Alloy strength

Keeping dispersions fine

Robert W. Cahn

HIGH-TEMPERATURE alloys, especially those used in aero engines, have to serve at temperatures well above half their absolute melting point. Extremely fine dispersions of insoluble intermetallic phases that impede dislocation motion are essential to prevent failure, the only alternative being strengthening by ceramic fibres, a strategy that is still being developed. The fine dispersion must resist coarsening for a particular matrix/dispersoid combination to be useful. Ostwald ripening, the growth of larger particles at the expense of smaller ones by a process of solute diffusion through the matrix, is not important if the particles are very insoluble in the matrix. But an alternative process, the dragging of particles attached to the migrating boundaries of growing grains, can still force coarsening: the particles which are being dragged sweep up stationary particles from the body of a grain as the boundary moves past them. This process has not been analysed as much as it deserves, and hence three recent papers on the subject by Russell and Froes[1,2] and by Hartland *et al.*[3] deserve a special welcome.

Russell and Froes[1], who analyse the thermodynamic factors that favour the creation of a fine-particle dispersion in the first place, discuss the probable rate of Ostwald ripening. They also analyse the limiting rate at which a particle can keep up with a moving grain boundary; this depends both on the particle diameter and on its solubility in the matrix. The authors conclude that a drift rate of 1 μm h^{-1} can be maintained by particles of 1, 10 and 100 nm radius for low (10^{-4} atom %), intermediate (0.1 atom %) and high (10 atom %) solubilities, respectively. This is fast enough to lead to a potentially dangerous degree of sweeping, at least for the larger particles.

The analysis is dealt with in greater detail in Russell and Froes's second paper[2]. The calculation is done on the assumption that the particles migrate by the process of diffusion along the particle/matrix interface, presumed to be faster than diffusion through the bulk of the particle. There is still uncertainty, dating back to a classic paper by Ashby and Centamore[4], about whether crystalline particles can drift at anything like the rate of amorphous particles (such as silica), because crystalline particles tend to have a more ordered interface with the matrix, associated with slower diffusivities in the interface.

Russell and Froes compare experimental observations of various dispersoid systems with their calculations, with special reference to the important case of Ti_3Al strengthened with dispersions of Er_2O_3 or Ce_2S_3. It turns out that the greater resistance of the latter to coarsening can be explained in terms of the characteristics of the two dispersoids.

Hartland *et al.*[3] study the special case of a population of empty or gas-filled pores drifting with a migrating boundary. This theme is older than the problem of particle drift: inclusion drift in a crystalline material was first observed for helium bubbles in copper[5], and this led to the first theoretical treatment of bubble drift in a temperature gradient[6] (without attachment to grain boundaries). The possible role of grain boundaries in dragging pores during the process of powder sintering and thereby hastening the elimination of porosity was pointed out several years ago[7], but evidence of such dragging is very scant and uncertain.

Hartland *et al.*[3] are the first to devise a theory of the dragging of pores by boundaries. Their special interest is the behaviour of fission-gas pores in uranium dioxide nuclear fuel. The authors analyse in rigorous detail the behaviour of various grain and pore geometries, including a range of porosity fractions and sizes, and for each situation calculate the retardation factor imposed by the presence of pores, compared to an identical grain geometry without pores. One factor they take into account (this has never been considered before) is the influence of misorientation across a grain boundary; this affects the curvature of the interface of a trapped pore and thereby influences surface diffusion along that interface. It also turns out that pores retard grain boundary mobility more on grain edges than when at grain corners.

One variable not considered in this work is the effect of impurities dissolved in the matrix segregating to the pore/matrix interface; it has been shown experimentally, in metallic systems[8], that such segregation can enhance surface diffusivity by factors of up to 10^4. In practical terms, it would be interesting to know whether segregation of this kind is possible to the interface between dispersoid particles and the matrix. If so, it is conceivable that dispersoid mobility and thus dispersoid coarsening through drift of particles attached to grain boundaries could be considerably enhanced in the presence of particular impurities. □

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Farming biotechnology

Regulating growth of animals

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LEADING international researchers took the opportunity at a recent meeting* to urge caution in making the assumption that biotechnology will necessarily improve farming practices by increasing growth rates of farm animals, resulting in 'super' strains. There is widespread fear that such techniques could exacerbate food surpluses and put small farmers out of business. Recent experiments indicate that the growth rate of farm species is not dramatically increased. It seems that centuries of genetic selection could already have produced individuals that cannot, or do not, respond markedly with increases in growth either following growth hormone gene insertion or parenteral treatment with recombinant growth hormone preparations.

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Despite these potential drawbacks, it is clear that biotechnology can be effective in other ways. Treatment with recombinant bovine somatotrophin (rBST), for example, can consistently increase milk yield with improved feed-conversion efficiency and no significant changes in milk composition even in high-yielding cows. This hormone also results in leaner lamb and pig carcasses, thus providing healthier meat for human consumption. Its main physiological effect is that metabolism is influenced in favour of net protein gain.

There could, of course, be other explanations of why some genetically modified or growth-hormone-treated animals do not grow faster, and these problems were addressed at the meeting. In the aftermath of recent political action which resulted in a ban on the use of anabolic steroids for growth promotion of animals within the European Economic Community (EEC),

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