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IRRADIATED TUBE TESTING FACILITY

NOVEMBER 1964

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IRRADIATED TUBE TESTING FACILITY

By

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IRRADIATED TUBE TESTING FACILITY

INTRODUCTION

A facility for determining the total effect of reactor exposure on the properties of pressure tubing is the subject of this report. The Irradiated Tube Testing Facility (ITTF) was constructed primarily for the evaluation of irradiated N-Reactor pressure tubes; however, it has also been beneficial to both the N-Reactor and other reactor programs. Within these programs this facility tests PRTR tubing for dimensional and reactor exposure variables.

The ability of a material to perform its design function can generally be evaluated by mechanically testing representative specimens. This is not true, however, for Zircaloy-2 pressure tubing because, during forming, crystal orientation becomes strongly textured. As a consequence, the mechanical properties are also anisotropic. Another consequence of this anisotropy is an exaggeration of the strengthening effect of biaxial stressing. Finally, since a major concern of the testing program is the propagation of cracks, there is a distinct advantage in testing actual pressure tube sections in preference to specimens cut from the tubing.

Properties of Zircaloy-2 pressure tubing affecting the service life and reactor safety are creep, critical crack length,* and cyclic growth of flaws under biaxial stress conditions. The functional relationship of these properties to service temperature, amount of cold work, amount of dissolved hydrogen, neutron flux, and radiation exposure need to be known.

With Hanford's Pressure Tube Testing Facility it has been possible to characterize the properties of unirradiated pressure tubing sufficiently to form a sound basis for relaxing the conservatism of design criteria neglecting neutron effects.^(1, 2) The effect of irradiation in addition to a neutron flux on the uniaxially stressed creep properties of Zircaloy-2 is being studied at Hanford and AECL, Chalk River.^(3, 4)

* Critical crack length is defined as the length at which a slowly growing crack propagates rapidly at a given stress or internal pressure.

SUMMARY

A logical sequence for evaluating the mechanical properties of N-Reactor pressure tubing in the as-received condition is similar to evaluation after reactor service. The usual difficulties associated with testing a heavy tube to failure with 300 C water are compounded after reactor service by the high gamma radioactivity of the discharged tubes. Success in testing of discharged reactor pressure tubing in a pilot underwater facility led to the construction of an Irradiated Tube Testing Facility (ITTF) adjacent to the Radiometallurgy Building. The ITTF consists of a 10 ft 6 in. deep, water-filled basin 15 ft long by 10 ft wide, with six test chambers placed within the basin. These chambers are stainless steel bell jars that enclose the specimen, blast shielding, and electric furnace. The vessels exclude water from the hot specimen and furnace during testing and contain the pressure surge that occurs when the hot pressurized water flashes to steam upon failure of the test specimen.

The ITTF basin is connected to the Radiometallurgy Building Basin by an underwater tube containing a conveyor system. The conveyor makes it possible to transfer highly radioactive materials with ease and safety.

Remote handling tools were developed to measure the tubes, attach end closures, attach thermocouples, and load the specimen within the furnace containment vessels.

DISCUSSION

General

Burst testing of reactor pressure tubing has been conducted at Hanford for several years for evaluation of tube manufacturing processes, establishing a basis for design criteria, and evaluation of the service life of pressure tubing. The use of Zircaloy tubing for reactor pressure tubes created a definite need for a facility in which irradiated tube sections of this material could be evaluated to determine the effects of reactor environment. In response to this need an Irradiated Tube Testing Facility was constructed as an addition to the Radiometallurgy Building within Pacific Northwest Laboratory. All Radiometallurgy Building facilities are immediately available to the ITTF.

Burst testing of irradiated pressure tubing is also conducted by P. A. Ross-Ross, AECL-Chalk River, Ontario; by E. Baldwin, G. E. - KAPL, Schenectady, N. Y.; and by L. A. Waldman, Westinghouse-Bettis Laboratory.⁽⁵⁾ At all of these locations the end closure developed at Hanford⁽⁶⁾ is used because of its effectiveness and convenience for remote assembly. Most sites desiring to conduct burst tests on irradiated specimens at elevated temperature use their dry hot cells and pressurize the tubes with a high-boiling-point organic fluid. They do this to avoid the violent blast associated with bursting a large tube with a compressible fluid or with a liquid at a temperature above its boiling point. Under these conditions most of the damage in the burst tube is caused by the elastic energy stored in the tube walls at fracture. Since at Hanford we were concerned with both the damage caused by the elastic stored energy and the energy stored in the pressurized water, water was selected as the pressurizing fluid. Further analysis of the economics and convenience in testing resulted in a decision to conduct the tests under water rather than in the hot cells, and to contain the explosion inside heavy stainless steel bell jars. This concept was developed and tested in a one unit prototype.⁽⁶⁾ Following the successful use of the prototype unit for the examination of Hanford K-East Reactor high pressure loop tubing, the PRTR tubing, and an NPD tube,^(7,8) a basin facility containing six testing furnaces and chambers was constructed.

Building

The Irradiated Tube Testing Facility is a 30 by 30 ft addition to the north side of the Radiometallurgy Building at Pacific Northwest Laboratory, and was constructed under Project CAH-922. The addition was designed to be an integral part of the building and is fully compatible throughout. The addition contains a basin 10 ft wide, 15 ft long, and 10 ft 6 in. deep, in which six pressure tube testing vessels are installed (Figures 1 and 2). This basin is connected to the Radiometallurgy Building basin by a 12 in. diameter tube in which a mechanical conveyor transports the irradiated tube sections from one basin to the other. This arrangement permits the unloading of the highly radioactive materials directly into the Radiometallurgy Basin

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FIGURE 1
Irradiated Pressure Vessel Testing Facility

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FIGURE 2

Irradiated Tube Testing Facility Basin

from the heavy transport casks using the existing 25-ton overhead bridge cranes. In addition, the tube section can be transferred via the water basin into a Radiometallurgy hot cell for trimming to size, measurements, visual inspections, and metallurgical examination.

The basin water, shielding-type facility was chosen so that manual control and direct observation of the test pieces would offer freedom to perform complex tasks difficult to accomplish with manipulators. A movable bridge spans the width of the basin providing a working platform. Two hoists located on the bridge give full basin coverage for any heavy load. One of the hoists can lift the vessels from the basin to the building floor for maintenance service. Continuously recirculating the basin water through a filtering system keeps it visually clear and radioactively clean. An ion exchange unit is being prepared to further improve the quality of the water. A heat exchanger in the filter system piping is connected to a 5-ton refrigerant-type water chiller to keep the basin water near ambient room air temperatures. A heat input to the basin from the six furnaces of 45,000 W is possible; therefore, cooling is required not only for personnel comfort, but also to reduce algae growth and associated poor visibility through the water.

Equipment

Furnace Containment Vessels

Since the stainless steel furnace containment vessels (Figures 2 and 3) are required not only to exclude water, but also to contain the steam released when the tubes fail, they were built and stamped in conformance with Section VIII of the ASME Unfired Pressure Vessel Code. The following sequence describes how the vessels are used:

1. The test piece is assembled with end closures and thermocouples
2. It is placed on the stand and connected to the pressure source located on the lower flange
3. The cover is placed over this assembly, and the flanges are bolted together
4. The water that is trapped in the base is blown down the drain with air pressure, then the test specimen is ready to be heated and pressurized.

Neg. 32178-1

FIGURE 3

Furnace Containment Vessel

The maximum measured pressure transients in the vessels resulting from burst of test specimens was 50 psi, well under the relief valve setting of 170 psi and the 300 F design pressure for the vessels of 200 psi.

Each furnace is heated by semicircular strip heaters attached circumferentially to the lower outside surface of the 10 in. schedule-80 blast shell and vertical strip heaters attached to the upper portion of the blast shield, which provides a total of 7600 W power. The lower set of heaters concentrates the heat at the bottom to preheat the water entering the test piece and to reduce the temperature gradient in test pieces by heating the lower end closure. The furnace heating elements are enclosed in the insulation-filled annulus between the 10 in. pipe blast shell and a section of 16 in. pipe. There are only two penetrations of this annulus, one for the electrical leads and the other for the thermocouple leads. The maximum test conditions established for design purposes were:

Burst Pressure	20,000 psi
Test Temperature	700 F
Test Specimen Length	30 in.
Test Specimen Diameter	6 in.
Maximum Water Volume	150 cu. in.

Instrumentation (Figure 4)

Temperature Control. The temperature of the upper and lower portions of each furnace is controlled independently. The controllers are of the semiproportioning on-off type and are capable of maintaining specimens within ± 2 C over the specimen length while at temperatures to 300 C. Each furnace has an over-temperature controller. The temperatures of the test specimen in any vessel may be recorded on a 12 point recorder. Jack panels for thermocouple connections are provided at the basin curbing and on the instrument panel.

Pressure Control. The system pressure operates a pressure transmitter that in turn sends a 3 to 15 psi air signal actuating either the high pressure pump or the bleed valve. This control is calibrated to maintain the system pressure within 1% of the transmitter range. If the pressure is not controlled within these established limits the system is automatically shut down.

Piping Containment. The high pressure equipment and piping for each of the six systems are contained within individual boiler plate enclosures to prevent injury to operating personnel if a component were to fail.

FIGURE 4
Instrument Panel

The doors to each of these enclosures have two electrical interlocks that will shut down or prevent startup of the system if the door is opened. The accumulators located within the enclosure are pressurized with high pressure nitrogen before starting a test; then the high pressure pump displaces the nitrogen with water until operating pressure is reached. The accumulators smooth out the system pressure fluctuations during the pump and bleeding operations. The accumulators were built in conformance with ASME coding and are designed for operation at 30,000 psi. The pressure system is further protected by a rupture diaphragm that is sized to protect the lowest pressure rated items in the system—the transmitters. Different transmitter pressure ranges are used for various testing programs since selecting a transmitter range near the desired operating pressure reduces pressure variations.

Pumps. The high-pressure source for each system is a small air operated reciprocating piston pump capable of generating pressures to 30,000 psi from a 100 psi air supply. This pump is actuated by a signal from the pressure controller.

Tools

All of the tasks performed upon a tubular specimen from its arrival within the Radiometallurgy Building require the use of specially designed, remotely operated tooling. Some of these are briefly described below.

Underwater Tongs. A gripping device with remotely operated jaws to pick up tubes, tools, bolts, etc., for movement to other locations. Two pairs of tongs are used, one long and one short pair.

Tube Vice (Figure 5). A swivelling underwater vice is used in attaching or removing the end closures, thermocouples, etc.

Tube Closures (Figure 6). Mechanical closures were designed to allow pressurizing the tubular specimens to failure without imparting axial end constraints on the tube. These closures are designed to be self-energizing—the greater the internal pressure the better the seal.

Neg. 37186-2

FIGURE 5

Swivelling Underwater Vice

Neg. 0643052

FIGURE 6

Mechanical Tube Closures

Reamers. Two reamers are used to remove burrs made when the tubes are cut to length. One reamer fits the inside of KER, NPR, and/or PRTR tubing and the other the outside of the same. Carbide cutters are used on both reamers. Reaming is required to allow easy entry of the copper sealing ring.

Work Bench (Figure 2). A work bench (3 by 4 ft) is adjustable so that it can be raised or lowered as the radiation limits of the tubing necessitate. This work bench permits working on the tubular sections as near the surface as possible for greater ease of operation. Many fixtures and tools are kept on this work bench.

Vacuum Cleaner. A swimming pool type basin cleaner is used in the basin. The cleaner is water operated, and a special filter separator removes particulate matter before the water is pumped down the drain. The separator catches particles that might be extremely radioactive and deposits them in a container where they can be safely disposed rather than allowing them to enter the system pump where they could cause excessive radiation.

Tube Measurement. A remotely operated measuring device is used to determine the exact tube length. This device is useful in checking to see if closures are properly affixed.

Changes in circumference are measured with a "Pi" tape attached to extension handles and read through a telescope to within 0.001 in. of the diameter. To obtain strain rates, periodic measurements are made as the test progresses.

Other. Many other tools are being used and other special tools are being built as required.

Special Equipment

Crack Propagation. A remotely operated and fired gun mechanism, for attachment to one of the containment vessels, was designed and built to permit the study of crack propagation on irradiated sections of the reactor tubing (Figure 7). This test had originally been conceived and developed for use on unirradiated material.⁽⁸⁾ The mechanism illustrated permits the firing of a wedge-shaped projectile into the tube wall while the test is at elevated temperature and/or pressure, thus producing a small crack that may propagate the full length of the tube under certain conditions.

Profilometer. A device has been developed for measuring the diameter and length of the tubes before and following testing (Figure 8). These measurements will provide elongation data for the irradiated materials. An ultrasonic tube-wall measuring device is an integral part of this equipment that will be used to measure radial strain and wall thickness.

Types of Tests

Burst Tests

A burst test is one in which the internal pressure of a tubular specimen is increased at a significant rate to cause rupture within a relatively short time. These tests can be conducted on any tubular section up to about 6 in. diameter and 24 in. length at temperatures to about 350 C, and on almost any size tubular section at room temperature. Internal plugs are used to reduce the water volume and blast severity. The maximum pressure available is 30,000 psi.

Neg. 0641384-7

FIGURE 7
Remotely Operated Gun Mechanism

Neg. 0643185-1

FIGURE 8
Profilometer

Stress Rupture Tests

Stress rupture testing is a slower test that blends with burst testing at one extreme and creep testing at the other. The facility is capable of stress rupture testing under maximum conditions of about 350 C temperature and 30,000 psi pressure. The temperature control is capable of providing ± 2 C for extended periods and a pressure control of $\pm 1\%$ of transmitter pressure range (50 psi with a 5000 psi unit). Currently it is necessary to shut down the test periodically to manually obtain strain rate data; however, some type of extensometer device will be developed to provide continuous remote strain readout.

Crack Propagation

A crack propagation testing program has been devised using two methods of introducing cracks into the process tube materials. These are the gun mechanism (previously described) and a procedure of machining a thin slot axially through about 80% of the tube wall. In this test the length of the slot is a variable. Both of these tests can be performed in the irradiated tube facility within the limits of 350 C and 30,000 psi pressure. A test of this type provides a measure of the susceptibility of the tubing to brittle failure once a crack has been formed.

Temperature and Pressure Cycling

The basic system was not specifically designed to allow temperature or pressure cycling; however, tests of this sort have been successfully accomplished with the Stress Rupture Facility and could certainly be adapted to the Irradiated Tube Testing Facility. Only minor revisions were required to the existing equipment.

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