STRESS-STRAIN PROPERTIES OF FAST REACTOR FUEL CLADDING UNDER CONSTANT PRESSURE TRANSIENT HEATING CONDITIONS

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SUMMARY

The design and licensing of Liquid Metal Fast Breeder Reactors (LMFBR) require an extensive and basic understanding of fuel pin response to a wide range of off-normal events, which vary from the anticipated mild events to purely hypothetical conditions. During severe loss-of-flow (LOF) or overpower (TOP) transient the temperature of the fuel pin cladding is rapidly elevated above its steady state service temperature. To model properly the fuel pin transient behavior and to predict failure, the mechanical properties (specifically failure strength, ductility, and stress-strain behavior) of the 20% cold worked Type 316 stainless steel cladding must be known under thermal and stress conditions encountered in transients. The temperature transient alters the strength, ductility and deformation behavior by causing recovery, recrystallization and annealing of the microstructure of the cold worked and irradiated cladding. Since the extent of the property alteration is dependent upon time as well as temperature, it is imperative that the mechanical properties be determined under appropriate time/temperature conditions.

Since in-reactor measurement of cladding stress and strain on fuel pins undergoing an actual transient is impossible, the Fuel Cladding Transient Tester (FCTT) was developed at HEDL to generate the requisite mechanical property information on irradiated and unirradiated fast reactor fuel cladding under temperature ramp conditions. The simulated transient testing is accomplished by rapidly heating internally pressurized specimens of prototype LMFBR 20% cold worked Type 316 stainless steel fuel pin cladding at ramp rates of $10^4$°F/s (5.6 K/s) and $2000$°F/s (111 K/s) above the steady state irradiation temperature. Specimen pressure and failure were indicated by a calibrated strain-gauge pressure transducer. Temperature was measured with a thermocouple. Diametral failure strain (ductility) was determined by pre- and post-test diameter measurements. Details of the testing procedure and failure strength and ductility results from unirradiated cladding, as well as cladding irradiated to 50,000 MWD/MTM burnup and fluences of $4 \times 10^{22}$ n/cm² ($E > 0.1$ MeV), have been previously presented.

The cladding stress-strain behavior has been determined with a diametral extensometer which continuously measures the specimen diameter during the test. The extensometer measures the specimen diameter at two orthogonal orientations by contacting the specimen through the induction coil with fused SiO$_2$ probes. Transient tests with failure temperatures from 1000 to 2300°F (811 to 1533 K) demonstrate the yield strength as well as the burst strength of cladding can be significantly affected by the transient rate and that the hold time in a high-temperature conventional constant temperature test can allow extra recovery and annealing. For example, at 1800 to 2000°F (1255 to 1366 K) the effective yield strength at the slow 10°F/s transient was similar to the standard tensile test yield strength, while the effective yield strength at the fast 200°F/s transient was 60% higher, and the burst strength at the fast transient was 50% higher. At lower test temperatures the percentage strength increase produced by the fast 200°F/s transient decreased until at 1000°F (811 K) the strengths were similar.