

### Grain Growth in High Purity Aluminum

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March 8, 1947

MEASUREMENT of the average grain size in a set of high purity aluminum specimens heated for various periods of time, ranging from 20 seconds to 11 days at a series of constant temperatures from 350°C to 650°C gave the following results:

(A) For isothermal grain growth the average grain size  $D$  at time  $t$  can be expressed as

$$D = D_0 t^n. \quad (1)$$

The exponent  $n$  increases linearly with temperature from  $n=0.06$  at 350°C to  $n=0.16$  at 500°C.

(B) The  $D = D_0 t^n$  relation holds true only until the grain size is well below the thickness of the specimen. When  $D$  (measured in the plane of the sheet specimen) is somewhat larger than the specimen thickness, grain growth completely stops; the grains extend through the thickness of the specimen, and their boundary surfaces are approximately perpendicular to the specimen surface. At 650°C this condition was fully reached in 20 seconds, and up to 11 days no further change occurred in the average grain size. At lower annealing temperatures the same maximum grain size was approximated in longer periods of time. The maximum grain size obtainable in a specimen through grain growth was found to increase linearly with the specimen thickness over a wide range.

As a result of the variation of  $n$  with temperature, it is not possible, strictly speaking, to derive a heat of activation from grain growth data. The  $Q$  value derived from plotting  $\log t$  vs. the reciprocal absolute temperature, for a certain grain size, varies with both the grain size and the temperature. The values thus obtained, however, are in the approximate range of 55 to 65 kcal./g atom. It is interesting to note that this range is in agreement with the  $Q$  values obtained by Anderson and Mehl<sup>1</sup> for growth during recrystallization of high purity aluminum. These values are considerably higher than the heat of activation for self-diffusion in aluminum, estimated to  $37.5 \pm 4$  kcal./g atom.<sup>2</sup> Perhaps this may be interpreted to mean that the energy for the activation of an aluminum atom to jump across a grain boundary is higher than that required to produce an exchange of position within the same lattice, as in diffusion.

Attempting to check the relative magnitude of the heat of activation derived from grain growth data and that for self-diffusion with other materials than high purity aluminum, we were unable to find satisfactory grain growth data in the literature. However, the data available for brass could be used if certain idealizing assumptions were made.

Let us assume the validity of the  $D = D_0 t^n$  relation, the independence of  $n$  on temperature, and the existence of a heat of activation  $Q$  for the process. Under such idealized conditions the following general formula can be derived

$$D = D_0 (t e^{-Q/RT})^n, \quad (2)$$

and for constant time

$$D = D_0 e^{-nQ/RT}. \quad (3)$$

The grain growth data by R. S. French<sup>3</sup> on brass satisfy the isothermal relation Eq. (1), if a correction of 10 min. is made in order to allow for the heating-up period. The corrected data for both 575°C and 640°C give  $n=0.16$ . By using the grain size vs. temperature data given in Fig. 1 of French's paper, in connection with relation (3), the value of  $nQ$  can be computed. From this, with  $n=0.16$ , one can obtain  $Q=73.5$  kcal./g atom for 70–30 cartridge brass. The heat of activation for self-diffusion in brasses, as determined by Rhines and Mehl, is 32 to 40 kcal./g atom. Although the heat of activation from grain growth data for brass, as given above, is merely a crude approximation, and the value of a comparison is further diminished by a difference in the zinc contents between the alloys used by French and by Rhines and Mehl, it is at least probable that, for brass too, the activation energy from grain growth data is considerably higher than that for self-diffusion.

This work is part of a research project on grain growth in metals sponsored by the Office of Naval Research, U. S. Navy.

<sup>1</sup> Anderson and Mehl, *Trans. A.I.M.E.* **161**, 140 (1945).

<sup>2</sup> Private communication from Dr. Wm. A. Johnson.

<sup>3</sup> R. S. French, *Trans. A.I.M.E.* **156**, 195 (1944). Correction for heating-up period is based on private communication from Mr. R. S. French.

### Separation by Diffusion in Fields of Ultrasonic Waves

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 March 21, 1947

IN a discussion of a paper of Willard,<sup>1</sup> Herzfeld<sup>2</sup> mentions the possibility of separation by ultrasonic waves, but finds the effect too weak for observation in a field of plane waves.

We have found that in a field of standing waves, or in an inhomogeneous field of ultrasonic waves, separation of homogeneous substances does occur. It has long been known that such a separation of inhomogeneous substances is easily attainable (dust tube method of Kundt<sup>3</sup> and others<sup>4-6</sup>).

Solutions of glycerin with water and of hexane with heavier paraffins have been subjected to a field of ultrasonic waves of approximately 2 watt/cm<sup>2</sup> and 1 Mc/sec. With the "Schlieren method" flaws (Schlieren) can be seen to remain in the nodes of the field after the ultrasonic waves are switched off, fading out only after 24 hours or more. Provision against convection which always occurs in a field of ultrasonic waves has been made by placing cover glasses parallel to the plane of the waves. It is considered that this method can be used for separation in a manner similar to thermodiffusion or ultra-centrifugation. Quantitative measurements as well as experiments with a view to develop a countercurrent method in order to obtain separation of appreciable amounts are being undertaken.

<sup>1</sup> G. W. Willard, *Phys. Rev.* **57**, 1057 (1940).

<sup>2</sup> K. F. Herzfeld, *J. Chem. Phys.* **9**, 513 (1941).

<sup>3</sup> A. Kundt, *Pogg. Ann.* **127**, 497 (1866).

<sup>4</sup> K. Buecks and H. Mueller, *Zeits. f. Physik* **84**, 75 (1933).

<sup>5</sup> O. Brandt and H. Freund, *Zeits. f. Physik* **92**, 385 (1934); **95**, 415 (1935).

<sup>6</sup> E. B. Pearson, *Proc. Phys. Soc. London* **47**, 136 (1945).