PHYSICS

Sedimentation and Effective Viscosity

In the course of a more extensive calculation, a set of equations has been obtained which relates the the sedimentation velocity u of particles falling through a liquid to the effective viscosity μ of a suspension of similar particles having the same density as the fluid. The volume concentration c is the same in both cases.

To a mixture with mean settling velocity u and concentration c, let us add a particle B the density of which is that of the fluid, that is, it is in suspension. Its mean velocity averaged over all possible positions, is equal to the mean fluid velocity modified by the pressure gradient in the fluid due to the falling particles A :

$$v = v_f + v_p \quad (1)$$

Now assume that its density is increased to that of the other particles A, so that its mean velocity increases to v'. The increase :

$$U = v' - v \quad (2)$$

is caused by the extra external force on it, the forces on the other particles being unchanged. Consequently, if the equations of motion of the fluid are linear, U is also the velocity of fall of B through a suspension of particles A with the same density μ, and, from Stokes's law :

$$U\mu = V\mu_0, \quad (3)$$

where V is the Stokes's velocity of the particle in pure liquid of viscosity μ_0.

Finally, if B is typical of the particles A, its mean velocity of fall is that of the suspension, namely :

$$u' = u \quad (4)$$

Combining the last three equations :

$$\mu u = V\mu_0 + \mu v \quad (5)$$

It is now necessary to estimate the velocity v of B when suspended in the settling mixture. Provided $v << v'$ it can be neglected and we obtain the approximation :

$$\mu u = u_0 V + \text{const.} \quad (6)$$

This is certainly true in the limit $c \to 0$, when $\mu \to \mu_0$ and $u \to V$. It is also an admittedly crude but valid approximation to u for all concentrations.

An approximate value of v, which might apply at low concentrations, can be obtained by neglecting the effect of a pressure gradient and assuming that a suspended particle B moves with the fluid. In a closed vessel the fluid rises as particles fall through it with a mean velocity $-cu/(1-c)$ determined by the equation of continuity. Assuming that :

$$v + v_p = -cu/(1-c) \quad (7)$$

we obtain from equation (5) :

$$\mu u = \mu_0 V(1-c) \quad (8)$$

This approximation seems to agree with the experimental results up to concentrations of about 20 per cent (ref. 1). Above this the value of μu rises fairly rapidly. It is rather surprising that equation 8 holds over such a range of concentrations. In a suspension where the force on a particle is k times its volume, one expects a pressure gradient of the order kc in a closed vessel in the direction of the force, and this corresponds to $v_p \sim \frac{3}{4} cV$ for a spherical particle. This is of the same order of magnitude as v_f and in the opposite dissection and quite large enough to alter considerably the correction factor in equation 8.

As the concentration rises and v_p increases, the value of u should certainly increase, and this agrees once more with experiment. If this analysis is correct, the increase can be used to estimate v_p. Finally, it would be very useful if measurements were made of this drift velocity of a particle suspended in a fluid containing sediment ; they should not be difficult.

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METALLURGY

A New Nitride Precipitate in Iron-Silicon Alloys

Recent work has indicated the presence of a new nitride precipitate in iron-silicon alloys. Leak, Thomas and Leak[1] using internal friction methods investigated nitrided iron-silicon alloys and deduced the presence of an unknown precipitate thought to be an iron-silicon nitride. Turkdogan, Bills and Tippet[2], using X-ray diffraction methods, examined nitrided iron-silicon alloys and found precipitates with an unknown structure which varied with the composition and heat-treatment of the specimen. After the precipitates had been isolated from the alloys by the Beeghly[3] bulk-extraction method, they were found to be α-Si_3N_4 silicon nitride. It was suggested[2] that the precipitates formed in the metal specimens were a complex nitride that decomposed during isolation. With the advent of the extraction replica method, in which included material can be isolated from metal specimens after very mild chemical treatments compared with bulk-extraction methods, a further attempt has now been made to isolate the new precipitate.

A high-purity iron-silicon alloy (B.I.S.R.A. Code No. 33*AF*2) of composition given in Table 1 was

Table 1

Silicon	3·05 per cent	Carbon	0·0026 per cent
Manganese	<0·005 per cent	Nitrogen	0·0014 per cent
Sulphur	0·0049 per cent	Oxygen	0·0010 per cent
Aluminium	0·001 per cent	Hydrogen	<0·000005 per cent

(Phosphorus, nickel, chromium and copper were not determined.)

nitrided for 18 hr. at 640°C. and furnace-cooled producing a nitrogen concentration gradient extending for about 0·22 in. inwards from the surface. Much of the nitrided zone had a mottled appearance when examined with the optical microscope. Extraction replicas obtained by the single-etch method[4] after etching for 3 min. with 10 per cent alcohol-iodine solution were examined in the electron microscope and showed the structure to be due to numerous cubic-shaped particles up to about 0·2 μ in size (Fig. 1). Although the appearance of the particles suggested that they possessed a regular crystallographic form, only weak transmission electron diffraction patterns were obtained. The patterns did not appear to correspond to any of the known iron or silicon nitrides and were not identified.

After the above examination, the specimen was further annealed for 6 hr. at 820°C. and furnace-cooled. This caused a considerable change in the appearance of the specimen, the mottled structure being replaced by a coarser, more definite structure. Examination of extraction replicas obtained in a similar manner showed that the structure was due to the presence of rod-like particles identified from electron diffraction patterns as silicon nitride (α-Si_3N_4). The rods occurring in the regions of low nitrogen concentration were few and large (Fig. 2) whilst those at higher concentrations were smaller and more numerous.