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CAVITY GROWTH MECHANISM MAPS

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Introduction

Cavity growth and shrinkage are of great technological and scientific interest in many areas of physical metallurgy. Small cavities, of diameter 10 μm or often much less, occur during creep deformation, during the later stages of sintering and as a result of radiation damage. They may arise as a side effect of ion implantation, or this technique may be used to produce them for experimental purposes. Similarly, quenching has been used to introduce and then study the behaviour of voids.

The term "cavity" covers a whole spectrum of defects, which may or may not contain gas. There will be a gas pressure which exactly balances the surface tension forces of the gas/solid interface and a cavity containing gas at this pressure is usually said to be an "equilibrium bubble". If the cavity contains more gas than this it is an overpressurised bubble and if it contains less it is strictly an underpressurised bubble. The limiting case of an empty cavity is clearly a "void" but in practice this term is often applied to any underpressurised bubble. Most cavities are thought to contain at least a small amount of gas, since it is generally agreed that a few gas atoms are necessary for the nucleation of even a "void". Other sources of gas within cavities are ion implantation (for example resulting from alpha particle bombardment) and the trapping of air (or other gas) during the closure of porosity in the early stages of sintering. There may also, at elevated temperatures, be a vapour pressure component in the total gas content of the cavities.

The behaviour of any individual cavity depends on a large number of factors. Among these will be the cavity size and shape, the pressure of the gas contained within it, the local point defect concentration, the temperature, the magnitude of any stress or temperature gradient within the solid and the proximity of further cavities or other point defect sources or sinks. It is the purpose of this note to point out that under certain conditions it is possible to predict whether a population of cavities will grow or shrink, and by what mechanism. This information can conveniently be presented in the form of a "map" analogous to the deformation mechanism maps proposed and successfully exploited by Ashby and several co-workers (1).

Mechanism maps

An isolated cavity can only grow or shrink† by the emission or collection of point defects, either singly or in the form of clusters or dislocation loops. However a population of cavities has available a further set of mechanisms which may modify the behaviour of the population as a whole and may locally change the growth rate of an individual cavity. Two of these mechanisms are cavity migration leading to coalescence and the interchange of gas between cavities leading to "Ostwald ripening". These mechanisms are detailed below.

In certain simple situations it is possible to consider the likely relative contributions of many of these competing processes. We shall only consider here cavities of a size resolvable in the TEM (i.e. > 1 nm), which are not sited on any short circuit diffusion path (e.g. a dislocation or grain boundary), in a material whose gas content remains constant and which is subject to no stress or temperature gradient. This of course excludes very interesting cases such as the growth of grain boundary cavities during creep, the migration of bubbles up a temperature gradient and the growth of bubbles during implantation, although these could be treated in the future. However the treatment does cover all the isothermal, unstressed regimes for which a great deal of experimental data exists on the growth of matrix cavities. A

† In the remainder of the text the word "grow" should be interpreted to mean "grow or shrink".

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