MECHANICAL RESPONSE OF FFTF REFERENCE AND P1 CLADDING TUBES UNDER TRANSIENT HEATING

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SUMMARY

Burst tests of Type 316 stainless steel cladding tube samples subjected to increasing temperature and relatively constant interval pressure were conducted to assist in the pretest analysis of the P1 experiment performed in the Sodium Loop Safety Facility. The paper summarized here reports and analyzes the burst test results and those of subsequent transient heating work. Fast Flux Test Facility (FFTF) reference cladding (20% cold worked, 0.230 in. OD, 15 mil wall) was tested as received and after annealing or electrolytic thinning. P1 tubing (38% cold worked, 0.230 in. OD, 10 mil wall) was tested before and after aging under conditions anticipated in the P1 reactor experiment. The P1 cladding was designed to simulate FFTF tubing that had experienced irradiation embrittlement and attack by cesium oxide and sodium impurities. The burst test results were compared with those of HEDL, where irradiated and unirradiated FFTF cladding had been similarly tested. Additional data for more general analysis were produced by measurements of sample diameter changes made continuously during our tests.

Burst tests were conducted by direct electrical heating at 6 to 600 ℃/s in a vacuum system. Tubes from 4.5 to 9 in. long (little effect of length was observed) were again pressurized in the 200 to 860 psi range, with a typical pressure of 425 psi. Sample temperature, pressure, and diameter were recorded continuously. Color movies were taken at 250 to 10,000 pictures/second.

Mode of failure was dependent on the heating rate. Longitudinal cracking in highly strained sample material was characteristic at 6 ℃/s. At 110 ℃/s brittle fracture was produced in reference cladding, while P1 failures displayed a mixture of ductile and brittle features. In the 550 ℃/s range the P1 behavior was predominately brittle. The final, unstable failure event was essentially complete in a one-picture interval. Failure temperatures generally between 1150 and 1350 ℃ were observed.

Maximum stable plastic strain was greater at the low heating rates, due probably to annealing during test. At 425 psi and ~6 ℃/s reference tubing yielded near 1130 ℃, burst at 1270 ℃, and displayed ~18% average stable diameter increase posttest, a value much higher than that reported by HEDL. Temperature gradients at ends of relatively short samples or absorption of ambient impurities may account for the lower values of HEDL at high strains or for correspondingly long testing periods.

The P1 tubing tests indicated that, in terms of maximum stable strain (<6%), failure temperature (>1300 ℃), and failure mode (brittle), the cladding would perform satisfactorily in the reactor experiment with a heating rate in the range of 550 ℃/s. A lower strain might have been expected for fast reactor-irradiated (~10^{22} n/cm^2) cladding of 10 mil wall, based on HEDL data.

Factors controlling strain and failure response appear to be separable by analysis based on the recorded data and the variety of materials and conditions of the tests.