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PRESSURIZED-THERMAL-SHOCK EXPERIMENTS WITH THICK VESSELS

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The series of pressurized-thermal-shock experiments at the Oak Ridge National Laboratory was motivated by a concern for the behavior of flaws in reactor pressure vessels having welds or shells exhibiting low upper-shelf Charpy impact energies, ~68 J or less. Evaluations of overcooling accidents, however, involved consideration of other complexities that had not been explored under particularly realistic conditions. Issues that have an important impact on accident evaluation and are also amenable to investigation in pressurized-thermal-shock experiments are: effect of sequences of warm-prestressing and anti-warm-prestressing episodes on crack initiation; behavior of cleavage fracture propagating into ductile regions; transient crack stabilization in ductile regions; and crack shape changes in bimetallic zones of clad vessels.

The intermediate test vessels are geometrically suitable for fracture experiments that can be directly related to fracture phenomena in reactor pressure vessels. The vessels are sufficiently long and thick for testing the validity of methods of linear elastic fracture mechanics for cracks extending less than halfway through the wall.

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In an experiment the test vessel is heated to nearly isothermal conditions and the vessel is pressurized to establish the desired initial conditions. The thermal transient is induced by forcing coolant axially along the outside flawed surface of the vessel. Pressure changes are coordinated with the thermal transient. The thermal and pressure transients cause temperature and stress gradients in the flawed region typical of the conditions that would obtain in some severe overcooling accidents in pressurized-water-reactor pressure vessels.

The first two experiments, PTSE-1 and PTSE-2, are concerned with crack behavior near to and on the ductile upper shelf and with warm prestressing. The flawed material in PTSE-1 had good upper-shelf toughness, while PTSE-2 is being planned to have low tearing resistance. The first experiment, PTSE-1, was performed with an unclad vessel with a 1-m-long surface crack in a welded-in plug of specially tempered steel. The plug was made of a forging that, with normal heat treatment, would meet the specifications for SA 508 class 2 steel, a material with extensively studied properties. PTSE-1 demonstrated the strongly inhibiting effect of simple warm prestressing ($\dot{K}_I \leq 0$) on crack initiation. In at least one of the anti-warm-prestressing phases of the experiment ($\dot{K}_I > 0$) K_I became much greater than K_{Ic} without causing the crack to run. In this instance, however, K_I during antiwarm prestressing was much smaller than its previously attained maximum value. Subsequently, the crack propagated by cleavage and arrested twice. Nearly pure cleavage persisted to the point of final arrest at a value of $K_{Ia} \simeq 300$ MPa$\cdot\sqrt{m}$ and a temperature of 179°C, which is well above the onset of the Charpy upper shelf.

The second experiment (PTSE-2) will have a similar arrangement, but the material in which the flaw will be implanted is being prepared to have low tearing resistance. Special tempering of a 2 1/4 Cr — 1 Mo steel plate has been shown to induce a low Charpy impact energy in the upper-shelf temperature range. The purpose of PTSE-2 is to investigate the fracture behavior of low-upper-shelf material in a vessel under the combined loading of concurrent pressure and thermal shock. The primary objective of the experimental plan is to induce a rapidly propagating cleavage fracture under conditions that are likely to induce a ductile tearing instability at the time of arrest of the cleavage fracture. The secondary objective of the test is to extend the range of the investigation of warm prestressing. Warm-prestressing phenomenon will be observed, if possible, in a transient in which K_I will, during anti-warm prestressing, exceed previous maxima.