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The role of intergranular precipitates in controlling creep cavitation*

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A satisfactory model for cavitational failure in creep must account for the fact that fracture can occur under a very low stress, for example, only 0.7 MPa for a solid solution magnesium alloy. A mechanism for growth based on the transfer of vacancies from high angle grain boundaries to intergranular cavities satisfies this low stress requirement for it converts a relatively high fraction of the work done by the applied load into surface energy of fracture. However, for such growth to proceed, cavity nuclei of radius greater than a critical value, r_c, must exist on those grain boundaries which are approximately normal to the applied tensile stress axis. It can be shown quite simply that $r_c = 2\gamma/\sigma$, where γ is the surface energy per unit area and σ the applied tensile stress. A typical value for r_c is 1 μm which is far too large to occur spontaneously by chance accumulation of vacancies. It is in fact generally agreed that cohesion is lost owing to the concentration of stress at some small obstacle in a sliding grain boundary. These cavities are nucleated along the boundary under applied stresses which are *lower* than those needed to cause triple point cracking where the whole of the length of the boundary is available to concentrate stress. This was a puzzle until Smith & Barnby (1967) demonstrated that the stress concentrated at a small obstacle in a sliding boundary was far higher than that concentrated at a very large obstacle as incorporated in, for example, the Stroh derivation. This pointed to precipitates being the nucleation sites, but a new difficulty emerged when Gibbs (1965) demonstrated that stress-directed diffusional flow around a precipitate should normally be too rapid to allow appreciable concentrations of stress to occur. This difficulty was resolved when it was realized that, unlike a high angle grain boundary, certain precipitate–matrix interfaces are not good sources or sinks for lattice vacancies. Another analysis demonstrated that only precipitates with radii close to r_c are suitable as cavity nuclei. Thus, for cavity nucleation to occur, the size, distribution and properties of the nucleating precipitates are quite critical but it is difficult to take advantage of this and avoid cavitation by removing the harmful particles because their minimum concentration is so low. A more practical solution is to arrange to have copious precipitation in the microstructure. These precipitates can impede grain boundary sliding to such an extent that cavity nucleation is prevented. In addition to this, even if some nucleation should occur, an array of intergranular precipitates can prevent the boundaries acting as a vacancy source thereby inhibiting diffusional growth of the cavities. A recently completed theoretical analysis (Crossland & Harris 1979) has in fact indicated that the presence of intergranular precipitates can delay the time to failure by many orders of magnitude.

References (Harris)

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