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Polymer Testing 26 (2007) 700–710
POLYMER TESTING
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Test Method

Influence of nonylphenol–polyglycol–ether environments on the results of the full notch creep test

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Received 12 December 2006; accepted 25 January 2007

Abstract

It is well known that resistance to slow crack growth (SCG) is important for the lifetime of pressurized polyethylene (PE) pipes. To investigate the SCG resistance, the full notch creep test (FNCT) is widely used, especially in Europe. It is generally accepted that FNCT times to failure correlate with results from internal pressure tests on pipes. Nevertheless, the reliability of the FNCT is regularly discussed in the relevant literature. In this research work the degradation of the surface active environment (2% wt Arkopal N110 in deionized water) was verified and it was found that the times to failure increase continuously with the age of the solutions. Furthermore, it was interesting that PE films stored in Arkopal solutions had a lower OIT value compared to samples stored in water. After these preliminary tests, a ranking of several PE pipe materials was established.

Keywords: Polyethylene; Slow crack growth; Full notch creep test; Surface active environment

1. Introduction

Pressurized polyethylene (PE) pipes have been used successfully for more than 50 years [1], primarily in fuel gas and water supply systems. Nowadays a service life of 100 years is aimed at, and internal pressure tests on pipe specimens are the traditional way to determine the long-term properties of PE pipes. Unfortunately, this method is expensive and very time consuming [2,3], especially when modern PE 100 materials are evaluated.

Usually, pressurized PE pipes show three different kinds of failure (see Fig. 1) [2–4]. In region 1, high-pressure leads to large deformations of the pipe wall and ductile failure of the pipes. When the pressure is lowered a transition occurs and in region 2 brittle failure due to slow crack growth (SCG) is found. Finally, at even lower loads global chemical degradation takes place and determines the lifetime of the piping systems. It is well known that crack initiation followed by SCG (in region 2) is the most important long-term failure mechanism, which is reflected by numerous publications dealing with this topic [2–7]. Furthermore, the importance of failure due to SCG of PE pipes is pointed out by current discussions about trench-less installation techniques and installations without sand embedding [8,9].

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doi:10.1016/j.polymertesting.2007.01.010

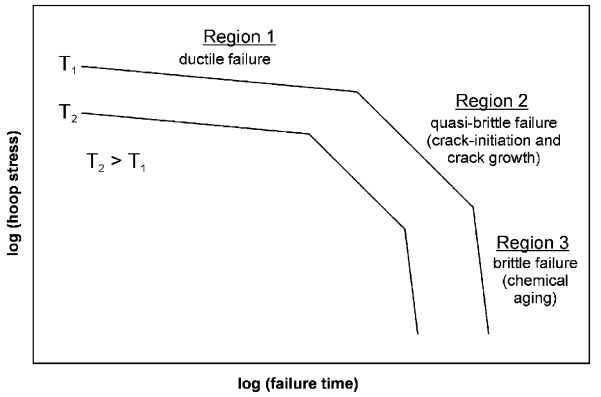

Fig. 1. Schematic stress rupture curve of internally pressurized PE pipes.

These methods cause scratches and point loads, respectively, whereby SCG is enhanced.

In the past 2 decades, strong efforts have been directed towards the development of methods to characterize the SCG behavior of PE pipe materials. As a result, several fracture mechanics methods have been introduced [10], with the goal to obtain information on the long-term behavior of PE pipes within reasonable time frames. The full notch creep test (FNCT) [7,8,11–13], various SCG tests evaluated according to linear elastic fracture mechanics [4,6,7,14,15], the Pennsylvania notch test (PENT) [16,17], the notched pipe test (NPT) [18] and the cone test [19], among others, were introduced and are widely used throughout the industry, as well as in the scientific community.

In particular, the FNCT is widely used in the industry to characterize the SCG behavior of pipe grade PEs, especially in Europe [7,8,11–13]. However, there are still discussions about the validity of FNCT data in predicting the long-term performance of PE pipe materials. For example, problems of poor reproducibility and large inter-laboratory scatter have been reported [20,21]. In addition, it has been said that the FNCT is not suitable to rate medium density PE according to the crack growth behavior observed in the NPT [21,22]. Furthermore, it is important to mention that the surface active environments usually used to accelerate the FNCT (e.g. Arkopal) are chemically degraded while used at 80 °C. It has been shown that this influences the failure times considerably [23–25]. Another problem is that a multitude of test conditions are used, which makes it almost impossible to compare results from different laboratories [20,26]. Although strong efforts were made in the past few years to develop standards for the FNCT [13,27], no generally accepted test conditions have yet been established. This was one obvious result from a recently published round Robin test where half of the results had to be excluded from the evaluation due to improper test conditions [20].

In the investigations presented here, a ranking of several PE pipe materials was established, but first preliminary tests were conducted to get first-hand information on the ability of the FNCT to characterize and rank materials according to their SCG behavior. Systematic and widespread investigations on the behavior of the surface active environment and its influence on the FNCT results were performed. Furthermore, the effect of different notch radii in water and surface active environments were compared.

2. General background

2.1. Full notch creep test

The FNCT is a long-term tensile constant load test that is conducted at elevated temperatures (mostly 80 °C and sometimes also 95 °C). Specimens with a cross-section of 10×10 mm and a length of 100 mm are used (see Fig. 2). The specimens can easily be manufactured from compression molded plates as well as from pipes. To promote SCG, a circumferential notch is introduced into the specimens and a surface active environment, usually a solution of 2% wt nonylphenol–polyglycol–ether (NPE) with different degrees of ethoxylation (see Fig. 3; n stands for the degree of ethoxylation) in deionized water is used [12,13,27].

To determine the SCG behavior, the time to failure at different ligament stress levels is measured. The results can be pictured on a double logarithmic diagram, where the ligament stress is plotted vs. the time to failure. Depending on the test parameters, either ductile failure or brittle failure (crack growth) can be observed [11,12,26,28].

It is generally believed that FNCT results in the brittle failure regime correlate with times to failure in region 2 of internal pressurized pipes, because in both cases a similar failure mechanism (crack initiation followed by slow crack growth) leads to fracture. It is quite surprising that only one publication was found by the authors where a correlation between internal pressurized pipes and the FNCT is presented [28]. This paper from