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Slow crack growth and failure induced by manufacturing defects in HDPE-tubes

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Abstract

Medium-diameter pipelines produced from High Density Polyethylene are an economic and generally reliable solution for the transportation of potable water in large infrastructure works. However, in the present case, widespread fracture occurred after a few months of operation. Semi-elliptical cracks ran out from multiple initiation points at the inner radius of tubes, without piercing the outer surface, instead connecting sideward by absorbing other crack initiation zones. Longitudinal crack extension was followed by sudden crack propagation at the moment of catastrophic failure. Cracks were stopped or deviated at the welds between tube sections. Some information on fracture toughness was inferred from compact tensile specimens, complemented by direct observation of the crack surface. The latter indicated excessive brittleness of the tube material, accelerating the process of slow crack growth at low stress intensity. Numerous extrusion defects were found to be responsible for crack initiation; an excessive amount of recycled resin may have increased crack propagation velocity.

Keywords: Polyethylene; Slow crack growth; Stress concentrations; Fracture surfaces; Fracture toughness

1. Introduction

High density polyethylene (HDPE) is an attractive material in geotechnical applications due to its combination of weight, corrosion properties and low-cost. It has been used in geomembranes and pipelines for transportation of potable and waste water. Tougher but less resistant medium density polyethylene is used for gas distribution networks. In water ducts, HDPE substitutes concrete and steel. While HDPE is considered one of the toughest polymers, its fracture toughness is lower than that of commercial alloys [1,2]. Also its strength and rigidity are low compared to both metals and concrete, which is partially offset by its low weight (specific strength). For drinking water applications, HDPE is used in small and medium-diameter ducts operating under moderate pressure.

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In such applications, as well as in geomembranes, two principal causes for failure appear to exist [3]. On the one hand, problems may be induced by inadequate welds between tube sections or sheets. On the other hand, slow crack growth (SCG) may ensue from small defects introduced during manufacturing or field assembly of the material [4–6]. This phenomenon should not be interpreted as environmentally assisted cracking, which does not seem to be a problem in sweet water or a broad range of contaminated waters, although certain organic compounds are used to accelerate the phenomenon under laboratory conditions [7–9]. A third problem, consisting of a ductile–fragile transition in rapid crack propagation (RCP) at low temperature appears to be a problem mainly in Nordic countries [10,11].

A brief description will be given of the case being studied, together with the experimental techniques applied. Results of mechanical tests will be used only as a reference for the failure hypotheses presented and will be resumed without focussing on the complications of obtaining reliable results for HDPE, which is a strongly non-linear material [12–15]. More detailed information is found by the analysis of the fracture zones on a macroscopic scale and in the Scanning Electron Microscope (SEM) observations. The latter, combined with simple macroscopic observation of the failed tube sections and literature data on HDPE allow reaching clear conclusions on the nature and causes of the failure case at hand and the quality of the material involved.

2. Case description

The failed tubes were retired from a large tract of medium-diameter (610 mm) pipeline which was installed during the amplification of the Chetumal-Cancún highway (Caribbean coast of Mexico). The aqueduct connects the city of Chetumal with an underground sweet water system 35 km to the north. Similar cases have been reported for the cities of Campeche (Gulf of Mexico), León (Guanajuato), Puerto Vallarta (Pacific coast) and have been observed by the authors in the City of Mexico, but were not studied into detail. Tube walls of 18, 25 and 40 mm were used along the pipeline. The thickest tubes were used in the geographically lowest sections of the aqueduct, where hydrostatic pressure is highest. Failure incidence was checked against geographic data, to detect possible relationships with industrial or agricultural activity along the highway. The only correlation found was that failure occurred at the points of lowest elevation (highest pressure), affecting mainly (but not exclusively) the thicker tube sections.

The first failures occurred in the first months of operation in one of two parallel lines. The second one started showing serious fracture after six months. After the first failures occurred, precautions were taken to dampen hydraulic transitory effects in the tubes, which somewhat alleviated the problem but did not solve

Fig. 1. Longitudinally cracked HDPE-tube.