Flux and Fluence Dependence of Irradiation Creep in Austenitic Stainless Steels

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The dimensional stability of in-core or near-core austenitic components of nuclear reactors is very important for long-term operation and safety. In this paper we have analysed the data from a well-designed set of pure-shear spring irradiation creep experiments conducted by Lewthwaite and Mosedale on 316, FV548 and EN58 austenitic alloys in and below the Dounreay Fast Reactor in the late 1970s and 1980s that spanned a range of stress levels, temperatures, dpa levels and dpa rates. These data were examined by Garner and Toloczko in 1997 and later by Boothby in 2012 with particular emphasis on separating the fluence and flux contributions and on separating the primary transient from "steady-state" creep. In the current effort we re-examine these experiments to yield a more comprehensive and sophisticated analysis that can lead to better predictive correlations for reactor design.

The major conclusions of the data analysis are that irradiation creep at low doses (<10 dpa) can be separated into three main stages : (i) primary creep, which occurs in the first few thousand hours of operation and is controlled by dislocation slip; (ii) transient secondary creep, which is controlled by varying amounts of dislocation slip and mass transport and continues up until the radiation damage microstructure in the form of dislocation loops reaches a steady state condition; (iii) steady-state secondary creep, which is controlled by a combination of dislocation slip and mass transport, all visible in the data. The effect of irradiation is two-fold: (a) hardening the material by increasing the barriers to slip from dislocation loop formation and also by helical climb on non-edge dislocations; (b) enhancing diffusional creep that both directly contributes to creep strain and can also promote the climb of gliding dislocations over barriers. At high doses, void swelling modifies the creep behaviour further because of the effect of the evolving cavity microstructure on the point defect fluxes to dislocations, but also because of the direct interaction of the cavities with gliding dislocations.

The results are discussed using rate theory to explore the effect of an evolving microstructure, radiation damage rate and temperature on the irradiation creep rate.