Creep of Nb-modified Zircaloy and Application to Prediction of Spent Fuel Reliability during Dry Storage

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Introduction

Creep induced dimensional changes of spent fuel during dry storage need to be considered in assessing the reliability of nuclear spent fuel during dry storage since the temperature of the fuel rod increases as soon as the assembly is transferred from cooling pool to dry storage cannister. Creep deformation is important to be well characterized to be able to predict the reductions in the wall thickness of Zircaloy tubing. In making these predictions accurately requires a good knowledge of transitions in creep mechanisms exhibited by these materials as lower stresses are approached that are relevant to dry storage conditions. In general, grain-boundary sliding (GBS) and viscous deformation mechanisms such as Nabarro-Herring, Coble or Harper-Dorn creep mechanisms become dominant at lower stress levels. Moreover, neutron radiation exposure results in hardening that is expected to lead to lower creep rates which is true for range of conditions where dislocation–dominated creep mechanisms control creep such as disloction glide-climb processes at high stresses and Harper-Dorn creep at low stresses. In contrast Coble and Nabarro-Herring creep mehanisms are not affected by neutron irradiation; in general, relatively small grain size of Ziraloy cladding materials result in Coble creep to be dominant at low stresses. We first consider here thermal creep characteristics of unirradiated material in predicting the accumulated hoop creep strains during dry storage involving dislocation glide at high stresses and Coble creep at low stresses. Secondly, recent experimental data on irradiated Zirlo[@] will be considered to compare with those predicted from thermal creep. We also present here the utility of ring tensile tests in obtaining the hoop creep characteristics of cladding tubes along with load-relaxation test technique that are well suited for characterizing the deformation behaviors of irradiated and spent nuclear fuel cladding.

Experimental Results and Discussion

We first consider hoop creep results from internally pressurized biaxial loading of closed-end tubing and use normalized or dimensionless stresses (σ/E) and strain-rates ($\dot{\varepsilon}$ kT/DEb) as shown in Figure 1; here σ is the applied hoop stress, E the temperature dependent elastic modulus, $\dot{\varepsilon}$ the hoop creep-rate, k Boltzmann constant, T the temperature in K, D the diffusivity ($=D_o e^{-Q/RT}$ with Q being the activation energy for appropriate diffusivity and R gas constant), and b the Burgers vector. We note that the data exhibit transitions in creep characteristics: Coble creep (n=1) at low stresses, viscous glide of dislocations such as is observed in alloy class of materials due to the solute atom locking of gliding dislocations (n=3) at intermediate stresses and climb of edge dislocations (n=5) at high stresses and power-law breakdown with exponential stress dependence at very high stresses. Predictions based on time variation of fuel rod temperature during dry storage along with data in Fig. 1 reveal that the accumulated hoop strain saturates at around 100 years to less than 0.75% beyond which the increase in strain is relatively insignificant due to reduced fuel rod temperature. Similar predictions based on recent experimental results on spent (irradiated) Zirlo alloy are in progress and will be reported.

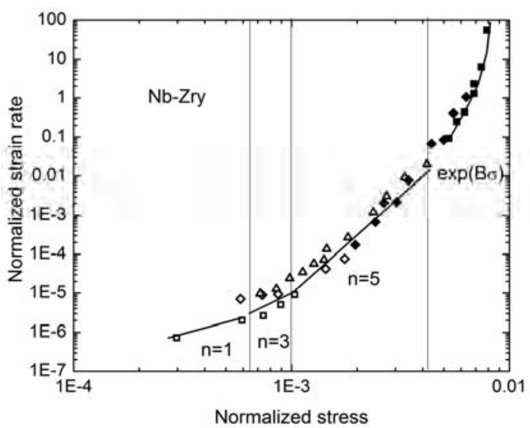

Fig. 1 Creep Results on Nb-modified Zircaloy tubing

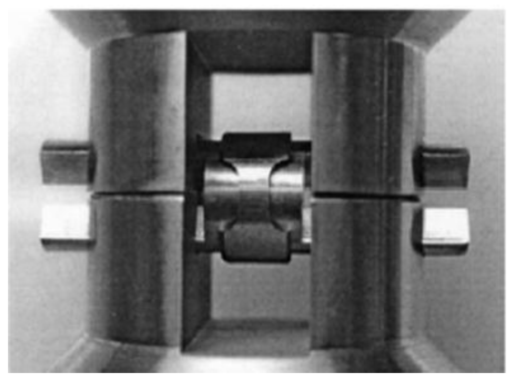

Fig. 2 Ring Tensile Test Jig

We describe here the utility of ring tensile and creep tests (Fig. 2) that would be of application in testing irradiated cladding materials that require relatively small amount of irradiated material to minimize radiation exposures. Creep and tensile tests using ring specimens correlated well with the standard biaxial hoop creep and burst tests on tubing. In addition, results from load-relaxation tests using ring tensile specimens (Fig. 2) are in progress and results to-date will be reported.

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