 DOI: 10.1002/masy.201051082

Notched Ring Test for Measuring Slow Cracking Resistance in Plastics Pipes and Fittings

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Summary: It is known, that the lifetime of polyethylene pipes is essentially limited by slow crack growth (SCG). For state of the art PE materials common SCG testing methods have reached their limits with respect to extension of testing times. A comparatively new method is the Notched Ring Test (NRT) as developed by Choi et al.[1] Pipe rings notched at the inner wall are used. The test is carried out in 80 °C water under constant bending load. The arrangement of the notch at the inner wall reduces testing times using the residual stress of extruded pipes. A disadvantage of this method is that there is no clearly defined failure time because SCG takes place between two phases of creeping. The output of this test is an ''on-set slow cracking time'' (crack initiation), obtained by analysis of the displacement curve. In this work it has been shown that the NRT method yields to brittle fracture within acceptable time frames.[2] Methods for data analysis are presented. This test could be very useful applied in research and development for resin evaluation and as a tool in quality control in pipe production for evaluating the process conditions.

Keywords: crack initiation; crazing; Notched Ring Test; polyethylene (PE); slow crack growth

Introduction

Slow crack growth is known as a limiting factor for the lifetime of polyethylene pipes. With the development of pipe resins in the last decades the resistance of polyethylene against slow crack growth has been improved tremendously. Concurrently new fields of application aroused taking benefit of this enhanced property.

Common methods for determining the resistance of slow crack growth are the ''Full Nochted Creep Test'' (FNCT),[3] ''Pennsylvania Notched Tensile Test'' (PENT)[4] or ''Notched Pipe Test'' (NPT),[5] Because of the long testing time of several thousand hours these tests are already not applicable for modern polyethylene pipe grades especially in routine testing operations (factory production control).

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An alternative test method has been developed by Corleto, measuring the deformation rate on an instrumented PENT Test to detect the time of crack propagation.[6] Another approach is to use fatigue testing on cracked round bar samples (CRB). These methods do not take account the pipe geometry and therewith the manufacturing influences on the final product.

The ''Notched Ring Test'' (NRT) uses a pipe ring sample preserving the original geometry and the residual stress distribution influenced by the manufacturing parameters.

Methodology

The Notched Ring Test is applied on a ring taken from a pipe or fitting. The notch geometry consists of two side wall notches and a razorblade notch at the inner wall of the ring (Figure 1). Sample preparation and notching has to be done carefully in order to

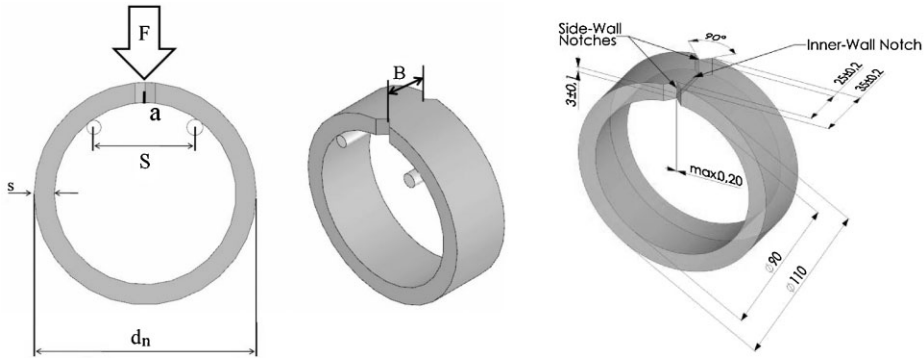

Figure 1.
Principle of NRT, Specimen geometry e.g. on dimension 110mm SDR 11 pipe.

achieve reliable results. As the notching speed has an influence to the SCG behaviour it has to be done at a speed of 0,25 mm per minute using a universal loading machine (Figure 2a). The test is carried out at 80 °C in air or water under constant bending load (Figure 2b).

As slow crack growth occurs, the displacement curve shows irregularities compared with the pure creep displacement curve. The appearance of these irregularities varies with the resistance to slow crack growth of the tested material. In this work the results of a PE80 pipe grade and a bimodal PE100 pipe grade are shown. The analyzed PE80 has a small resistance to SCG. The displacement-time diagram shows stick-slip crack growth (Figure 3). The first step in the creep curve displays the initiation of slow crack growth. The number of steps is corresponding to the rest line on the fracture surface (Figure 4 and 5).

Data Evaluation

The PE100 material has a higher resistance to slow crack growth. Thus the effect of SCG to the creep curve is very slow in the initial phase. To detect the on-set slow cracking time mathematical methods are needed.

A common method in functional analysis is differentiation. To evaluate the numerical measurement date a segmental differentiation method (SDM) is used. Thus signal noise is reduced and basic information to the local displacement rate is provided. In many cases, especially when SCG initiation occurs in the first phase of

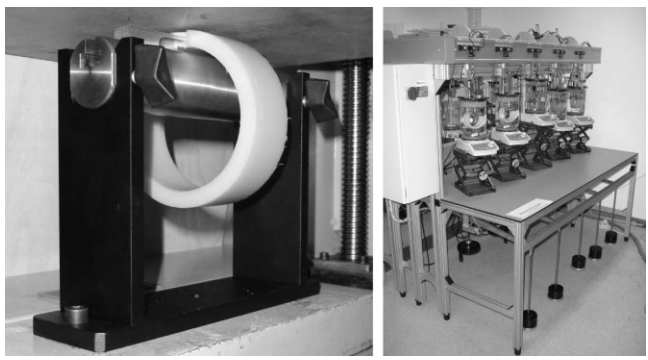

Figure 2.
Notching Equipment (a), Test Equipment with 80 °C water bath (b).

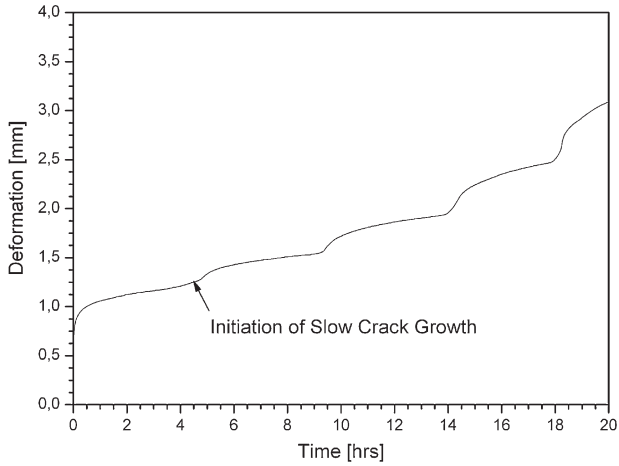

Figure 3.
Time-displacement curve PE 80, load 137 N.

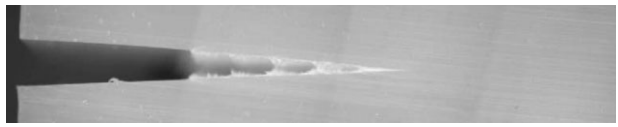

Figure 4.
Crack formation with progress steps, corresponding with Figure 3.

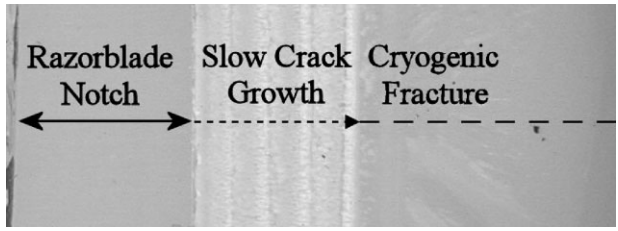

Figure 5.
Fracture Surface corresponding to Figure 3 and Figure 4.

creeping, this is not enough to determine on set of SCG (Figure 7).

An additional method is the Modified Displacement Method (MDM), (Equation 1)[7]. The displacement data is magnified by an exponential factor (Figure 6 and 7).

$$MD = \Delta H^{((\tan\theta)^n)} \quad (1)$$

$$\tan\theta = \frac{S/2}{H_0 - \Delta H}$$

MD. . .Modified Displacement [mm]

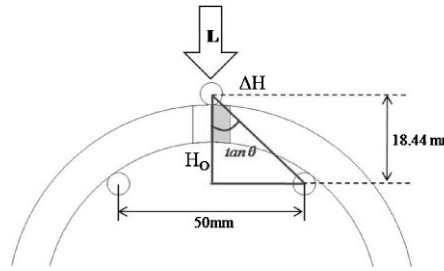

Figure 6.
Geometry for the calculation of the Modified Displacement (MD) on dimension 110 mm SDR11 pipe.

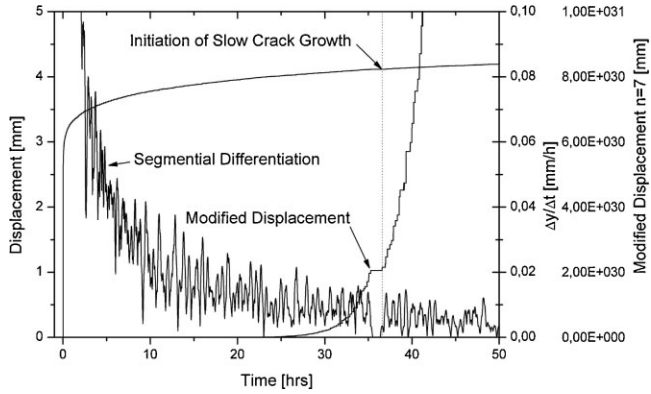

Figure 7.
Time-displacement curve PE100, load 238 N. Segmental Differentiation Method (SDM) and Modified Displacement Method (MDM) are used to detect on-set slow cracking time.

H_0... Initial distance [mm]
ΔH...Displacement [mm]
S... Span length [mm]
n... Arbitrary number,
usually in the range between 2 to 7.
It has to be set for a suitable
magnification of the curve

Figure 8 shows the crazing zones after slow crack growth has started. Figure 9 is a SEM picture of the same surface. It shows the initial crack tip of the razorblade notch and the fibrillated crazing zone. In doubt whether slow crack growth has taken place or not the fracture surface after cryogenic cracking has to be observed.

In the double logarithmic diagram there is to find a linear correlation between load and on-set slow cracking time for both materials (Figure 10 and 11). At a reference

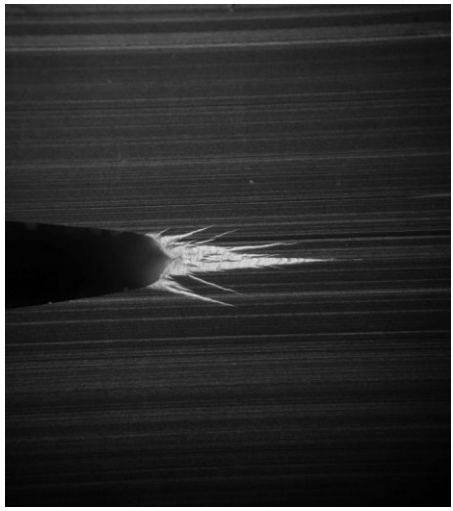

Figure 8.
Crazing and slow crack growth in PE100, load 275N after 118 h.

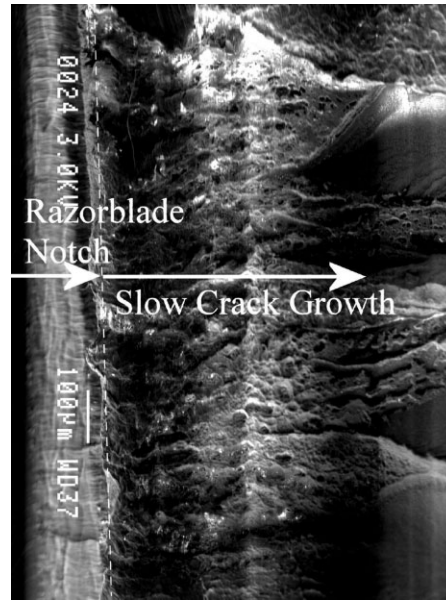

Figure 9.
SEM picture of PE100 fracture surface corresponding to Figure 8. Fibrillated material indicates slow crack growth with brittle macroscopic failure.

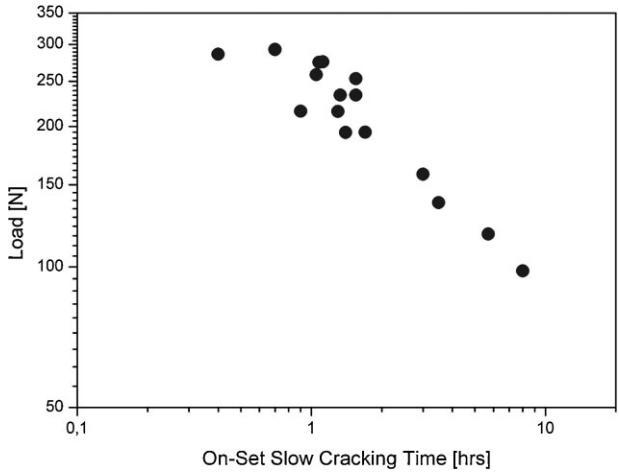

Figure 10.
PE80 on-set slow cracking time versus load.

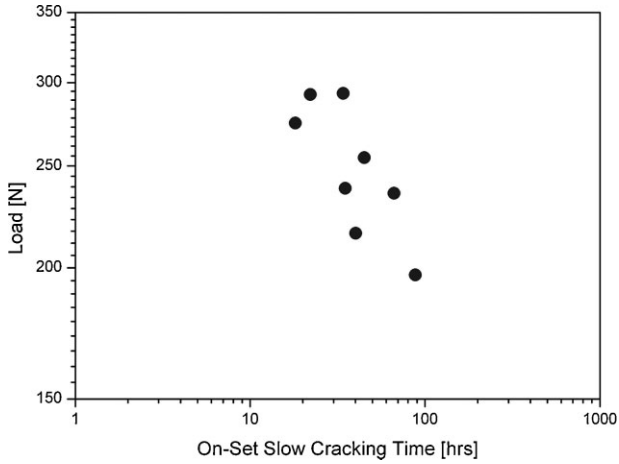

Figure 11.
PE100 on-set slow cracking time versus load.

load of 256 N the PE 100 material shows a 43 times longer on-set-time than the PE 80 sample.

Conclusion

It has been shown that the NRT-method produces starting the slow crack growth in a short time frame. It provides information about the resistance to slow crack growth in a time frame of order of magnitude shorter than currently standardized methods. This test method therefore might be useful especially for testing resins and products with high slow crack growth (SCG) resistance especially for quality control operations.

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