Harmony of the spheres

from Robert W. Cahn

VERY gingerly, the proponents of fibre reinforcement are beginning to approach the serious possibility of using fibre-reinforced materials for service at high temperatures—for instance, in gas turbine components. One central difficulty about this is that the metallic matrix may chemically attack the fibres; for example, tungsten fibres interact chemically in a complicated way with a nickel matrix. The other tricky problem is to keep the shapes of the fibres inviolate. It is not too difficult to generate a regularly spaced array of long, thin fibres in a suitable matrix; much research has been done on the directional growth of monocrystals of appropriate binary and ternary alloys, consisting of aligned fibres (or plates) in a matrix. The trouble is that a long thin cylindrical fibre is not in geometrical equilibrium with its matrix.

In a slowly grown eutectic, the total quantity of fibrous phase will be in equilibrium with the total quantity of matrix: the disequilibrium is purely a matter of geometry. This has long been known to metallurgists familiar with ordinary mild steel. The pearlite ($Fe+Fe_3C$) eutectoid lamellae, if sufficiently heated, turn into arrays of fine Fe_3C spheres. The process, spheroidisation, is driven purely by the tendency to minimise the total area of Fe/Fe_3C interface. The same can happen to a long fibre in a matrix.

As so often in physical science, one of the key ideas comes from Lord Rayleigh. In 1878 he showed that a cylindrical jet of water tends to instability: it is apt to pinch off at intervals of about eight diameters. Recently, McLean of the National Physical Laboratory, showed (*Phil. Mag.*, **27**, 1253; 1973) that, correspondingly, cylindrical inclusions of lead in aluminium split into separate short cylinders if the aspect ratio (length/diameter) exceeds 8. Each cylinder then gathers up into a sphere. The relevance to the stability of a population of fibres is manifest. Although aluminium–lead is no candidate for high temperature use, it is a useful model system.

With the collaboration of Loveday, McLean (*J. Mater. Sci.*, **9**, 1104; 1974) has now taken his investigation of Al/Pb alloys a long step forward. The main improvement is one of technique: instead of using X-ray microradiography between anneals, the investigators examined their foils in a 1-MeV electron microscope fitted with a heating stage. With the aid of cinematography, and exploiting the high penetrating power of the energetic electron beam, the investigators were able to trace in detail the stages of spheroidisation and make accurate kinetic measurements. In addition to the advantages of *in situ* micrography, they also achieved a much higher resolution by this technique.

The lead inclusions in the Al+5wt% Pb alloy were turned into cylinders by mechanical swaging (there is no suitable eutectic) and foils cut from this material were heated in the microscope to above the melting temperature of the lead. The spheroidisation process is governed by diffusion of matrix atoms through the cylinders; since the lead was molten diffusion was rapid and so was the spheroidisation. The cylinders either broke up into shorter ones which then turned into spheres, or short cylinders spheroidised directly; Rayleigh's criterion was approximately obeyed. The detailed observations allowed the diffusivity of aluminium in molten lead to be determined for a range of temperatures.

McLean and Loveday were also able to examine the merging of individual spheres once they had formed. The lead spheres behaved just like the bubbles of helium in nuclear fuels which have been extensively investigated in recent years, migrating under the driving force merely of a temperature gradient. The kinetics of merging of large bubbles (diameter ~ 1 μm) was studied and found, again, to be controlled by volume diffusion of aluminium in liquid lead. These large bubbles moved at a speed, independent of their size, which was consistent with the estimated temperature gradient in the microscope hot stage. Bubbles with diameter less than 0.8 μm moved more slowly the smaller the bubble; this is proof positive that the motion of these small bubbles was controlled by interface energy and not by volume diffusion. Very small bubbles, less than 0.12 μm in diameter, did not move at all. This immobility is a new phenomenon and its origin is not clear.

The observations showed the merging of pairs of large bubbles when one catches up another, and the kinetics of this process were consistent with the theory developed by earlier investigators of bubbles in nuclear fuels. It seems that bubbles behave in the same way irrespective of whether they are filled with gas or with molten metal.

McLean and Loveday point out that their observations have practical implications (quite apart from their relevance to the stability of composites). Free-machining alloys such as leaded brass contain small particles of soft metal in a hard alloy matrix, and it should now be possible to develop a prescription for a combined mechanical/thermal treatment to produce form of spherical dispersion with the best machining characteristics.

Correction

In the News and Views article "Bugs are Beautiful" (**250**, 533; 1974), the abbreviation AISB stands for Artificial Intelligence and Stimulation of Behaviour Group; the published explanation is incorrect.

Light from QSOs

from a Correspondent

THE QSOs—the quasi-stellar objects, or quasars—are believed by many astronomers to be remote galaxies that radiate extraordinarily large amounts of energy as a result of some violent explosion in the galactic nucleus. In all probability the source of energy is gravitation, but the process whereby some of that energy is converted into visible radiation is ill-understood. Although the total flux may be thousands of times greater than in a normal 'quiet' galaxy, the size of the source region must be quite small, no more than a few light days, since fluctuations in light intensity have been observed over a few days, and with a larger source they would be smeared out. The investigation of possible radiation mechanisms is therefore an important task in contemporary astrophysics, and the suggestions put forward by Colvin (*Astrophys. J.*, **190**, 515; 1974) are of considerable interest.

The popular approach, adopted by nearly all theorists, supposes that the explosive event produces a relatively dense plasma in the radiating volume (perhaps 10^8 or more ionised atoms per cm^3), a strong magnetic field linked to the plasma, and high energy relativistic electrons. These are certainly the ingredients involved in producing radiation from supernova remnants like the Crab nebula, and it is attractive to try using them again with the QSOs. Indeed, the most straightforward hypothesis is that the observed radiation from the QSOs, like that from the Crab nebula, is the synchrotron radiation produced by the spiralling of relativistic electrons round the magnetic field lines. The relativistic electrons act as a link in the chain of energy flow: energy comes to them from the explosive event and is reradiated by them as synchrotron radiation.

Unfortunately, difficulties appear on a closer examination. The observed spectral distribution of the radiation does not conform very well with that expected for synchrotron radiation, and in the physical conditions of a QSO one could expect the relativistic electrons to lose energy more readily through the inverse Compton process. The inverse Compton process can be pictured as radiation by the electrons