Mr A. Grange of Ultrasonics Ltd, Shipley, Yorkshire, and Professor Waldron for their interest.

C. T. WALKER
R. WALKER

Department of Metallurgy and Materials Technology,
University of Surrey,
Stag Hill, Guildford,
Surrey GU2 5XH

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Void Volume Swelling dependent on Grain Size in an Austenitic Stainless Steel

THE phenomenon in which the formation of voids in metals and alloys is induced by irradiation is now well documented. Void formation and the concomitant swelling in volume is undesirable in fast breeder reactors, so a great effort is being made to understand the phenomenon in detail. The process of void formation is, however, a complex function of several variables to do with the irradiation (flux, energy, temperature and so on) and material (dislocations, impurities, grain boundaries, particles and so on). The influence of only a few of these parameters on the void characteristics of metals and alloys has been studied theoretically and/or determined experimentally. As grain boundaries act as neutral and unsaturable sinks for both vacancies and self-interstitials, grain refinement is expected to reduce the void volume swelling. Here I describe some of the main findings of a systematic study of the effect of grain size on the void volume swelling.

In this study a powder-produced 20 Ni/20 Cr austenitic stainless steel, with 0.02% carbon and without carbide-forming elements was used. Some specimens containing dispersions of alumina particles ($\sim 0.8 \times 10^{15}$ particles of 500 Å diameter cm^{-3}) were also irradiated. For theoretical and practical convenience, high energy electron irradiation was used to study the formation and growth of voids in these materials. All the irradiation experiments were done at 600° C in the EM-7 1 MeV electron microscope at Harwell. Before irradiation 10 p.p.m. of helium was injected into the samples using a 100 kV heavy ion accelerator.

A series of experiments recently carried out on this stainless steel without dispersions of oxide particles have clearly demonstrated that in grains smaller than ~3.0 μm the formation of voids is strongly affected by grain size. A detailed analysis of the present results shows beyond doubt that the void concentration and the void volume swelling is significantly reduced by decreasing the grain size. Some of the present results quoted in Fig. 1 provide an unambiguous demonstration of the dependence of void volume swelling on grain size.

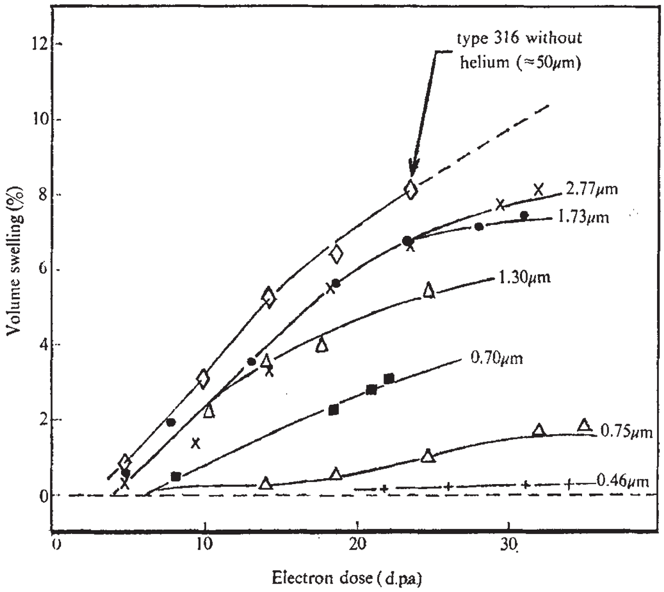

Fig. 1 Void volume swelling dependent on grain size and its dose dependence at 600° C for dispersed and undispersed stainless steel with 10 p.p.m. helium. △, +, Dispersed; ×, ●, ▲, ■, undispersed. Grain sizes are quoted on the right hand side. D.p.a., Displacements per atom.

Similar results are obtained for specimens without implanted helium.

In exactly the same experimental conditions, samples containing aluminium oxide particles and similarly doped with helium were also irradiated; some of these results are also shown in Fig. 1. It seems that the presence of particles makes an additional contribution to the grain size effect in that the void volume swelling for a given grain size and at a given dose level is always smaller in samples containing dispersions of oxide particles (almost always situated at the grain boundaries) than in samples without dispersions.

It must be emphasized that the grain size effect described here is significantly greater than that expected from a simple consideration of a void-denuded zone adjacent to grain boundaries[1]. This arises from the fact that the void number density in the grain interior (well away from the denuded zone) decreases very markedly with decreasing grain size and this cannot be accounted for by the conventional denuded zone effect. A clear example of this is the absence of void nucleation in grains <0.45 μm in size; from the measured void denuded zone of ~800 Å (which remains almost constant for different grain sizes) at 800° C a lower limit of ~0.16 μm might have been expected. The void nucleation and void volume swelling dependent on grain size have been explained in terms of a model based on the depletion of point defects not only from the denuded zone but from the whole grain due to the presence of grain boundaries. Recent calculations (unpublished work of B. N. S. and A. J. E. Foreman) of vacancy concentration and supersaturation profiles in three-dimensional grains of sizes in the range 0.5 to 3.0 μm reinforce the defect depletion model.

The present investigation thus suggests that the grain refinement and its stabilization by dispersed particles can lead to a material highly resistant to swelling which may prove useful in applications in fast breeder reactors. Further theoretical and experimental studies of the effect of grain size on void nucleation and growth will be reported elsewhere.

B. N. SINGH

Metallurgy Department,
Danish Atomic Energy Commission,
Research Establishment Risö,
Roskilde

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