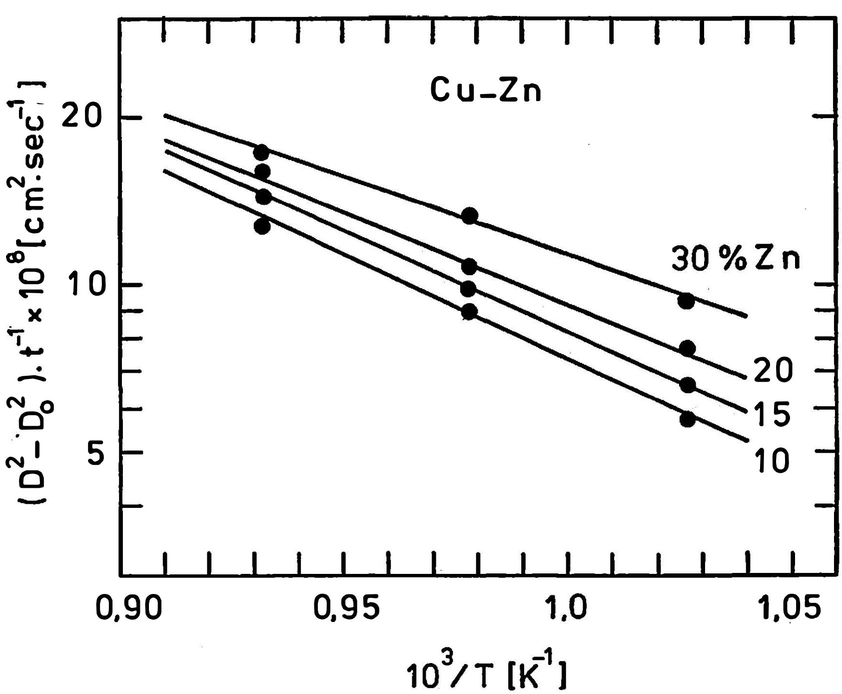

Fig. 2. Temperature dependence of the slope of the grain-growth isotherms referred to in Fig. 1.

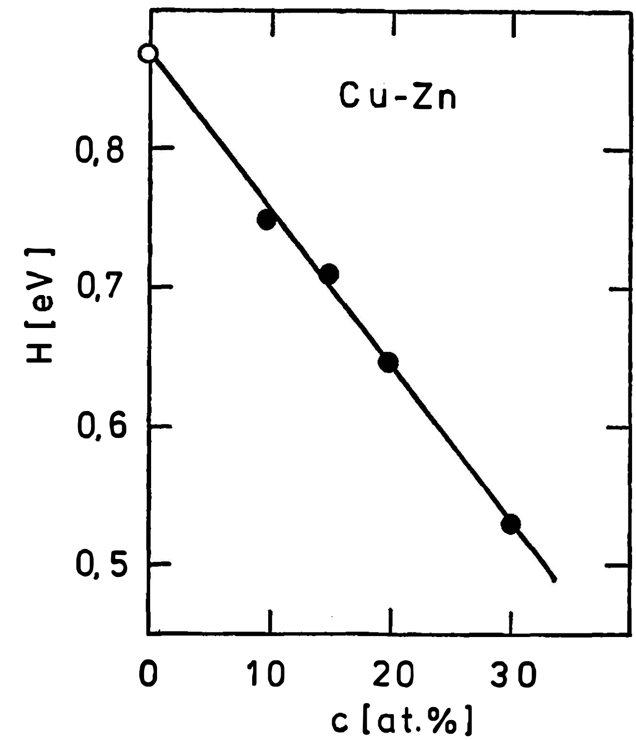

Fig. 3. Dependence of the activation energy for grain-boundary self-diffusion on zinc content in α-brasses (equation 3). The empty circle at $c = 0$ refers to the experimental value obtained by Butt and Feltham[5] with copper of 4N purity.

Acknowledgments

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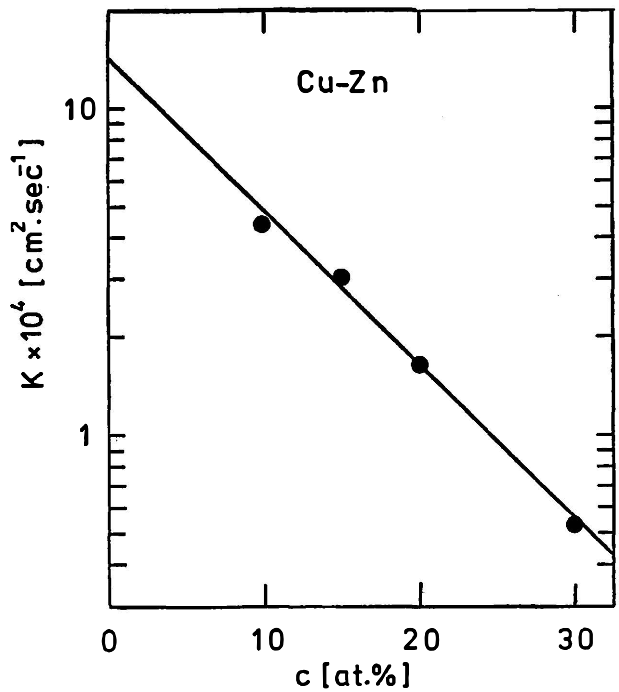

Fig. 4. Dependence of K on zinc content in α-brasses (equation 4).

RAST ZRNA U ALFA MJEDI

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Istražen je rast zrna alfa mjedi u šipkama diametra 1 cm koje sadrže 10, 15, 20 i 30 atomskih postotaka cinka na temperaturama 973, 1023 i 1073 K.