CREEP-RUPTURE PROPERTIES OF 20% COLD-WORKED TYPE 316 STAINLESS STEEL AFTER HIGH FLUENCE NEUTRON IRRADIATION

NT LETTER

R. L. FISH *Hanford Engineering Development Laboratory*
P.O. Box 1970, Richland, Washington 99352

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Creep-rupture tests have been performed in the biaxial mode on 20% cold-worked Type 316 stainless-steel cladding specimens after irradiation in the Experimental Breeder Reactor-II (EBR-II) to fluences of 5.1 and 9.1×10^{22} n/cm^2 ($E > 0.1$ MeV) at a nominal temperature of 922 K (1200°F). Preliminary results on two heats of steel indicate that average rupture lives were reduced by a factor of 20 to 30, and minimum creep rates were increased by a factor of 5 to 10 over the unirradiated values.

The long-term steady-state mechanical response of fast reactor core structural components is of interest for reactor design. Knowledge of the expected lifetime and ductility parameters for the component materials is essential to the safe design and operation of the reactor. Creep-rupture tests were performed on two heats of Fast Flux Test Facility (FFTF) 20% cold-worked Type 316 stainless steel: a developmental lot of cladding (Heat #87210) fabricated from iron scrap melt-stock and a virgin melt-stock lot of cladding (Heat #81592) typical of that to be used in the FFTF first core. Each of these materials was irradiated in the EBR-II to a fluence of 5.1 and 9.1×10^{22} n/cm^2 ($E > 0.1$ MeV) at 922 K (1200°F). The tubing specimens were pressurized and tested at 922 K (1200°F) to provide failure times ranging from 68.4 to 1602 ks (19 to 455 h). Testing is continuing to provide data at longer rupture times [up to 21 600 ks (6000 h)]. The additional data,

TABLE I

Recent High Fluence Creep-Rupture Test Results on FFTF First Core and Developmental Cladding

[Test Temperature = Irradiation Temperature = 922 K (1200°F)]

Specimen Identification	Neutron Fluence (10^{22} n/cm^2, $E > 0.1$ MeV)	Hoop Stress (MPa)	Hoop Stress (ksi)	Rupture Life (ks)	Rupture Life (h)	Strain $\Delta D/D$ %
			Developmental Cladding			
AU[a]	9.1	207	30	198	55	0.60
AA[a]	9.1	207	30	137	38	1.16
AN[a]	9.1	172	25	234	65	0.54
AK	9.1	172	25	410	114	1.07
AM[a]	9.1	138	20	929	258	0.71
AJ	9.1	138	20	1166	324	
			First Core Cladding			
AO	5.1	207	30	68	19	0.84
AT	5.1	172	25	137	38	0.37
AS	5.1	138	20	137	38	0.22
AR	5.1	103	15	968	269	0.80
AQ	5.1	86	12.5	1602	445	
AE	9.1	172	25	137	38	0.68
AD	9.1	138	20	292	81	0.82
AC	9.1	103	15	968	269	0.74

[a] Denotes 44.5-mm (1.75-in.)-long specimens; all others are ~27.9 mm (1.1 in.) long. All specimens are 5.84-mm o.d. × 0.38-mm wall (0.230-in. o.d. × 0.015-in. wall).

along with a more thorough presentation and analysis of the data, will be available in published form at a later date.

Specimens were fabricated for this work by welding endcaps onto the ends of each irradiated tubing sample, filling with helium, and welding off the fill tube. The hoop stress in this type of specimen remains approximately constant throughout the test for strains less than ~5% $\Delta D/D$. The specimens were then placed in a capsule, and the capsule was placed into a furnace. The capsule cover gas was monitored regularly using a small pressure gauge to provide the rupture time measurements. The specimens were extracted from the furnace for diameter measurements at predetermined intervals to determine the creep strain as a function of test time. Diameters were determined to within ±0.02% using a laser interferometer measuring device.[1]

The current high fluence creep rupture data on both developmental and FFTF first core cladding are presented in Table I. The specimen irradiation conditions are given along with the test conditions and results. Although two different specimen lengths were used in this work, no length effect on properties is expected based on studies performed at this laboratory. The hoop stress values for the specimens presented in Table I are plotted against the respective rupture lives in Figs. 1 and 2. The developmental cladding for both fluence levels is shown in Fig. 1 along with the unirradiated rupture behavior for this cladding at 922 K (1200°F). A band is used to describe the failure times of the irradiated material. There are not sufficient data available to show a detailed fluence dependence for this property, but the data provide evidence for, at worst, only a mild fluence dependence for the materials above 5×10^{22} n/cm^2. The reduction in rupture life from the unirradiated curve for the developmental cladding at 922 K (1200°F) as shown in Fig. 1 is a factor of ~30.

The first core cladding rupture life data for both fluence levels are plotted along with the unirradiated rupture behavior in Fig. 2. The developmental cladding behavior band is also shown in this figure for comparison purposes. The first core cladding behavior is represented by a band that includes data from both fluence levels. No fluence dependence is readily obvious in these data. The reduction in rupture life from the unirradiated curve for the first core cladding at 922 K (1200°F) is a factor of ~20. Although the first core material is not degraded from the unirradiated condition to the same extent that the developmental material is degraded, the first core material rupture

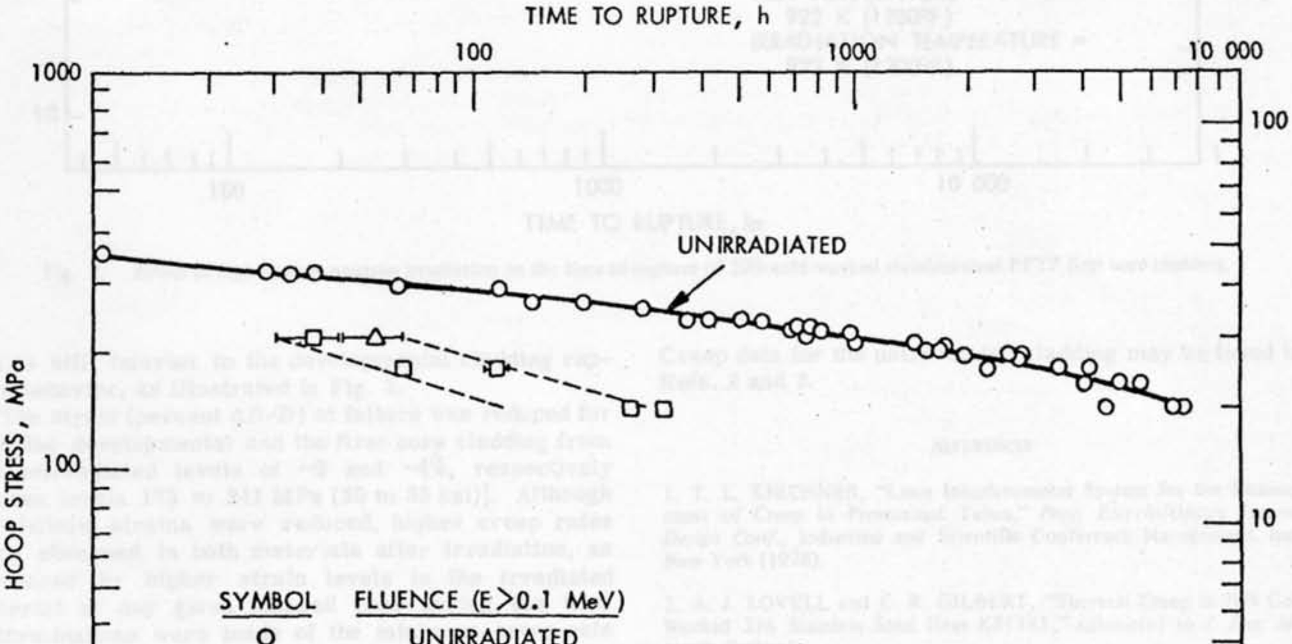

Fig. 1. Effect of high fluence neutron irradiation on the time to rupture of 20% cold-worked developmental cladding.

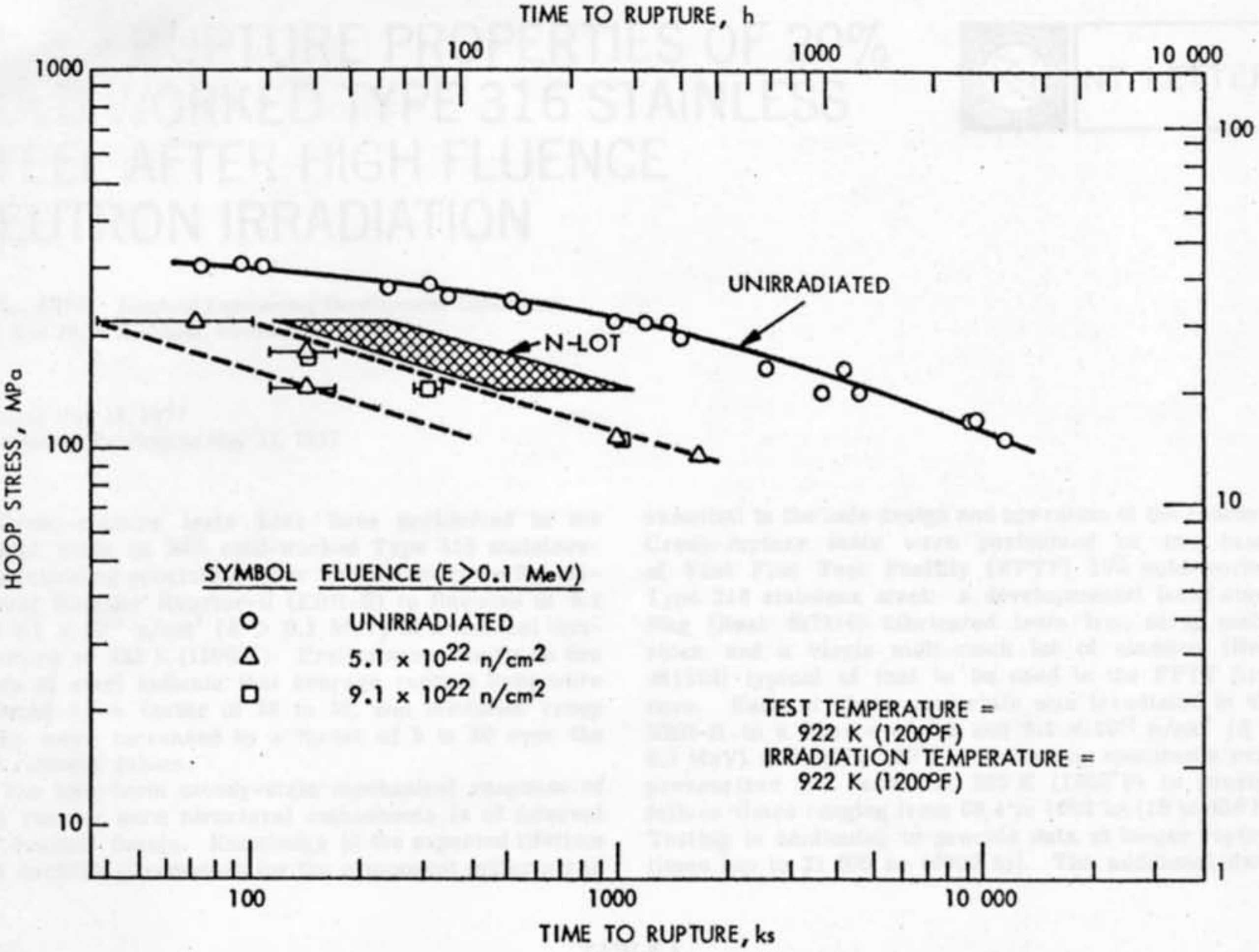

Fig. 2. Effect of high fluence neutron irradiation on the time to rupture of 20% cold-worked stainless-steel FFTF first core cladding.

life is still inferior to the developmental cladding rupture behavior, as illustrated in Fig. 2.

The strain (percent $\Delta D/D$) at failure was reduced for both the developmental and the first core cladding from the unirradiated levels of ~2 and ~4%, respectively [stress levels 172 to 241 MPa (25 to 35 ksi)]. Although the failure strains were reduced, higher creep rates were observed in both materials after irradiation, as evidenced by higher strain levels in the irradiated material at any given elapsed time during the test. Determinations were made of the minimum creep rate for the materials in both the unirradiated and irradiated conditions. A factor of ~5 to 10 increase in minimum creep rate over the unirradiated level was found for hoop stresses between 103 and 207 MPa (15 and 30 ksi). Creep data for the unirradiated cladding may be found in Refs. 2 and 3.

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