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IRRADIATION EFFECTS ON ZIRCALOY-2- URANIUM BONDS

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IRRADIATION EFFECTS ON ZIRCALOY-2-URANIUM BONDS

J. W. Goffard

April 11, 1960

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IRRADIATION EFFECTS ON ZIRCALOY-2 URANIUM BONDS

INTRODUCTION

A broad program of defect-testing is being conducted within Reactor and Fuels Research and Development Operation to answer many of the questions regarding coextruded fuel element failures and to develop a knowledge of failure mechanisms and behaviors. Most of the tests to date have been made on unirradiated fuel. Perhaps the most important parameter which may influence failure behavior, the effect of irradiation and exposure, has not been evaluated. Radiometallurgical examination of KER fuel element failures and ETR rupture experiment elements is providing an insight to the parameter of irradiation and exposure effects.

SUMMARY AND CONCLUSIONS

The failure mechanics of high exposure, in-reactor coextruded fuel rods are quite different from those of defected unirradiated rods. The appearance and corrosion behavior of the high-exposure in-reactor failures suggests that the strength of the coextruded Zircaloy-2 to uranium bond has deteriorated. Notch-fracture tests, in which the strength of the Zircaloy-2 clad to uranium bond is evaluated in a qualitative manner, suggests that the bond strength has not deteriorated to the degree indicated by the failure behavior. It is believed that the irradiation induced property changes of the uranium fuel and not a deterioration of the character of the bond are responsible for the difference in irradiated and unirradiated failure behavior.

DISCUSSION

Appearance and Corrosion Behavior

Two KER (in-reactor) failures of coextruded fuel rods have occurred and have been examined at the Radiometallurgy facility. A high exposure rupture experiment conducted at the ETR has also been examined. The superficial appearance of these ruptures is quite different from the appearance of unirradiated defect-tested specimens of similarly beta heat treated material. Figure I compares the appearance of the three failures and of four unirradiated defected specimens tested in ex-reactor loops. In the irradiated cases it appears that failure has propagated by separation of the clad from the fuel, presumably by fracturing of the bond. The unirradiated defect-test pieces usually fail by localized blistering and tearing of the clad followed by continued corrosion of the fuel without separation of the clad from the fuel by fracturing of the bond. Failure of the unirradiated and power generating rod (heated by its own electric resistance) appears similar superficially to the irradiated rods, but as will be seen in Figure II the similarity is only superficial. Specific power and temperature fluctuations caused by electric resistance transients at the failure site may be responsible for the formation of the large split blister on this rod. (*)

(*) The same effect may occur in-reactor with operating fuel. As power-generating UO_2 is developed by corrosion, temperatures at the failure site may increase which might in some way affect the failure behavior.

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Figure II compares fuel rod cross-sections at the site of the irradiated failures and of ex-reactor unirradiated defect-test specimens. Again, in the irradiated cases, it appears that failure progresses by fracturing of the bond. The remaining uncorroded fuel in the cross-section of the ETR rupture experiment has been completely separated from the clad. The cross-sections of unirradiated defect-test pieces with strong bonds reveals that failure progresses by corrosion of the exposed fuel and that additional fuel surface is not exposed by bond failure. A defect-tested unirradiated specimen with a bond weakened by thickening (lower right, Figure II) appears similar in failure mechanics to the irradiated failures. Based upon these comparisons, it appears that the strength of the coextruded bond has deteriorated during irradiation.

Notch-Fracture Tests

A simple destructive test has been applied to coextruded fuel material to differentiate between "good" and "poor" bonds. The test is performed by fracturing a notched cross-section of coextruded material by prying or wedging apart. If the bond is good (high-strength) the fracture will propagate through the composite fuel and clad at the root of the notch. If the bond is poor (low strength) the fracture will terminate at the clad and the clad will peel from the uranium along the fuel-clad interface. Notch-fracture tests have been performed on wafers from coextruded fuel rods of varying bond strengths and on two of the failed irradiated fuel rods.

Figure III shows the results of the notch-fracture tests. The unirradiated pieces varied in bond shear-strength from about 60,000 to 10,000 psi and the degree of clad peel increases with decreasing bond strength. The behavior of the notch-fracture tests on the irradiated pieces indicates that bond strength deterioration has not been severe. When making a comparison of the notch-fracture behaviors of the irradiated and unirradiated specimens, however, it must be recognized that the properties of the uranium in the two cases are quite different. The lack of ductility and the susceptibility to cracking of the irradiated uranium may influence the nature of the notch-fracture test such that a valid comparison cannot be made. The Zircaloy-2 clad, however, demonstrated comparable properties of strength and ductility in the irradiated and unirradiated notch-fracture tests.

CONCLUSIONS

The superficial appearance and corrosion behavior of high-exposure (~ 2200 to 2400 MWD/T) in-reactor coextruded rod failures infers a deterioration of bond strength during irradiation. Bond evaluation by notch-fracture testing of wafers from the failed rods does not show this bond deterioration. It is believed that irradiation induced changes in the properties of the uranium fuel and not in the character of the bond are responsible for the difference between irradiated and unirradiated failure behavior. In-reactor failure mechanics may be governed by the mechanical properties of the irradiated uranium fuel rather than the mechanical behavior of the irradiated bond.

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Irradiated Failures

KER Rod Failure - 2240 MWD/T,
0.020" clad, probably defective
clad.

KER Rod Failure - 2520 MWD/T,
0.020" clad, failure probably
caused by fuel split.

ETR Rupture Expt. - 2400 MWD/T,
0.030" clad, failure intentional.

Unirradiated Defect-Tests

ELMO-4 loop, pin-hole defect-
test, 4 hours at 300°C, 1500 psi.

ELMO-4 loop, slit clad defect-
test, 2 hours at 300°C, 1500 psi.

Heated-rod loop, pin-hole defect-
test, 2 hours at 300°C, 1500 psi
and 30 kw/ft.

ELMO-4, rupture expt. mock-up,
about 1-1/2 hour at 300°C, 1500 psi.

FIGURE 1

Appearance of In-Reactor Failures and Loop Defect-Test Specimens.
In-Reactor Failures Operated Only a Few Minutes at Most After
Detection; Loop Test Pieces Exposed as Indicated. All
Rods a Nominal 0.6 In. Dia. - Unirradiated Rods
0.030" Clad.

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Irradiated Failures

KER Rod Failure - 2240 MWD/T

KER Rod Failure - 2520 MWD/T

ETR Rupture Expt. - 2400 MWD/T

Unirradiated Defect-Tests

Typical of bond behavior in ELMO-4 loop defect - tests at 300°C, 1500 psi.

Bond behavior of pin-hole defect rod operated in heated-rod loop at 30 kw/ft., 300°C, 1500 psi for 2 hrs.

Pin-hole defect behavior with bond strength reduced to about 20,000 psi shear by diffusion-anneal thickening.

FIGURE II

Cross-Section Appearance of In-Reactor Failures and Unirradiated Defect-Test Specimens. The Irradiated Failures are Characterized by Apparent Bond Failure and Cracking of the Fuel. All Rods a Nominal 0.6 In. Dia. - Unirradiated Rods 0.030" clad.

Irradiated

KER - 2240 MWD/T failure, 0.020" clad,
0.0002" thick bond, ~60,000 psi pre-irrad.
bond shear strength.

ETR - 2400 MWD/T failure experiment,
0.030" clad, 0.0002" thick bond, ~60,000
psi pre-irrad. bond shear strength.

Unirradiated

All 0.030" clad					
bond thickness -	0.0003"	0.0006"	0.0015"	0.0035"	0.0085"
bond shear strength -	~60,000 psi	~60,000	~42,000	~25,000	~10,000

FIGURE III

Comparison of Notch-Fracture Tests on Irradiated and Unirradiated Coextruded Rod Wafers.
Variations in Bond Thickness and Bond Strength of Unirradiated Wafers were Produced by
Bond-Thickening Diffusion Anneals. All Rods a Nominal 0.6 In. Dia.

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