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Environmental stress cracking in gamma-irradiated polycarbonate – A diffusion approach

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HIGHLIGHTS

- An analysis of ESC action combined to γ-irradiation on polycarbonate is proposed.
- Mechanical tests revealed that the ESC behavior is more complex than expected.
- The ESC behavior was modified when external load acted on the irradiated PC.
- Hansen Parameters are important to predict how aggressive the liquids are.

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ABSTRACT

Polycarbonate (PC) is an engineering polymer which presents interesting properties. This material has been also used in medical devices, which is frequently exposed to gamma radiosterilization and to chemical agents. This may produce significant changes in polymer structure, leading to failure in service. The present work brings about a new approach on environmental stress cracking (ESC) processes elucidation in 100 kGy gamma-irradiated PC, by evaluating the diffusion process of methanol or 2-propanol in test specimens and determining the diffusion parameters on solvent-irradiated polymer systems. A comparison of diffusion parameters for both solvents indicated that methanol has a considerable ESC action on PC, with diffusion parameter of $7.5 \times 10^{-14} \pm 1\%\ m^2\ s^{-1}$ for non-irradiated PC and $7.8 \times 10^{-14} \pm 2.8\%\ m^2\ s^{-1}$ for PC irradiated at 100 kGy. In contrast, 2-propanol did not act as an ESC agent, as it did promote neither swelling nor cracks in the test specimens. These results were confirmed by visual analysis and optical microscopy. Unexpectedly, structural damages evidenced in tensile strength tests suggested that 2-propanol is as aggressive as methanol chemical for PC. Moreover, although some manufacturers indicate the use of 2-propanol as a cleaning product for PC artifacts, such use should be avoided in parts under mechanical stress.

1. Introduction

Polycarbonate (PC) is widely used as an engineering plastic due to its combination of transparency, toughness, low moisture absorption, good thermal stability and good mechanical properties (Kjellander et al., 2008). In medical uses, polymers such as PC are exposed to physical and chemical agents that may cause several changes in their properties (Al-Saidi el al., 2003; Kjellander et al., 2008; Lewis, 2009; Nielsen and Hansen, 2005). Good examples are radiosterilizable reusable PC cases and connections for extracorporeal membrane oxygenators (artificial lungs devices), blood dialyzers and other medical devices. Due to relatively high costs and, in order to reduce medical waste, used pieces are inspected, washed and sterilized according to the manufacturer instructions or medical facility protocol, and reused for a predetermined number of times (Shoemake and Stoessel). Changes caused by the process of reusing polymer artifacts may include increase in material weight (if the polymer undergoes swelling; molar mass decreasing, caused by solvolysis – reaction with solvent molecules resulting in lysis of main chain bonds); dissolution, if the cleaning solution is a solvent for the polymer; or other changes such as

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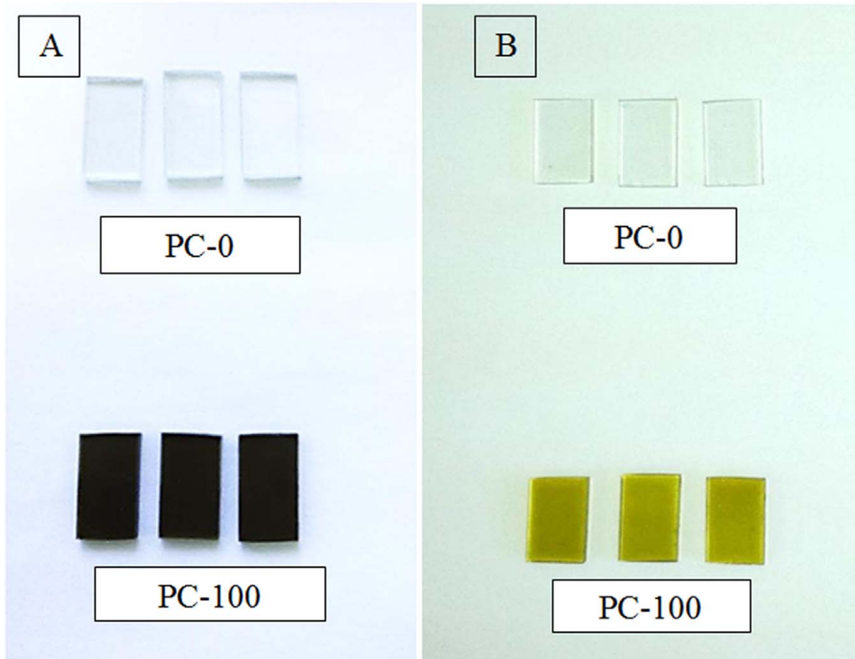

Fig. 1. Samples (A) immediately after gamma-irradiation and (B) one week later.

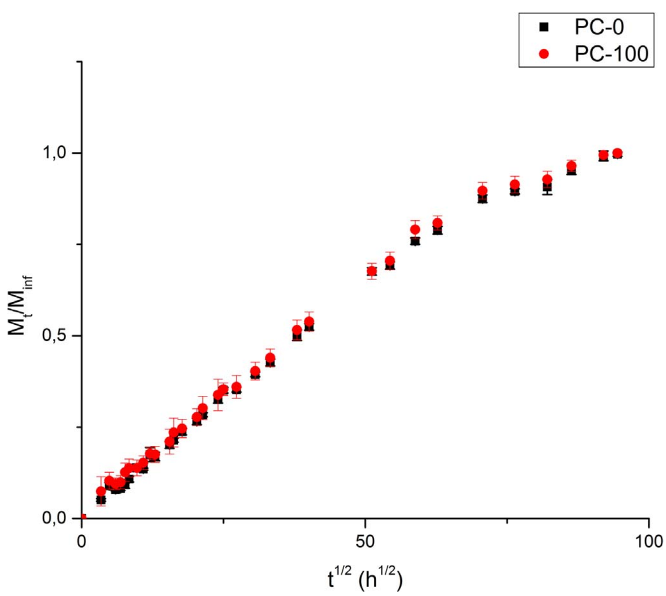

Fig. 2. Methanol sorption curve of non-irradiated polycarbonate (PC-0) and polycarbonate irradiated at 100 kGy (PC-100) showing swelling of samples with time.

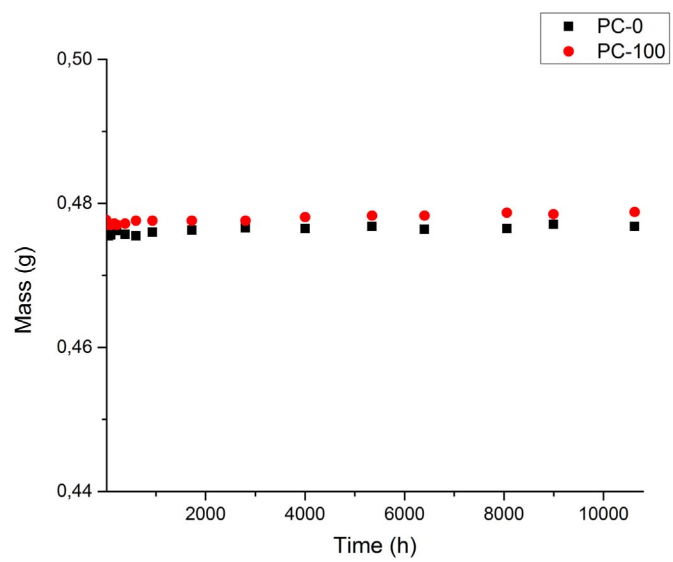

Fig. 3. Non-irradiated polycarbonate (PC-0) and gamma-irradiated PC (PC-100) mass gain as a function of time after immersion in 2-propanol, showing that this alcohol do not act as ESC agent.

increase in opacity or color changing.

When a polymer is exposed to a vapor or a liquid, it can crack spontaneously or fail under low mechanical stress. This phenomenon is called environmental stress cracking (ESC). Such a degradation mechanism can dramatically reduce materials lifetime (Al-Saidi el al., 2003; Kjellander et al., 2008; Lewis, 2009; Nielsen and Hansen, 2005; Scheirs, 2000). Initially, microfibrillations or crazings trigger the process subsequent cracking, which can occur by the combined action of either external (under use) or internal (residual) stress – with the exposure to chemical environment. ESC is very relevant to medical plastics used as artifacts and/or components of medical supplies, such as taps, syringes and others, as these devices are submitted to aggressive chemical exposure.

Medical plastics are usually sterilized by gamma irradiation (^{60}Co) or electron beams irradiation with doses of 25 kGy (Clegg and Collyer, 1991). The two main effects of high-energy radiation on the structure of polymer material are: 1) crosslinking, three dimensional molecular networking with consequent increase in molar mass; 2) main chain scissions, with consequent reduction in polymer molar mass. These effects usually occur simultaneously and the predominance of one over the other depends primarily on the chemical structure of polymer and the irradiation conditions.

Main chain scissions are predominant in Durolon® PC gamma-irradiated up to 400 kGy (Araújo et al., 1999). Molecular degradation under irradiation leads to the formation of phenyl and phenoxy radicals (Araújo et al., 1999; Ramani et al., 2003; Torikai et al., 1984). Phenyl radicals decay rapidly in the presence of processing stabilizers. Phenoxy radicals, in their turn, decay slowly and remain trapped in the polymer matrix. Trapped phenoxy radicals are long-lived and absorb light in the visible region, causing