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Fracture of high-density polyethylene used for bleach bottles

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Abstract

High-density polyethylene (HDPE) can be blow-molded and used for the production of bottles for aggressive products. These products can interact both chemically and physically with the polymer constituting these containers, leading to a decrease in the performance of the material and undermining the structural integrity of the component.
A fracture mechanics approach was adopted to evaluate the Environmental Stress Cracking Resistance (ESCR) of two HDPE commercial grades used for bleach containers; two different solutions, with and without sodium hypochlorite (the main ingredient of commercial bleach solutions), were considered as aggressive environments. Size effects were studied using different test configurations and loading histories in air. The correlation between the stress intensity factor and the initiation time was found. A clear effect of the aggressive solutions on the fracture resistance of the two HDPEs was observed, irrespective of the presence of sodium hypochlorite; the effect therefore has to be ascribed to other bleach components.

Keywords: Polyethylene; Environmental Stress Cracking; Fracture mechanics; Bleach

1. Introduction

High-density polyethylene (HDPE) is a polymer widely used for packaging applications, such as bottles for household detergents. One of these products is bleach, an alkaline aqueous solution of sodium hypochlorite, which can also contain perfumes and surfactants.

Once filled with the product, these containers are packed on pallets, which in turn are stacked one on top of the other. The containers at the bottom may be subjected to very high mechanical stresses due to the weight of the

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surmounting bottles, even for a long time (i.e. several months); this mainly occurs before the shipment to the distributors, in the manufacturing facility, and before the display of the product on the retailer's shelves. The presence of bleach can cause accelerated craze formation, leading to bottle failures in shorter times and with lower loads than in absence of such an active environment. This phenomenon, known in the scientific literature as Environmental Stress Cracking (ESC), is related to a mainly physical interaction between a given substance and the polymer. The main effect of the fluid is to promote Slow Crack Growth (SCG) by being absorbed at craze, developing in close proximity of an existing defect, reducing the local strength by a plasticization. The diffusion of the active environment results in an easier disentanglement of the molecules making up the craze fibrils. This phenomenon affects craze initiation, its growth and the subsequent crack initiation and propagation leading to the failure of the material.

The ESC phenomenon has been widely studied in the literature. Altstaedt et al. (2004) used a fatigue crack growth approach to analyze the behavior of HIPS in contact with sunflower oil. On HDPE, Kurelec et al. (2005) found a correlation between Environmental Stress Cracking Resistance (ESCR) and strain hardening modulus; Men et al. (2004) and Munaro and Akcelrud (2008) reached good results considering the mobility of the amorphous phase as a main indicator for ESCR; Cazenave et al. (2006) showed that Natural Draw Ratio (NDR) and Stepwise Isothermal Segragation (SIS) could be adopted for predicting ESCR.

Williams and Marshall (1975) obtained good results applying from Linear Elastic Fracture Mechanics (LEFM); this approach, also followed by Moskala (1998), Rink et al. (2003), Andena et al. (2013) and a few others, was adopted also in this work to study ESC of two commercial HDPE grades used for bleach bottles.

The composition of commercial bleach is such that chemical interaction with HDPE (e.g. oxidation) could occur, as reported by Hassinen et al. (2003) and Castillo Montes et. Al (2004). However, preliminary tests showed that chemical interaction between HDPE and bleach occurring within six month of exposure to the product has a negligible effect on the material's mechanical properties; therefore, in this work ESC was investigated independently and only the results obtained from fracture tests are reported. Before considering the effect of the environment, the fracture behavior in air of the two HDPEs and relevant size effects were investigated.

2. Experimental

2.1. Materials and sample preparation

Two blow-molding HDPE grades (HDPE-MONO and HDPE-BI), characterized by different molecular weight distribution, were considered.

6 mm and 11 mm thick plates were manufactured via compression molding using the following procedure:

- HDPE pellets were heated at 190°C for 5 minutes
- A pressure of about 20 bar was applied for 5 minutes; temperature was kept constant at 190°C
- A pressure of about 40 bar was applied for 5 minutes; temperature was kept constant at 190°C
- Mold and samples were cooled down to room temperature with a water cooling system

Plates were subsequently thermally treated at 130°C for 40 minutes in order to reduce thermal stresses in the material.

In order to evaluate size effects Single Edge Notched (tested in three point bending configuration, SENB) and Double Cantilever Beam (DCB) specimens were prepared with varying thickness B, ligament length $W\text{-}a$ and relative crack depth a/W and tested to evaluate their apparent fracture toughness K_{IC} (in the following the subscript I referring to mode I fracture will be omitted). Specimens were grooved with a V profile on both sides in order to guide crack propagation in the notch plane; specimen dimensions are shown in Fig. 1. Notches were made via automated "chisel-wise" cutting, obtaining a final notch root radius lower than 10 μm. A series of SENB blunt notched samples were also prepared using a circular profile blade with 1 mm radius; these specimens were necessary to detect the initiation point in creep test (see next section). All the test performed for the evaluation of the size effects were performed on an Instron 1185R5800 electro-mechanical dynamometer at a constant displacement rate of 10 mm/min and in standard condition (23°C and 50% RH).