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Test method

# Influence of specimen geometry on the slow crack growth testing of HDPE for pipe applications

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ABSTRACT

The majority of field failures in piping are attributable to slow crack growth (SCG) fractures. These fractures are characterized by the stable growth of a crack with little deformation in the plastic material. Slow crack growth (SCG) testing involves accelerating the growth mechanism through elevated temperature, concentrated stress, constrained geometry, surfactants or some combination of these factors. Some of these accelerated tests, Pennsylvania Edge-Notch Tensile (PENT) and Full Notch Creep Tests (FNCT), have been designed specifically to promote the SCG failure by stress concentration. However, the development of new polymeric materials used in pipes for transportation, has greatly increased the time required to happen SCG failure through these accelerated tests. Recently, new specific geometries for specimens to promote the failure by SCG have been analyzed, such as the Circumferentially Deep Notched Tensile (CDNT) sample.

In this work, the reliability of the CDNT specimen to promote SCG failure on two types of ethylene copolymers was studied. The ligament surfaces after failure were analyzed to identify the SCG. The failure times were compared with those obtained on the same materials tested with a PENT geometry.


## 1. Introduction

The slow crack growth phenomenon (SCG) is a characteristic failure mechanism of polyethylene pipes for gas and water transportation [1–3]. This long term mechanism normally occurs at a stress level below the yield point, and exhibits brittle morphology [4–6]. SCG failure originates at points of stress concentration, and its development compromises several stages [7]. After crack initiation from notches, scratches or others imperfections, micro-voids develop ahead of the crack tip. These micro-voids gradually grow into large voids. The material between these voids forms fibrils of highly oriented material. This process is known as crazing. This phenomenon is governed by the global stress surrounding the craze. The strength and extension of these fibrils governs the growth of the crack until the failure.

SCG failure times are in the range of years and are associated with a crazing mechanism developed in several stages: formation of crazes in the material [8], damage zone evolution and, finally, damage propagation through the rest of the component [9,10]. Consequently, knowing the resistance to this type of cracking is critical to insure materials intended for the distribution of fuel gas offer high durability with adequate long-term strength.

SCG resistance has been traditionally determined using internal pressure tests. Unfortunately, the cost and long duration of these tests make them not viable in many practical circumstances, in particular, in ranking materials in the basic research development stages. For that reason, accelerated tests have been designed to characterize SCG material behavior in the laboratory in such a way that the failure mechanism is the same as that developed during actual SCG of PE pipes. Lu and Brown [11–13] showed that the time, $t_{SCG}$, for failure by SCG is a function of 4 variables:

$$t_{SCG} = \sigma_{SCG} \cdot K^{-n} \exp\left[\frac{Q}{RT}\right] \quad (1)$$

where $\sigma_{SCG}$ is the resistance of the resin to SCG; K is the stress

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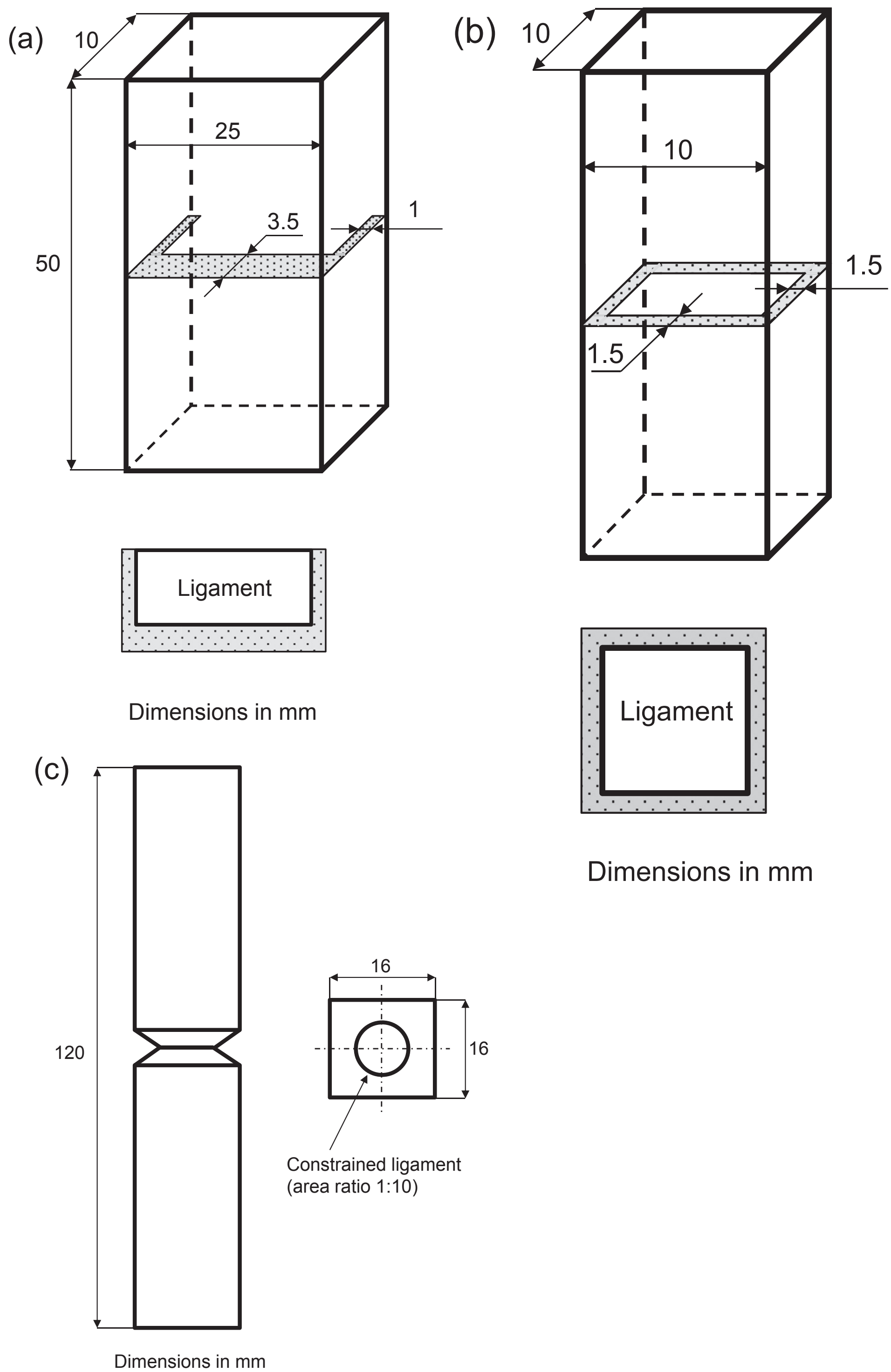


**Fig. 1.** Geometries of the samples for SCG tests: (a) PENT; (b) FNCT; (c) CDNT.

intensity factor; n is a constant for given resin and varies from 2.5 to 4.0; Q is the activation energy for the SCG failure; R is the gas constant; and T is the absolute temperature.

The stress intensity factor is given by the following equation:

$$K = Y \cdot \sigma \cdot \sqrt{(\pi \cdot a)} \qquad (2)$$

where a the size of the defect from which fracture originates; Y is a geometric factor that depends on the ratio of the defect size and the specimen dimension; and $\sigma$ is the global stress.

Several tests have been introduced during recent decades for measuring $\sigma_{SCG,}$ and probably the most accepted by the scientific and industry communities are the PENT test (Pennsylvania Edge-Notch Tensile) and the FNCT test (Full Notch Creep Tests). The PENT test was designed by Norman Brown and coworkers at the Pennsylvania University in the 1990s and it is now standardized in ASTM F 1473 and ISO 16241 [14–16]. A prismatic rectangular specimen of dimensions 25 × 10 × 50 mm with a principal notch of