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ELASTODYNAMIC FRACTURE ANALYSES OF LARGE CRACK-ARREST EXPERIMENTS*

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The WP-1 series of HSST wide-plate crack-arrest tests are being performed at the National Bureau of Standards (NBS), Gaithersburg, MD, using specimens from HSST Plate 13A of A533, Gr B, Cl 1 steel. The six tests in the WP-1 series are aimed at providing crack-arrest data at temperatures up to and above that corresponding to the onset of the Charpy upper-shelf, as well as providing information on dynamic fracture (run and arrest) processes for use in evaluating improved fracture analysis methods. The tests use single-edge-notched (SEN) plate specimens that are cooled on the notched edge and heated on the other edge to give a linear temperature gradient along the plane of crack propagation. Upon initiating propagation of the crack in cleavage, arrest is intended to occur in the higher-temperature ductile region of the specimen. The specimens are instrumented with strain gages and thermocouples to provide strain and temperature data as functions of position and time.

Crack propagation-arrest behavior has historically been interpreted and analyzed in terms of static fracture mechanics concepts. However, the events are inherently dynamic, so that the analysis methods should consider inertial and strain-rate effects that are known to be present. Accordingly, the HSST program is developing, in concert with subcontracting groups, dynamic fracture analysis procedures and applying them to the analyses of the wide-plate crack-arrest experiment. The elastodynamic analyses of the wide-plate tests described in this paper were carried out with the SWIDAC and ADINA/EDF dynamic crack analysis codes. These codes utilize a displacement-based finite element formulation and the implicit Newmark-Beta scheme for time integration of the equations of motion. The dynamic stress-intensity factor K_I is determined in each time step from the dynamic J-integral containing the appropriate inertia and thermal terms. The crack-growth modeling technique of these codes utilizes a scheme in which crack-plane nodes, initially restrained normal to the crack plane by stiff springs, are released incrementally according to the selected analysis mode (application or generation). In an application-mode analysis,

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the crack is propagated incrementally according to a prescribed dynamic fracture toughness relation, and the crack-front position history is determined from the finite element solution. In a generation-mode analysis, the crack tip is propagated according to a prescribed position-time history estimated from crack-line strain-gage data recorded during the test.

Elastodynamic analyses have been completed for the actual test conditions of the four tests WP-1.1 through WP-1.4 conducted thus far in the WP-1 series. In this paper, the computed results are compared with data for crack-line strain-time response, crack-propagation speed, crack opening displacement, arrest location and post arrest tearing. Results from both application-mode and generation-mode dynamic analyses are presented. In addition, the paper includes a summary of the arrest toughness calculations compiled in the four tests at temperatures that range from transition to upper-shelf values for the wide-plate material.

These same elastodynamic fracture analysis techniques have been applied to the analysis of the first pressurized-thermal-shock experiment (PTSE-1) performed at ORNL. The calculated results for crack depths and crack opening displacements compared very favorably with measured data.

The results obtained to date show that the essence of the run-arrest events, including dynamic behavior, is being modeled. Refined meshes and optimum solution algorithms are important parameters in elastodynamic analysis programs to give sufficient resolution to the geometric and time-dependent aspects of fracture analyses. Further refinements in quantative representation of material parameters and the inclusion of rate dependence through viscoplastic modeling is expected to give an even more accurate basis for assessing the fracture behavior of reactor pressure vessels under PTS and other off-normal loading conditions.