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BURST TESTING OF IRRADIATED ZIRCALOY TUBING

AUTHOR

V.E. Kahle

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BURST TESTING OF IRRADIATED ZIRCALOY TUBING

INTRODUCTION

An extensive knowledge of the effect on the mechanical properties of metals of prolonged exposure to neutron radiation is considered necessary to properly establish design and operating criteria for in-reactor pressure tubes and test loops. An opportunity to obtain a limited amount of this information on Zircaloy-2 presented itself when, after two years of service, the pressure tubes were replaced in the KE reactor recirculating test facility. Three Zircaloy-2 tubes, with a two-inch inside diameter and 48 feet long, had operated intermittently with prototypical fuel elements at water temperatures up to 250 C (480 F) and pressures up to 1350 psi. During this period, the tubes received an estimated integrated neutron exposure of 1.9×10^{22} nvt.

The pressure tubes were fabricated from Zircaloy-2 ingots cast by the Bureau of Mines, Albany, Oregon. Extrusion, using glass lubricant, was performed by Allegheny Ludlum Steel Corporation and the tube was reduced to finished dimensions on a Rockrite tube reducing machine at the Tube Reducing Corporation. Limitation on the length of input blank to the tube reducing machine necessitated a single-pass reduction in area of 65 percent to achieve the 48-foot length. Though the specialized knowledge required to design Rockrite tooling for fabricating Zircaloy-2 has made great strides in the past few years, it was non-existent at the time these tubes were fabricated. This lack of knowledge coupled with the high reduction in area caused cracking of four of the six tubes processed. All of the tubes exhibited fine surface tears, laps, seams, evidence of die pickup, and all of the other defects associated with excessive reductions in area with less than optimum tool designs. The tubes were carefully inspected, the largest defects were radiographed, (1,2) some of the cracks were repaired by welding, and the tubes were subsequently charged into the reactor. Maximum operating conditions were restricted because of the poor quality of the tubes.

After the tubes were removed from the reactor, metallographic examinations, longitudinal-tensile tests, flattening tests, and burst tests were performed. In this report, the techniques for performing the burst tests are described and the results of the burst tests are compared with the results from tensile tests on coupons cut from corresponding locations along the tube.

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SUMMARY AND CONCLUSIONS

Two samples of Zircaloy-2 tubing were burst after the 65 percent cold worked tube had operated for about two years under intense neutron radiation and at water temperatures up to 250 C (480 F). The irradiated tube sections failed at pressures 10 to 15 percent above those for the unirradiated control pieces. Analyses of the relative appearance of the fracture surfaces and the circumferential elongation after fracture revealed little change in ductility as a result of irradiation. These results were confirmed by tensile data from corresponding tube sections; however, flattening tests showed a marked decrease in the deflection at fracture after irradiation and tensile data from other locations in the tube also revealed a decrease as well as an increase in ductility.

From these observations, it may be concluded that no gross changes in properties occur in two years in 65 percent cold worked Zircaloy-2 that would lead to catastrophic failure under these service conditions.

EXPERIMENTAL PROCEDURE

Two sections of tubing from the high flux region of KER loop #2 were prepared for testing by cutting them to 16-in. lengths with an abrasive cut-off wheel and removing the resulting burr. These sections had a gamma activity of 20 R/hr at three feet in air. The outside diameter of the tube was 2.405 in. and the tube wall thickness ranged from 0.142 to 0.150 in. Closures, shown in Figures 1 and 2, developed by the Hanford Radiometallurgy Laboratory to facilitate remote handling, were placed on each end of the specimen while under five feet of water and the assembly was connected to a high-pressure system. After filling the high-pressure lines completely with cold water the pressure was slowly increased until rupture of the tube occurred.

DISCUSSION OF RESULTS

The irradiated tubes burst at an average internal pressure of 15,500 psi compared to 14,200 psi for the unirradiated samples. The circumferential elongation measured after fracture averaged about 3 percent for both irradiated and unirradiated tubing. The detailed data are tabulated in Table I. The results from the burst tests were compared with results from tensile tests⁽³⁾ on coupons from corresponding tube sections, Table II. Both show about 10 percent increase in ultimate strength and little if any decrease in elongation as a result of exposure to these conditions of temperature, stress, and irradiation. It should be noted that data from flattening tests and from tensile tests on other portions of the tube, to be reported elsewhere, reveal more definite decreases in ductility as a result of irradiation.

The arrows in Figure 3 indicate the points where the fracture of the irradiated tubing probably initiated. The irradiated tube sample #1 in Figure 3a split longitudinally to the end closures and then broke off circumferentially at one end-closure. Irradiated tube sample #2 in Figure 3b fractured from end-closure to end-closure, but did not break circumferentially. The fractures of both tubes appeared to follow the defects introduced in the material by the heavy cold working.

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Some fragmentation of tube section #1 occurred with two slivers separated from the tube. The largest sliver measured about 1.5 in. long and 1/2 in. wide. One small piece of metal fragmented from tube #2. The unirradiated tubes did not fragment. Fragmentation generally occurs in this type of test when the test material has low ductility. It is probable that the presence of the defects introduced by the severe cold working contributed to the fragmentation.

One of the unirradiated tubes is illustrated in Figure 4 for comparison. The fractures of the unirradiated tubes also followed the cold working defects; however, there was a difference in the fracture characteristics of the irradiated and unirradiated tubing. The unirradiated tube fractured at a 90-degree angle with the direction of principle stress at the point of initiation of the crack and along its entire length, see Figure 5. The irradiated tube fractures propagated with more than half of the fracture surface forming a 45-degree angle with the direction of principle stress. However, in the zone of initial failure, the fracture surfaces formed a 90-degree angle in the irradiated tube, indicating that the irradiated fracture probably initiated by a cleavage type failure mechanism and propagated by a shear-type failure mechanism. The transverse section of irradiated tube section #2 in Figure 6 illustrates the 45-degree fracture-surface angle about four inches from the point of initial failure. A transverse section of the same tube at the point of initial failure, Figure 7, shows that the fracture-surface angle here is about 90 degrees.

The fracture surfaces of the unirradiated tubing were not jagged and were only slightly laminated but the fracture surfaces of the irradiated tubing were rather jagged and irregular. It has been observed in other hydrostatic tests on Zircaloy-2 tubes,⁽⁴⁾ that the surfaces produced by ductile fractures are rough and highly laminated and become progressively smoother as the ductility decreases.

V. E. Kahle

V. E. Kahle
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TABLE I

ROOM TEMPERATURE BURST TEST RESULTS ON IRRADIATED AND UNIRRADIATED KER SIZE ZIRCALOY-2 PROCESS TUBING

<u>Test No.</u>	<u>Burst Pressure (psig)</u>	<u>Hoop Stress (psi)</u>	<u>Percent Total Elongation</u>
1 Irradiated	16,300	129,000	3.0
2 Irradiated	14,800	117,500	2.73
3 Unirradiated	14,200	108,000	3.3
4 Unirradiated	14,200	108,000	3.3

TABLE II

TENSILE DATA OF LONGITUDINAL TENSILE SPECIMENS COMPARED WITH BURST TESTS OF TUBULAR SECTIONS

	<u>TUBING</u>		<u>LONGITUDINAL TENSILE SPECIMENS</u>	
	<u>% Total Elongation</u>	<u>Hoop Strength (x 10³ psi)</u>	<u>% Total Elongation</u>	<u>Tensile Strength (x 10³ psi)</u>
Control Samples	3.3	108.0 (Avg. of 2)	5.8	100.5 (Avg. of 5)
Irradiated Samples	2.8	123.0 (Avg. of 2)	4.1	112.8 (Avg. of 2)

NOTE: For comparison longitudinal tensile specimens were taken from an unirradiated tube which had been in loop #2 and experienced the same water temperature and pressure conditions as the in-pile tube. The burst-test control samples had not been in the loop but were in the as-received condition.

The irradiated tensile specimens were taken from tube sections adjacent to the tubular burst-test samples.

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ACKNOWLEDGMENTS

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1/5 X

FIGURE 1

Exploded View of Closure Parts and Closure
Assembled on Burst Tube Section

1/5 X

FIGURE 2

Assembled Closure
Showing Special Neoprene Sealing Cup

3a

0.45 X

3b

0.45 X

FIGURE 3

Irradiated Tube Section #1 (above) and #2 (below) After Burst Testing
The arrows indicate the point of maximum strain or maximum bulging of the tube.

FIGURE 4

Photograph of Nonirradiated Tube Section After Burst Testing

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1/2 X

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FIGURE 5

Cross Section of Nonirradiated Tube Section
Showing Typical Hoop Stress Failure
at 90 Degrees to Tube Wall

3/4 X

FIGURE 6

Cross Section of Irradiated Tube #2
Showing Crack at 45-degree Angle with Respect
to Tube Wall Approximately 4 Inches from Zone
of Maximum Strain

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1.15 X

FIGURE 7

Cross Section of Irradiated Tube Section #2
at Zone of Maximum Strain
Showing Direction of Fracture

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