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PERFORMANCE OF LIQUID METAL REACTOR FUEL PINS WITH D9 CLADDING

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The use of 316 stainless steel (SS) for Liquid Metal Fast Reactor applications is limited because of its tendency to swell significantly under neutron irradiation. Consequently, a number of alloys have been proposed[1] as advanced cladding materials including precipitation hardened alloys, ferritic materials, and titanium modified versions of austenitic 316 SS. One of the latter type of alloys is called D9[1] and is similar in composition to 316 SS but with titanium additions of ~0.25%. Three mixed-oxide $(U,Pu)O_2$ fuel tests containing D9-clad pins have been successfully irradiated in EBR-II. They have demonstrated significantly lower swelling for D9 than for the reference 316 SS cladding and have shown that the behavior of D9 is very similar to 316 SS with respect to other properties important to reactor design. In two of the tests (designated P43 and P44), D9 was irradiated side-by-side with various other cladding materials. Two different variations of D9 (differing primarily in molybdenum), two cladding cold work levels, and two fuel smeared densities (85% and 89% TD) were explored. The third test, P45, was made up exclusively of 20% CW D9-clad pins. Table 1 summarizes the tests and includes pins added at various reconstitutions and irradiated to various burnup and fast fluence levels. The D9 cladding in all three tests was 0.230 in. in diameter with 0.15 in. wall thickness. All of the tests had beginning-of-life peak cladding temperature of ~660°C.

In the case of the P43 test, six D9-clad pins were irradiated to a peak burnup of 109 MWd/kgM without cladding breach. In P44, the first breach in D9 cladding occurred at 125 MWd/kgM, while in P45, breaches occurred at 165 and 185 MWd/kgM. The earliest D9 cladding breach (in P44) was probably induced by a combination of factors including reconstitution, unequal swelling of neighboring pins and wires (for a multitude of alloys in the test) and cladding/wire wear (due to excessive bundle porosity). In all cases, breaches in D9 behave in a fashion similar to breaches in 316 SS.[2] The cracks begin as pinholes and slowly expand axially along the cladding tube with increasing sodium ingress. In no case have the cracks shown a tendency to propagate circumferentially.

Peak diameter changes for the D9-clad pins have been less than those observed for 316 SS-clad neighbors. The strains are primarily due to gas pressure induced creep and to mechanical interactions between fuel and cladding. Previous reports[3,4] of a significant localized low temperature diameter peak for titanium modified steels have not proven to be a concern for D9. Cladding volumetric swelling plays little part in the diameter changes observed in the P43, P44 or P45 pins. Figure 1 summarizes swelling (immersion density data) versus fast fluence for D9 samples taken from all three tests. Also shown are previous 316 SS swelling data.[5] The superiority of D9 cladding from a swelling point of view is obvious.

Microstructural evidence of corrosion for the outer surface of the D9 fuel pin cladding was limited to a continuous ferrite layer 0.002 mm deep at the top of the fuel column. Corrosion of the inner cladding surface, through interaction with the oxide fuel, was within the limits of what would be predicted for 316 SS using existing design correlations.[6] A difference in the fuel microstructure has been found between oxide pins with low and high swelling cladding. D9-clad pins have shown significantly smaller central voids and smaller radial cracks than their high swelling counterparts. The eventual effect of this on the lifetime of pins at extremely high burnups is unknown.

D9 continues to show promise as a cladding and duct alloy due to its low swelling characteristics and other desirable properties. It is now being irradiated in a program of fueled tests in the Fast Flux Test Facility.

References

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SWELLING IN D9 AND 316 SS CLADDING

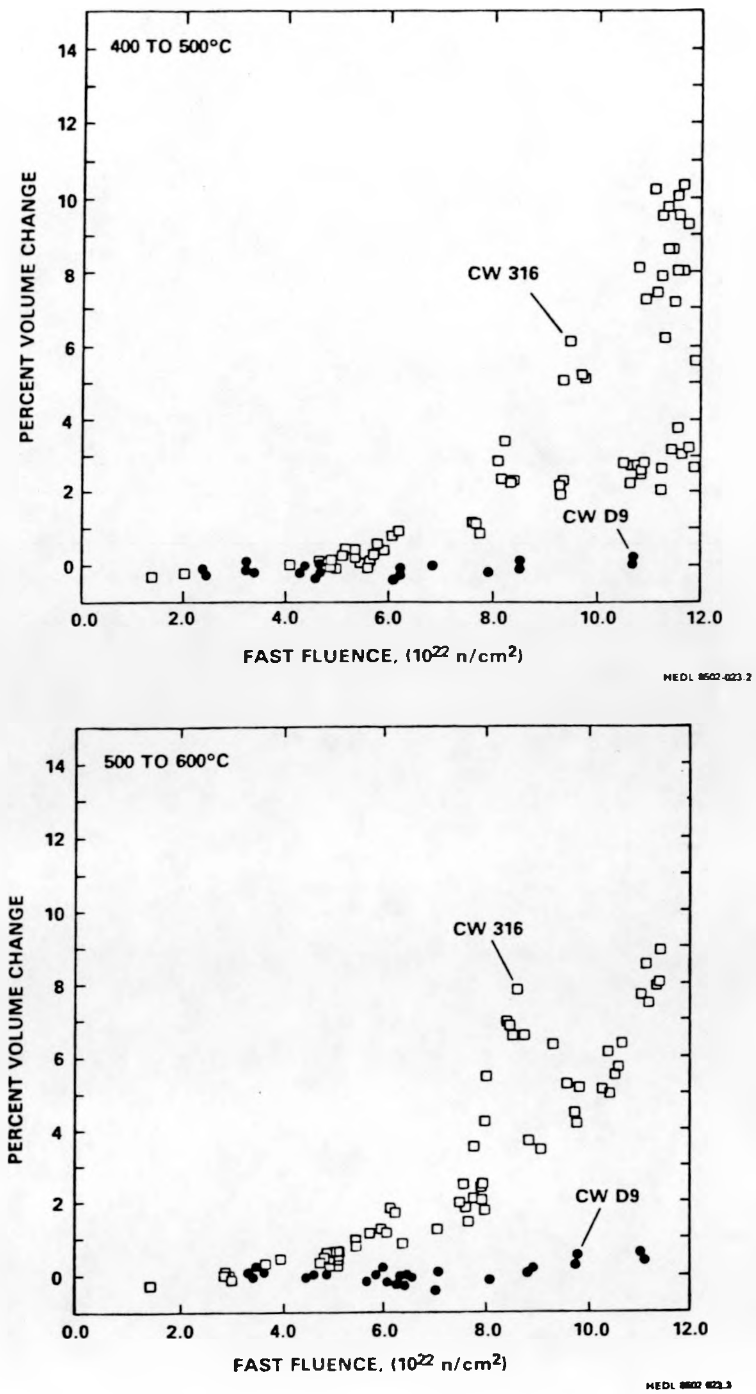

FIGURE 1. Swelling of Cold Worked D9 and 316 SS Cladding Versus Fast Fluence. Data are immersion density measurements made on irradiated fuel pin cladding from which the fuel had been removed.

TABLE 1

SUMMARY OF EBR-II TESTS WITH D9 CLADDING

Test	Assembly Size	Number of Reconstitutions	Number of D9 Pins Irradiated	Peak Burnup (MWd/kgM)	Peak Fast Fluence (10^{22} n/cm^2, E > 0.1 MeV)
P43	61 Pin	2	6	109	7.1
P44	37 Pin	4	26	135	9.2
P45	37 Pin	2	39	185	13.2