



Test Method

Special fracture mechanics specimens for multilayer plastic pipes testing

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ABSTRACT

Pipes consisting of layers of different materials (multilayer pipes) are considered. The fracture toughness value of the main pipe is taken into account as a parameter relevant to fracture assessment connected with the resistance of pipe material against slow crack growth. With the aim of simplifying estimation of main pipe material fracture toughness, non-homogeneous test specimens cut directly from multi-layer pipes are suggested and numerically analysed. The values of the corresponding stress intensity factor K_I and biaxiality factors B are calculated for the case of two and three layer test specimens. Based on the results obtained, the transferability of fracture toughness values measured on laboratory specimens to pipe systems is discussed. It is shown that in most cases of multi-layer commercial pipes and routine fracture toughness measurements the values of the stress intensity factor calculated on the basis of homogeneous specimens can be used.

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1. Introduction

The development of new materials has supported new technologies which it had not previously been able to employ in laying new pipes and sanitation systems [1]. So-called multi-layer pipes have recently been supported more in pipe systems. The purpose of this development was to partially improve the property profile of pipes, especially their resistance to small crack growth [2,3] and rapid crack growth [4], which limits their lifetime. Understanding of the phenomena governing brittle slow crack growth (SCG) and rapid crack propagation (RCP) as a property of polyethylene pipes has attracted much attention on the part of researchers and workers in the gas industry in recent years [5,6,7,8]. SCG together with RCP constitute key factors when selecting materials for pressure pipes. An important role in determining the lifetime is played by the crack initiation stage and slow crack growth. It is clear that pressure pipe applications require polymers with very long

lifetimes, but the problem is to develop a test that is able to estimate the lifetime in a relatively short time.

The currently used quality check test of slow crack growth (test method EN 33479) generally takes more than 1000 h after which the test is terminated. Similarly, in order to qualify a new resin, the conventional hydrostatic pressure test must last 10^4 h (ISO 9080).

Some accelerated tests, utilising fracture mechanics, have been developed in the last ten years. The PENT [9] test developed by N. Brown and his co-workers produces the same type of brittle fracture that occurs in pipes after a long time in service.

The essential characteristics of the RCP phenomenon are the dependent relations between critical pressure and temperature. At present, there are in principal two tests that are applied (FST [10] and S4 [11] test). The S4 test is a laboratory test on pipe which is widely used to measure the resistance to RCP. Brown and Leever [7,8] proposed an alternative test that can estimate the resistance to RCP of the native material and yield good correlation to S4 test results.

As the relevant values that can distinguish materials in relation to resistance to SCG and RCP are fracture mechanics

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parameters, K or G , critical values of the parameters (e.g. fracture toughness) are then measured on the standard test specimens. From this perspective, knowledge of the stress intensity factor K as a function of a crack length (K calibration) for a given specimen and/or pipe and the corresponding boundary conditions is fundamental [12]. In the case of homogeneous test specimens, K calibration curves are generally known and can be found in the literature, e.g. [13].

Multi-layer systems generally can consist of many layers which have different functions. Particularly, multi-layer pipes consist of the following parts, which influence their behavior and applicability: a contact layer between medium and pipe wall, an inner protective layer, a sealing layer for the medium, an initial load-bearing layer, a layer to increase the pipe wall thickness, a second load-bearing layer, a main (functional) layer, a sealing layer vis-à-vis the surrounding soil, an outer protective layer and a contact layer between the medium and the surrounding soil. The manufacturing facility must be designed specifically for the various pipe structures. As far as polymeric materials selection is concerned, what is mostly used is a combination of HDPE, for example PE 100, but also PE-Xd (peroxide cross-linked) or PE-Xb (silan cross-linked), and PP (block and random copolymers) [14]. The lifetime of a multi-layer pipeline system is usually limited by SCG and RCP, but there are additional conditions, e.g. elastic collapse and loss of adhesive strength that contribute to limit the lifetime.

In the following it is assumed that the lifetime of pipe systems is controlled by damage to the main pipe. Two layer pipes with an outside protective layer and three layer pipes with inside and outside protection are considered. To evaluate the reliability and service life of a multi-layer pipe system using a fracture mechanics approach it is necessary to discuss specimen preparation for fracture toughness measurement and transferability of the measured data to the real pipe system. To measure the fracture toughness of the main part of the pipe material, the special non-homogeneous C-type tension and bending specimens machined directly from the multilayer pipe have been suggested.

Contrary to homogeneous cases, values of stress intensity factors for non-homogeneous specimens depend on the material combinations employed, and their estimation is more complicated and needs numerical simulations. To this end, a simple numerical model of two and three layer

pipes consisting of main and protective layers only (see Fig. 1) is used.

The goal of the present paper is to estimate values of stress intensity factor K for two types of suggested non-homogeneous specimens, to calculate the corresponding values of biaxiality factor B and discuss the applicability of the results obtained. Special attention is paid to the transferability of the experimental data obtained from this type of specimen to a real pipe system.

2. Non-homogeneous C-type specimens

Usually, fracture toughness values are measured on test specimens following standard conditions [15]. The geometry of the fracture mechanics test specimens is prescribed in standards, and corresponding K -calibration curves for common test specimens can be found in the literature [13]. Due to the complicated geometry and material non-homogeneities of multi-layer pipes it is difficult to prepare specimens corresponding to given standards. To avoid this difficulty, new types of non-homogeneous specimens, namely, the C-type tension specimen and C-type bend specimen were suggested. The advantage of the suggested specimens consists in the fact that they are machined directly from the pipes and can be easily produced. The disadvantage of this approach is the absence of the corresponding expressions for estimation of K -values.

2.1. Specimen characterization

C-type specimens for tension and bending corresponding to two and three layer pipes are considered here, see Fig. 1. The studied geometries and material composition of the pipes and specimens correspond to pipes used for water and gas distribution. Specifically, the following multi-layer pipes have been considered:

1. Pipes with the dimensional addition of a protective layer, i.e. a two layer system consisting of an inner main (functional) pipe and one outer protective layer (see Fig. 1a). GERODUR CZECH supplied the extruded pipe (PE100 SDR 11 PN16 with a PP protective layer) used in this investigation. The main tube thickness of the PE 100 pipe was 10 mm and the average outside diameter was

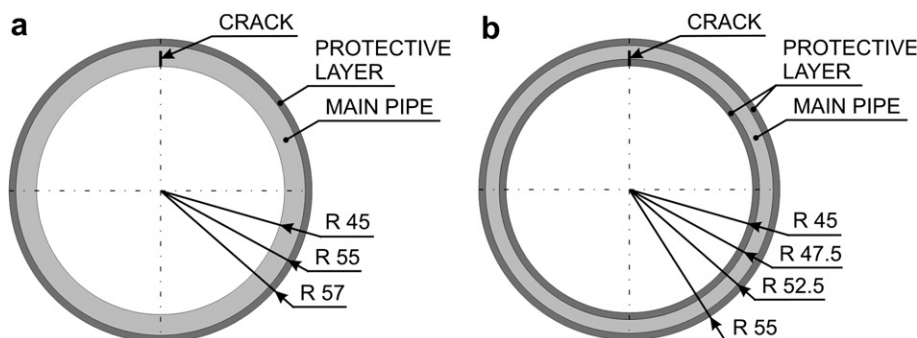


Fig. 1. (a) Two-layer pipe with protective layer (b) Three-layer pipe with protective layers.

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