Polymer Testing 65 (2018) 242–248

Contents lists available at ScienceDirect

Polymer Testing

journal homepage: www.elsevier.com/locate/polytest

Test Method

Identifying mechanically induced chemical changes to vintage grade high density polyethylene pipes during squeeze-off

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ARTICLE INFO

Keywords:
Polyethylene pipes
Squeeze-off
Pipe failure
Carbonyl index

ABSTRACT

Squeeze-off is widely used within the gas industry for temporary interruptions to supply, both when extending and repairing the polyethylene (PE) pipe network. Over the years a number of pipe failures, have been attributed to damage caused at the squeeze-off location, often linked to non-standard squeeze-off practices. The purpose of this paper is to examine PE pipes that have been squeezed in the laboratory under ASTM and non-ASTM standard conditions to determine if any changes to the PE structure can be measured. Changes in the PE due to squeeze-off was measured by FTIR at the squeeze-off ear. The carbonyl index (CI), a measure of polymer degradation, was calculated for the various squeeze-off conditions and it was found that over-compression of the PE pipe caused the greatest amount of damage to the pipe and that is directly linked to the integrity of the pipe prior to being squeezed-off.

1. Introduction

A major advantage of PE pipes is the ability to conduct squeeze-off [1,2]. Squeeze-off is a procedure that temporarily prevents/restricts the flow of gas within the pipe to allow repairs or the extension of existing pipes to enable new services. During the squeeze-off, a section of the pipe is compressed between two parallel bars to restrict the gas flow. The pipe remains compressed (hold stage) while the repair or extension is completed after which the pipe is released. During the squeeze stage (Fig. 1a), squeeze-off ears are formed at the edges of the pipe underneath the squeeze-off tool, where the inner surface of the pipe wall is compressed and the outer surface is under tension. In Fig. 1 the pipe is only compressed until the walls touch, whereas the ASTM standard allows a maximum wall compression of 20%, meaning the thickness can be reduced to 80% of its original value. During the hold stage the inner surface of the squeeze-off ears experience very high levels of compressive stress that are significantly beyond the elastic limit of the material. During the release stage, the compressed region at the inner surface of the squeeze-off ears changes to become a region of high tensile stress. After the squeeze-off bars are removed, the pipe is often to re-round (or may be mechanically re-rounded) and in either case a permanent deformation results and a stress concentrator at the squeeze-off ear is created [3].

Failures due to squeeze-off have been documented, and in some cases have resulted in catastrophic explosion and deaths [1,4–9]. Only a few previous studies have been carried out to investigate the effect of the squeeze-off procedure on PE pipes with all studies to date focussing on the mechanical properties of the squeezed pipe [2,6,9–12]. Inspection of squeeze-off failures typically show evidence of a slow crack growth (SCG) failure mode with the crack initiating at the squeeze-off ear [6,13]. Uzelac et al. [11] noted a reduction in the pipe wall thickness at the squeeze-off ear. Brown and Crate [6] demonstrated that when an internal flaw is present the lifetime of the pipe is reduced significantly, from that they assumed that squeeze-off performed under non ASTM conditions has the possibility to create a stress concentrator which leads to failure via a SCG mechanism.

Quantification of the degree of damage to the properties and structure of the squeezed material has had comparatively little attention. The tensile properties of the squeezed material has been investigated and shown a reduction in the yield stress for PE80 and PE100 at increasing squeezing ratios [2]. Some studies have reported observations of stress whitening on the internal wall of the squeeze-off ear [2]. It has been suggested by Brown et al. [6] that squeeze-off can break covalent bonds, however, to date this has not been proven. The aim of this paper is to determine if any mechanically induced chemical degradation can be detected as a result of squeeze-off on PE pipes. It is

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https://doi.org/10.1016/j.polymertesting.2017.11.029
Received 23 October 2017; Accepted 27 November 2017
Available online 28 November 2017
0142-9418/

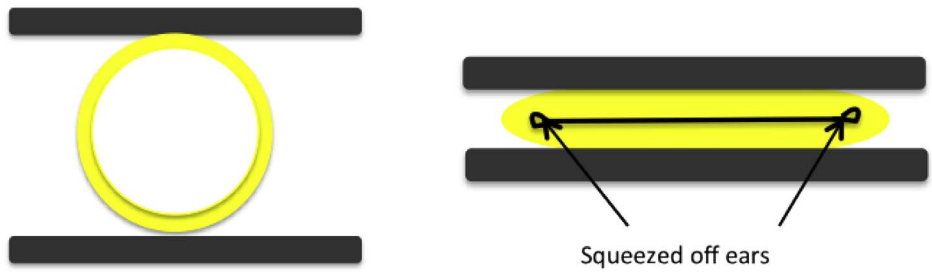

Fig. 1. a) the initial stage of squeeze-off and b) the compressed stage showing where the squeeze-off ears form.

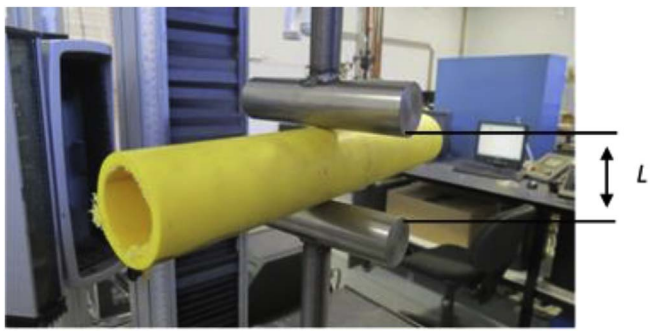

Fig. 2. Laboratory squeeze-off set up.

widely acknowledged in the gas industry that squeeze-off cannot, or has not, always been conducted as per the ASTM standard or industry guidelines, and that higher compression ratios and faster release rates in particular will result in more damage to the pipe. The age and grade of the pipe are also commonly believed to be factors in the extent of damage caused to the pipe material.

Samples of older grade HDPE (type PE63) pipes have been squeezed investigated here, squeeze-off has been conducted using a laboratory squeeze-off set up (see Fig. 2) at ASTM and non-ASTM standard conditions by varying the release rate and the percentage compression. Fourier transform infrared spectroscopy (FTIR) has been used to map across the cross section at the squeeze-off ear to identify if chemical damage has occurred and if differences in the amount of damage can be detected between pipes of different ages and subjected to different squeeze-off conditions. These findings indicate that chemical degradation is present in the squeeze-off ears. The amount of chemical degradation detected increases significantly when the pipe is squeezed beyond the recommended % compression. This is the first report highlighting chemical degradation at squeeze-off ears due to the squeeze-off procedure.

2. Material & methods

2.1. Materials

Three HDPE, PE 63 grade vintage pipe samples were used in this study, each of the pipes have been in service details provided Table 1.

Table 1
PE pipe samples studied.

Specification	Pipe A	Pipe B	Pipe C
Grade	HDPE, PE63	HDPE, PE63	HDPE,PE63
Average Outer Diameter	60 mm	48 mm	60 mm
Average Wall thickness	6.10 ± 0.18 mm	5.26 ± 0.17 mm	7.07 ± 0.13 mm
Location	St. Albans, Victoria, Australia	Melbourne, Victoria, Australia	Mt.Eliza, Victoria, Australia

2.2. Methods

2.2.1. Oxidative induction time, OIT

The Oxidative Induction time, OIT, is a qualitative assessment of the level (or degree) of the level of antioxidant package remaining within the polymer. OIT determination using Differential Scanning Calorimetry (DSC) was conducted according to the ASTM D 3895 standard. Isothermal temperature of 210 °C was used. Samples were heated to 210° C in nitrogen flow rate 20 ml/min held at 210 °C for 3 min before switching to an oxygen air flow of 40 ml/min. Experiments were conducted on a Perkin-Elmer DSC 4000 Differential Scanning Calorimetry (DSC). The onset of the exothermic reaction was taken as the OIT time [14].

2.2.2. Squeeze-off tests

A laboratory hydraulic universal material testing frame (Instron 8801) equipped with a 100 kN load cell was used to recreate the squeeze-off procedure as shown in Fig. 2. The length of the PE pipe samples for squeeze-off tests were at least 1 foot long (305 mm) or ×3 diameters long whichever is greater as described in the ASTM F1734 squeeze-off standard procedure [15]. The pipe sample was positioned in between the squeeze-off bars where the maximum pipe wall thickness was parallel to the squeeze-off bars (squeeze-off ear). The centre point of the pipe length was between the squeeze-off bars as seen in Fig. 2. The squeeze-off bars were cylindrical with a diameter of 38 mm which is suitable for the diameter of pipes investigated based on ASTM F1563 [15].

The wall compression (WC); the % extent to which the pipe walls are compressed when the pipe is squeezed for each squeeze-off test were calculated from the below equation (1); where L: distance between the squeeze tool bars as shown in Fig. 2, t: uncompressed pipe wall thickness.

$$\%\ \textbf{Wall compression}\,(\boldsymbol{WC}) = \left(1 - \frac{\boldsymbol{L}}{2\boldsymbol{t}}\right)\boldsymbol{x}\ 100 \tag{1}$$

3 different sets of squeeze-off conditions were investigated as shown in Table 2. Firstly, the squeeze-off was conducted as stated in the standard (ASTM) to a 20% wall compression using the maximum allowable release rate. Secondly, the % compression was increased beyond that recommended by the ASTM standard with the release rate remaining as the maximum allowable as per the standard (40%STD). In the final condition, the release rate was increased beyond that allowed in the standard (20%FR) using the maximum release rate possible which was 180 mm/min.

Table 2
Squeeze-off parameters used.

	ASTM	20%FR	40%STD
Squeeze rate	50 mm/min	50 mm/min	50 mm/min
Wall compression	20%	20%	40%
Hold time	60 min	60 min	60 min
Release rate	10 mm/min	1800 mm/min	10 mm/min
Bar diameter	38 mm	38 mm	38 mm