FACT SHEET

Multiaxial Creep Behavior of Type 304 SS Tubular Specimens

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Short Paper

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(5) WARD-HT-3045-8
(6) WARD-HT-3045-10
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MULTIAXIAL CREEP BEHAVIOR OF TYPE 304SS TUBULAR SPECIMENS

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SUMMARY

Creep measurements were made on Type 304 SS tubular specimens at 1100°F. Various constant load multiaxial stress and strain states were introduced by a combination of pressurization and axial loading. The measurements were processed to determine the average values for temperature, pressure, and effective stress and for axial, radial, circumferential, and effective strains. Based upon these data the creep model, $\varepsilon_c = \varepsilon_t (1-e^{-rt}) + \dot{\varepsilon}_m t$, was evaluated and the coefficients, ε_t, r, and $\dot{\varepsilon}_m$ were derived for the multiaxial constant load creep tests (10 to 20 ksi) at 1100°F as a function of stress. Microstructural characterization, including hardness measurements, grain size distribution, cracking characteristics, of the post-test specimens was made and correlated with the effective stress.

INTRODUCTION

The development of a design technology applicable to LMFBR components and core structures has long constituted one of the most vigorous experimental efforts in the liquid metal fast breeder reactor program, with studies ranging from basic specimen testing to sophisticated component testing. The objective of the present investigation is to obtain experimental data on the multiaxial creep behavior of Type 304 SS tubular specimens at elevated temperature. The purpose is to develop techniques for testing at elevated temperature, confirm models used for multiaxial creep behavior, and provide data to verify methods of inelastic (elastic + plastic + creep) analysis.

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EXPERIMENTAL

Applied Test Systems lever arm tester (series 2410) with 22-inch load frame and quick change connections in the alignment couplings was used in the present study. A split test furnace with three 5-inch zones was constructed so as to provide access ports for diametral extensometers at three locations. Electronic Control Systems (ECS) model 6821 controllers were used for temperature control and calibrated K-type thermocouples were used for temperature measurements.

Super Linear Variable Compacitive (SLVC) tranducers, with a standard accuracy of better than 2 microinches, were used to monitor the axial and circumferential strains. In this case, both the axial and diametral extensometers are of rod and tube construction of Inconel 601 alloy. They are also equipped with adjustable gaging platforms with provision for mounting the Model 1081 SLVC transducers and micrometer heads for adjustable zero setting.

The test specimens were made of the ORNL standard heat (9T2796) of type 304SS pipe (2.5" O.D. x 0.56" wall thickness). The pipe was cut into 10-inch sections and annealed at 2000°F for 30 minutes before they were machined into specimens with 1.8" O.D., 1.6" I.D. and 8" uniform gage length.

The specimen is first brought up to the test temperature of 1100 ± 3°F, the extensometers adjusted, and the SLVC transducers properly zeroed before the testing is initiated by applying the axial load first and then internal pressurization. Two axial strain measurements are made along the uniform gauge length of the test sample at positions 180 degree apart. Circumferential measurements are made in 3 positions, 2 inches apart over the middle 6 inches of the 8-inch gauge section. The measurements are taken every 6 minutes during the first hour of testing and then they were taken twice a day. A semiautomatic data acquisition system has been developed to handle the test measurements and related information to facilitate subsequent data reduction.

RESULTS AND DISCUSSION

The test matrix including the loading conditions and the test results obtained is shown in Table 1. Tests were conducted at various effective stresses which were calculated according to the following equation:

$$\sigma_e = [\sigma_\theta{}^2 + \sigma_z{}^2 - \sigma_\theta \ \sigma_z]^{1/2} \qquad (1)$$

where: $\sigma_\theta = P \frac{r_{av}}{t}$

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$$\sigma_z = P\frac{r_{av}}{2t} = \frac{L}{2\pi r_{av}t}$$

r_{av}, t = average radius and wall thickness of the tube, respectively

P, L = internal pressure and axial load, respectively

The strain versus time relationships at various stress levels are evaluated according to Equation (2).

$$\varepsilon_c = \varepsilon_t\ (1 - e^{-rt}) + \dot{\varepsilon}_m t \qquad (2)$$

where: ε_c = effective creep strain (in/in).

t = time (hour).

ε_t, r, and $\dot{\varepsilon}_m$ are constants.

The above 3 constants are obtained for all tests by using the computer program, CREEP FIT, transmitted from ORNL[1] and their values can be represented by the following equations for the stress (σ) ranging from 8.9 to 20 ksi:

$$\log \varepsilon_t = 6.88 \log \sigma - 29.0 \qquad (3)$$

$$\log r = 2.86 \log \sigma - 13.78 \qquad (4)$$

$$\log \varepsilon_m = 6 \log \sigma - 28.64 \qquad (5)$$

By substituting Equations (3), (4), and (5) into Equation (2), a master equation is obtained which describes the current results. The experimental results obtained in the present investigation apparently correlate very well with the master equation.

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Microstructural characterization, including hardness measurements, grain size distribution, and cracking characteristics, of the post-test specimens was made. Correlation of the hardness value with the effective stress level appears to show a linear relationship. In addition, it is noted that the hardness for a given specimen seems to have primarily resulted from the initial loading strain for a given effective stress and is independent of the creep strain.

Transgranular cracks were observed in all post-test specimens tested at 20 ksi in addition to the classic grain boundary separation which was predominant in specimens tested at lower stress levels. It was also noted that the cracks and grain boundary separation propagated predominantly in a direction perpendicular to the maximum principal stress.

CONCLUSIONS

1. The performance of the Super-Linear Variable Capactive (SLVC) transducers was evaluated to be satisfactory in the study of multiaxial creep behavior of tubular specimens.

2. The specimens, tested with the effective stress level above 20 ksi at stress ratio (σ_θ/σ_z) ranging from 0.9 to 2.0 reached tertiary creep stage less than 2000 hours at 1100°F.

3. Grain boundary separation was observed in all post-test specimens while transgranular cracking appeared only in specimens tested at 20 ksi. In addition, a linear relationship appears to prevail between the hardness measurements of the post-test specimen and the effective stress level at which they were tested.

REFERENCE

1. W. L. Greenstreet, J. C. Corum, and C. E. Pugh, "High Temperature Structural Design Methods for LMFBR Components Quarterly Progress Report for period ending September 30, 1972, ORNL-TM-4085, January 1973.

TABLE 1

MULTIAXIAL CREEP TEST - CONSTANT LOAD NOMINAL TEST TEMPERATURE 1100°F

Test No.	Nominal Effective Stress (psi)	Nominal Principal Stress Radio (σ_θ/σ_z)	Test Time Hours	Average Loading Strain (%) Axial	Hoop	Nominal Average Creep Strain (%) Radial	Hoop	Axial	Effective
4A	8920	1.79	1965.7	0.01668	0.05777	-0.0988	0.0900	0.0087	0.1089
5*	13400	1.79	1998.0	0.07660	0.9000	-0.6090	0.5830	0.0260	0.6879
6	20000	2.00	808.6	0.06730	2.7640	-2.8300	2.8900	-0.0620	3.2999
7A	9000	1.38	1648.0	0.03669	0.0426	-.0282	0.0208	0.0074	0.0287
8	15000	1.50	2009.1	0.19592	0.8627	-0.8810	0.754	0.1271	0.9522
9	20000	1.50	502.0	0.27200	3.3900	-1.4400	1.2380	0.1979	1.5543
10	9217.8	.94	2033.8	0.07715	0.0448	-.0758	0.0402	0.0355	0.0750
11	13800	.94	2012.9	0.41400	0.1200	-0.4760	0.22000	0.2550	0.4677
12	20000	1.00	1096.5	1.8200	1.1800	-[illegible].0000	1.7400	1.2600	2.9777

*Test conducted at 1115°F