187e Rapid Crack Propagation Failures in Pressurized Hdpe Pipes: Structure-Property Investigations

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When a pressurized PE pipe is subjected to an instantaneous and intense impact, a pre-existing or consequently initiated crack or flaw can propagate axially at speeds in excess of 100 m/s. Such an event is referred to as RCP or Rapid Crack Propagation. While RCP occurrence in PE pipes is noted to be rare, its consequences can be very significant. Further, RCP failures can be initiated at pressures well below the design stress of the pipe. For instance, a PE-100 pipe with a long-term stress rating of 10 MPa, can fail at lower stresses if the operating temperature is low enough. Because of the catastrophic nature of RCP and its associated dire consequences, pipe producers have to design pipes and applications such that RCP may be avoided under the worst possible conditions. This has led to the development of several tests, of which the Full-Scale (FS) and Small-Scale Steady State (S4) tests are most relevant. In the S4 test, whose details and procedures are defined in ISO 13477, the pipe specimens are seven diameters long. Typically, specimens are conditioned at the test temperature externally, and then moved to the S4 test rig where they are sealed at both ends and pressurized with air. A sharp chisel-edged striker impacts the pipe at one end and initiates a fast-running crack. While the crack propagates through the main section of the pipe length, internal disc baffles spaced along the axis suppress axial decompression. Further, a containment cage around the specimen prevents flaring of the pipe to suppress outflow. These features help to stabilise crack propagation at a crack-tip pressure which remains approximately constant and equal to the test pressure.

A series of S4 tests can be performed at a fixed temperature (usually taken as the minimum operating temperature) to determine the critical pressure (PcS4) required to sustain RCP. If the temperature is increased, the critical pressure usually increases, and above a critical temperature RCP finally becomes unsustainable. By observing whether RCP is sustained or arrested in S4 tests at various temperatures, at a fixed pressure usually taken as equivalent to the maximum operating pressure, a critical temperature can be defined. Generally speaking, RCP can be sustained only at temperatures below Tc, and pressures above Pc. Therefore low S4 Tc and high S4 Pc will minimize the risk of pipe RCP failures.

In order to develop a better understanding of the influence exerted by molecular architectural variables on rapid crack propagation (RCP) failures in HDPE pipes, a series of 110 mm SDR-11 pipes were recently produced and characterized using the Small-Scale Steady-State (S4) test. Key observations from this investigation include:

High molecular weight, high crystallinity and relatively narrow molecular weight distribution appear to be important elements for superior resistance to RCP.

High melt elasticity appears to be detrimental for RCP performance.

Co-polymers based on 1-hexene appear to be better suited to resist RCP compared to co-polymers based on 1-butene, all else being equal.

The presence of carbon black and poor dispersion of carbon black are both detrimental to the RCP performance of PE pipes.

Data obtained on a wide variety of HDPE pipes clearly demonstrates that a simple room-temperature impact energy (razor-notched Charpy Impact test per ASTM F2231) for a given HDPE is an inadequate or a poor indicator of the S4 critical temperature of the ensuing pipe.

The ductile-brittle transition temperature, as measured on compression-molded specimens using the razor-notched Charpy impact test, appears to be a reasonably good indicator of the S4 critical temperature of the resultant pipes.